Analysis of Water Quality of the Mahoning River in Ohio

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1859-C

Prepared in cooperation with the Ohio Department of Health

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By GENE A. BEDNAR, CHARLES R. COLLIER, and WILLIAM P. CROSS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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Correlation of water quality with streamflow and water use

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By Gene A. Bednar, Charles R. Collier, and William P. Cross

ABSTRACT

The Mahoning River drains the densely populated and industrialized Warren-Youngstown area in northeastern Ohio. Significant chemical constituents and physical properties generally regarded as important in establishing water-quality standards for the Mahoning River are evaluated on the basis of hydrologic conditions and water use. Most of the interpretations and the appraisal of water-quality conditions are based on data collected from January 1963 to December 1965. Generally, streamflow during this period was lower than during a selected long-term reference period; however, extremely low flows that occurred in the reference period did not occur in the 3-year study period.

Water temperatures of the Mahoning River at Pricetown and Leavittsburg were not affected by thermal loading. Water temperatures at those stations ranged from the freezing point to 78°F during the 1963–65 period. Downstream from Leavittsburg the use of large quantities of water for industrial cooling caused critical thermal loading during periods of low streamflow. Maximum water temperature were 108°F and 104°F at Struthers and Lowellville, respectively. Water temperatures of the Mahoning River were lower during high water discharges and increased with higher steel-production indices. Flow augmentation and modifications in industrial processes have improved the water-temperature conditions in recent years.

A combination of oxygen-consuming materials and warmed water from industrial and municipal wastes discharged into the lower reaches of the Mahoning River frequently depleted the dissolved-oxygen content. At Lowellville, the river water had a dissolved-oxygen content of 5 ppm (parts per million) or less for 67 percent of the time and 3 ppm or less for 16 percent of the time during the study period. The percentage of saturation of dissolved oxygen followed a similar trend. Both the dissolved-oxygen concentration and the percentage of saturation were noticeably lower downstream from Leavittsburg during the warm months when water temperatures were high and streamflow was low. The dissolved-oxygen content in the Mahoning River at Leavittsburg and Pricetown was almost always at acceptable levels.

The calculated dissolved-solids concentration of the Mahoning River ranged from 150 to 450 ppm at Leavittsburg and from 200 ppm to 650 ppm at Lowellville. Industrial use of the water caused an increase in the dissolved-solids concentra-

tion at Lowellville. During one steel-mill shutdown the average dissolved-solids concentration decreased from about 360 to about 280 ppm.

Chloride concentrations in the Mahoning River ranged from 42 ppm at Pricetown to 108 ppm at Struthers. The chloride load at 50-percent flow duration was 9 and 69 tons per day at Pricetown and Lowellville, respectively. The chloride content of the Mahoning River was well within acceptable levels.

Sulfate from wastes disposal and acid mine drainage made up the largest quantity of dissolved-solids load in the Mahoning River. The sulfate load at 50-percent flow duration increased from 38 tons per day at Pricetown to 300 tons per day at Lowellville. At Pricetown the sulfate load ranged from about 2 to 588 tons per day, while at Lowellville, downstream from the industrialized area, the range was from 106 to 2,420 tons per day. Comparison of sulfate loads during periods of steel production with periods of steel-mill shutdown indicated that during low flow about half the sulfate load at Lowellville was derived from steel-mill wastes when the production index was 100.

The alkalinity load of the Mahoning River at 50-percent flow duration increased from Pricetown (23 tons per day) to Lowellville (41 tons per day). During steel production the alkalinity of the water showed a marked decrease from Leavittsburg downstream to Lowellville. However, during steel-mill shutdowns the chemical composition of the river at Youngstown and Lowellville was similar to that at Leavittsburg. Acid mine drainage and pickle-liquor wastes reduced the alkalinity and lowered the pH of the river downstream from Warren. Between Warren and Niles, the pH was less than 6.0 for some periods.

The total iron concentration of the Mahoning River upstream from Leavittsburg was generally less than 2 ppm. From Leavittsburg downstream to Lowellville, total iron concentrations were frequently greater than 20 ppm.

INTRODUCTION

OBJECTIVE AND SCOPE

This investigation was conducted to define and describe certain water-quality characteristics of the Mahoning River in Ohio for use by that State in establishing water-quality criteria. Compilation of the basic data in tabular and graphic form is presented for use in the appraisal and evaluation of water facts for establishment of feasible and equitable water-quality standards. The study was based on the 3-year period, 1963–65 calendar years.

Correlations were made to determine the relation between certain chemical- and physical-quality parameters with streamflow and causal factors which affect the water quality of the Mahoning River. The effects of industrial use on the water quality of the Mahoning River are shown by the comparison of some important chemical and physical parameters that existed during various rates of steel production with those observed during two periods of steel-mill shutdown. Water-quality and streamflow data for the 1963–65 calendar years were compiled for six sampling sites—at Pricetown, Leavittsburg, Niles, Youngstown, Struthers, and Lowellville. Descriptions of the sites are:

Mahoning River—	Site
At Pricetown	Approximately 0.4 mile below Lake Milton Dam.
At Leavittsburg	Highway Bridge.
West of Niles	Park Avenue Bridge.
At Youngstown	Division Street Bridge.
At Struthers	Highway Bridge.
At Lowellville	Washington Street Bridge.

It is recognized that water-quality criteria for the Mahoning River will include parameters other than those described in this report. Sufficient data for the 1963–65 period were not available in this study to include such parameters as heavy metals and organic materials.

ACKNOWLEDGMENTS

The report was prepared as a part of the cooperative program between the U.S. Geological Survey and the Ohio Department of Health, under the direction of J. J. Molloy, district chief, U.S. Geological Survey. Special acknowledgment is due P. W. Anttila, engineer, U.S. Geological Survey, for his technical assistance. Much of the water-quality data were collected and analyzed under the supervision of the Ohio Department of Health. All streamflow records and compilations, along with supplemental water-quality data, were provided by the U.S. Geological Survey.

DESCRIPTION OF AREA

The main stem of the Mahoning River flows through a densely populated and heavily industrialized region of northeastern Ohio before flowing into Pennsylvania about 1 mile downstream from Lowellville. (See pl. 1.) At Pricetown the Mahoning River has a drainage area of 273 square miles. Between Pricetown and the Ohio-Pennsylvania State line, a distance of approximately 50 miles, the river drains an additional 802 square miles, or about 75 percent of the basin within Ohio. Approximately 55 square miles of the drainage basin lies in Pennsylvania. The average stream gradient is 2.2 feet per mile from Pricetown to Leavittsburg and 2.6 feet per mile from Leavittsburg to Lowellville.

Four multipurpose reservoirs in the basin, with 256,810 acre-feet of storage, provide for flood control, low-flow augmentation, public water supply, and recreation. In December 1966, since the 1963–65 study period, West Branch Reservoir began operation. This reservoir will provide an additional 42,700 acre-feet of storage in the winter and 52,900 acre-feet in the summer and will furnish an additional 50 cfs (cubic feet per second) minimum average annual flow.

Downstream from Leavittsburg there is a series of low dams which pond water for industrial intakes. Earthfills for railroads and mills in this reach constrict the natural stream channel.

The Mahoning River from Leavittsburg through Warren and Youngstown to Lowellville, a distance of approximately 25 miles, is the principal source of water for most industries in the area. The development of the lower Mahoning River basin into a thriving industrial complex can be attributed to the availability and utility of the water from the Mahoning River. The water is utilized primarily for nonconsumptive purposes, mainly for industrial cooling.

Between Leavittsburg and Lowellville the disposal of domestic and industrial waste waters has burdened the river's natural purification processes. Adverse water-quality conditions are more prevalent in the warmer months when stream temperatures are naturally high and streamflow is low. During these periods streamflow is augmented for the control of water temperature.

STREAMFLOW

Streamflow is probably the most important consideration in evaluating water-quality characteristics of a stream. When streamflow is low, many interrelated conditions may result which can adversely affect the water quality of a stream. A stream must be capable of diluting, mixing and assimilating waste materials. If it cannot, the stream is liable to become a public nuisance and a potential health hazard.

The flow of the Mahoning River during the 1963–65 calendar years was generally lower than during selected 21- or 22-year reference periods, as shown in table 1. For 10 percent of the time during the reference period, the flow equaled or exceeded 2,300 cfs at Lowellville, compared with only 1,780 cfs during the study period (table 1). At the 90-percent duration, the low-flow or base-flow condition, the differences were proportionally smaller—about 300 cfs for the reference period compared with about 285 cfs for the 3-year period. Flow-duration curves based on the data from table 1 reverse their relative positions at the lower end, a change indicating that extremely low flows did not occur during the 3-year study period. During 1963-65 a minimum daily flow of at least 228 cfs was maintained, compared with the minimum daily flow of 136 cfs during the reference period. Mean flows for several time periods and the average low flows of 7-day and 30-day durations for a 5-year frequency are given for the Mahoning River at Pricetown, Leavittsburg, Youngstown, and Lowellville in table 2.

In general, streamflow during the period 1963–65 was lower than during the long-term period, except during low-flow periods. Because water quality generally improves with increased streamflow (as will be shown later), water-quality conditions during 1963–65 may have been less favorable than those which prevailed during the long-term reference period. During the base-flow periods the chemical analyses are more representative of flow conditions equal to or somewhat better than in previous years when extremely low flows occurred. Improvement in water quality in future years should result from the additional flow augmentation provided by West Branch Reservoir.

TABLE 1.—*Flow duration of the Mahoning River*

[Discharge in cubic feet per second]

Period	Maximum daily discharge for period	Minimum daily discharge for period	Discharge equaled or exceeded that shown during indicated percentage of time: 5	10	30	50	70	90	95
Mahoning River at Pricetown									
Oct. 1944 to Sept. 1965	3,370	0.4	765	430	241	183	129	71	50
Jan. 1963 to Dec. 1965	2,330	7.4	430	235	197	142	86	45	32
Mahoning River at Leavittsburg									
Oct. 1944 to Sept. 1965	15,500	60	1,880	1,260	430	292	229	157	132
Oct. 1951 to Sept. 1953	8,740	60	2,100	1,300	410	280	243	178	154
Jan. 1963 to Dec. 1965	6,390	80	1,650	940	257	223	178	121	109
Mahoning River at Youngstown									
Oct. 1945 to Sept. 1965	16,200	112	3,010	1,930	710	470	350	230	193
Oct. 1951 to Sept. 1953	12,500	112	3,350	2,000	640	470	360	245	202
Jan. 1963 to Dec. 1965	11,500	164	2,600	1,500	455	355	280	204	180
Mahoning River at Lowellville									
Oct. 1945 to Sept. 1965	19,300	136	3,500	2,300	870	590	435	300	258
Oct. 1951 to Sept. 1953	16,500	147	3,800	2,280	810	590	470	308	270
Jan. 1963 to Dec. 1965	11,300	228	2,850	1,780	600	480	370	285	265

TABLE 2.—*Mean discharge and average low-flow discharge of the Mahoning River for indicated frequency and durations*

Mahoning River at—	Drainage area (sq mi)	Mean discharge, in cfs, for indicated years: Water years 1944–65	1945–65	1952–53	1957–65	Calendar years 1963–65	Average low-flow discharge, in cfs, 5-yr. frequency [1]: 7-day duration	30-day duration
Pricetown	273	249	254	280	--------	171	5.9	26
Leavittsburg	575	549	559	574	--------	408	110	126
Youngstown	898	843	861	885	--------	673	171	191
Lowellville	1,073	1,029	1,051	1,068	972	809	212	237

[1] The discharge, which was averaged over the indicated number of days, was less than that shown on the average of once every 5 years.

WATER QUALITY

WATER TEMPERATURE

Water temperatures of the Mahoning River at Pricetown and Leavittsburg are controlled largely by air temperature. Approximately 95 percent of all water withdrawn from the Mahoning River is used for industrial cooling downstream from Leavittsburg in the Warren-Youngstown area, and nearly all of it is returned to the river with a thermal load (Cross and others, 1952, p. 32). Warmed water that is returned to the river by one plant must also serve other industries further downstream; consequently, the temperature of the river con-

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tinues to rise as the water is reused for industrial cooling. The increase in water temperature in the downstream direction is shown on plate 1. Upstream from Warren the water temperature was 79°F or less, whereas downstream from Youngstown it was 94°F or less for 90 percent of the time.

The maximum water temperature at Pricetown and Leavittsburg was 78°F during 1963–65. At Struthers and Lowellville, water temperatures as high as 108°F and 104°F, respectively, occurred during 1963–65. The water temperature duration data for these stations and for Niles and Youngstown are shown in table 3.

The low-flow conditions of the Mahoning River that existed during the 1963–65 period resulted in slightly higher river temperatures at Leavittsburg than during the reference period 1950–65. However, at Lowellville, the river temperatures during 1963–65 did not increase over the temperatures during the reference period (fig. 1). In fact, about 75 percent of the time the temperatures were lower during 1963–65 than during the 16-year period. These lower temperatures were the result of modifications in industrial processes, which now require less cooling water. There has also been a decrease in coke production, which in the past required large quantities of cooling water. Although the thermal loading of the river was noticeably decreased, water temperatures remained significantly higher at Lowellville than at Leavittsburg, as shown in figure 1.

The relation of water temperature to streamflow at Leavittsburg and at Lowellville is shown in figures 2 and 3. These flow durations and water-temperature durations show the percentage of days that water temperatures occurred at various streamflows. The water temperatures at Leavittsburg may be used to represent those under natural conditions. The effects of thermal loading can be seen by the increases in water temperatures from Leavittsburg to Lowellville. For example, at 90-percent flow duration, 157 cfs at Leavittsburg (table 1), the water temperature was 70°F or less for 70 percent of the time and 50°F or less for 37 percent of the time (fig. 2). The 90-percent flow duration at Lowellville was 300 cfs (table 1). At this discharge the water temperature was 90°F or less for 67 percent of the time, 70°F or less for 34 percent of the time, and 50°F or less for 12 percent of the time, as shown in figure 3. Curves similar to those in figures 2 and 3, but for the period 1950–58, are shown by Hubble and Collier (1960, p. 38–39).

TABLE 3.—*Duration of water-quality parameters in the Mahoning River basin for the period January 1, 1963, to December 31, 1965*

[Figure in parentheses is number of observations]

Percentage of time parameter equaled or was less than that indicated	Parameters in Mahoning River at—					
	Pricetown	Leavittsburg	Niles	Youngstown	Struthers	Lowellville
	(153)	(154)	(154)	(152)	(155)	(153)
Specific conductance:						
1	260	220	260	280	340	330
5	300	290	330	340	380	390
10	320	320	370	380	450	440
25	360	360	480	450	550	570
50	410	410	560	550	660	690
75	480	480	670	660	790	800
90	600	580	800	770	910	910
95	650	620	820	820	940	970
99	670	670	900	910	1,070	1,020
Maximum	680	740	940	940	1,100	1,050
Minimum	230	185	225	240	330	300
Mean	425	423	570	556	666	675
	(147)	(151)	(148)	(150)	(149)	(147)
pH:						
1	6.3	6.8	4.1	4.0	6.1	5.3
5	6.7	7.2	5.2	5.1	6.3	6.2
10	7.0	7.3	5.8	6.1	6.5	6.5
25	7.3	7.6	6.6	6.6	6.7	6.8
50	7.5	7.8	6.9	7.0	7.0	7.1
75	7.7	8.0	7.2	7.3	7.4	7.4
90	7.9	8.1	7.5	7.7	7.7	7.8
95	8.0	8.2	7.8	7.9	7.9	8.0
99	8.3	8.4	8.0	8.2	8.2	8.3
Maximum	8.5	8.6	8.9	8.2	8.3	9.0
Minimum	6.3	6.6	3.5	3.9	5.8	4.4
Mean	-----------	-----------	-------	-----------	-----------	------------
	(153)	(154)	(155)	(152)	(155)	(152)
	(153)	(154)	(154)	(152)	(142)	(148)
Dissolved oxygen (upper value in ppm; lower value in percentage of saturation):						
1	6.5	3.8	0.6	2.1	1.7	1.3
	64	37	.5	23	16	20
5	7.3	6.8	1.3	3.0	2.2	2.4
	78	72	12	32	22	26
10	7.5	7.5	1.8	3.4	2.4	2.7
	79	75	22	36	26	30
25	8.1	8.0	2.9	3.9	3.0	3.4
	82	79	32	44	37	42
50	9.6	9.1	4.5	5.0	4.1	4.3
	86	84	48	54	48	52
75	11.1	10.9	6.9	6.8	5.6	5.6
	92	89	63	66	60	61
90	11.7	11.7	9.1	8.5	7.4	7.7
	95	95	76	76	71	72
95	12.0	12.0	10.1	9.4	8.2	8.7
	97	97	81	82	76	78
99	13.6	12.4	11.8	10.8	10.3	9.8
	100	100	88	92	84	92
Maximum	14.0	12.8	12	11.6	11.0	11.4
	106	120	98	101	107	106
Minimum	6.8	3.4	.1	1.5	1.0	1.5
	80	24	1	19	14	19
Mean	9.4	9.3	4.9	5.4	4.4	4.6
	86	83	47	55	48	51
Alkalinity as $CaCO_3$:	(144)	(149)	(146)	(141)	(148)	(148)
1	6.0	5.9	1.2	1.0	5.8	4.2
5	12	10	4.3	4.0	8.8	6.0
10	22	19	9.0	8.0	13	9.0
25	45	32	17	19	23	21
50	59	68	28	28	35	32
75	81	92	42	40	51	46
90	90	110	58	54	65	65
95	95	120	70	66	75	76
99	100	140	92	85	94	90
Maximum	103	148	101	92	99	91
Minimum	4.0	5.0	0	0	4	0
Mean	60	70	31	30	37	34
	(153)	(154)	(154)	(153)	(155)	(153)

TABLE 3.—*Duration of water-quality parameters in the Mahoning River basin for the period January 1, 1963, to December 31, 1965*—Continued

[Figure in parentheses is number of observations]

Percentage of time parameter equaled or was less than that indicated	Parameters in Mahoning River at—					
	Pricetown	Leavittsburg	Niles	Youngstown	Struthers	Lowellville
Iron (ppm):						
1	----------	----------	----------	----------	----------	----------
5	----------	----------	1.2	1.0	1.3	1.0
10	----------	----------	2.5	1.2	1.8	1.1
25	----------	----------	4.8	2.0	3.0	2.0
50	----------	----------	8.7	4.3	6.2	4.9
75	----------	----------	15	8.5	11	8.5
90	1.4	1.0	28	12	20	13
95	1.6	1.4	33	18	27	18
99	2.0	2.6	91	34	52	44
Maximum	2.0	5.0	160	60	91	107
Minimum	----------	----------	----------	----------	----------	----------
Mean	----------	----------	12	5.9	8.6	6.6
Sulfate (ppm):	(139)	(141)	(141)	(137)	(142)	(138)
1	49	31	48	32	58	62
5	60	56	71	78	94	98
10	70	64	94	98	120	130
25	83	78	160	140	170	160
50	100	98	210	190	210	230
75	130	120	280	260	300	300
90	170	150	350	330	360	360
95	200	170	410	370	420	410
99	225	220	450	440	470	460
Maximum	227	233	453	469	520	500
Minimum	36	22	37	22	42	45
Mean	110	100	220	205	231	237
	(153)	(153)	(154)	(151)	(154)	(153)
Chloride (ppm):						
1	4.9	12	16	17	17	21
5	17	17	22	23	31	29
10	19	19	25	25	37	36
25	20	21	29	35	44	44
50	23	25	38	40	55	56
75	28	29	48	50	68	68
90	34	35	56	61	79	80
95	39	40	63	66	90	90
99	41	44	66	71	100	98
Maximum	42	48	68	79	108	141
Minimum	3	8	10	11	18	16
Mean	24	25	38	41	56	56
	(153)	(154)	(154)	(152)	(154)	(150) (1,107)
Temperature [1] (°F):						
1	34	33	34	35	36	35 40
5	35	34	36	39	46	44 49
10	35	34	41	43	53	51 54
25	38	36	49	53	62	60 61
50	54	54	65	68	82	77 77
75	69	68	78	82	93	89 90
90	75	75	83	86	100	96 96
95	76	76	84	87	102	98 98
99	77	76	85	96	104	100 99
Maximum	78	78	86	98	108	104 103
Minimum	32	32	32	32	33	32 38
Mean	54	53	62	66	77	74 75

[1] Lower value is U.S. Geol. Survey record based on maximum daily values.

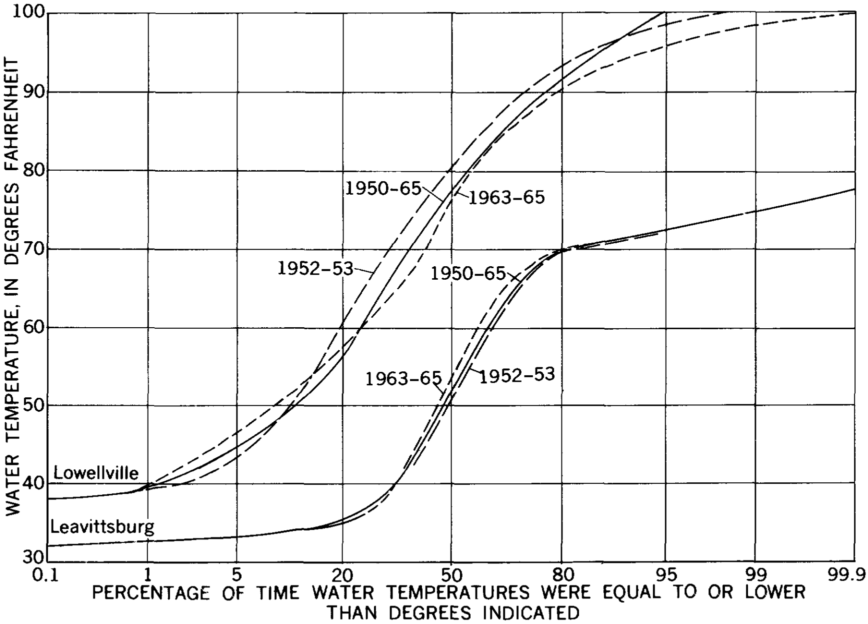

FIGURE 1.—Temperature duration, Mahoning River at Leavittsburg and Lowellville.

Monthly means and monthly maximum water temperatures of the Mahoning River from 1943 through 1965 at Leavittsburg and Lowellville are shown in figure 4. The continuous thermographs show that the highest water temperatures of the river generally occurred during May through October at both sites. This is to be expected because these months of higher air temperatures are also the months of lower streamflow. However, the periods in which cooler water temperatures occur are not the same at each site. At Leavittsburg the water temperatures approach the freezing point during December through February when air temperatures are the lowest, while at Lowellville the lowest water temperatures occur in March and April. This lag in temperature decrease at Lowellville shows that lower air temperatures during winter months do not overcome the thermal loading of the river. Below Leavittsburg the lowest water temperatures occur during periods of high runoff when air temperatures are still comparatively low. As a result of thermal loading, the river downstream from Leavittsburg seldom freezes.

Maximum observed water temperatures and steel-production indices for the months when maximum water temperatures were observed at Lowellville are shown graphically in figure 5. Production indices are based on data published by the American Iron and Steel Institute. A production index is expressed as a percentage. An index of 100 is based on the average net tons produced per 7-day week during 1957–59. In general, the correlation between maximum water temperatures and steel-production indices is good over the 16-year period shown. It is also noted from figures 4 and 5 that the maximum monthly temperatures observed since 1955 have shown a decline.

The increase in water temperatures of the Mahoning River from Leavittsburg to Lowellville exhibit a definite correlation with industrial use. Increases in mean monthly water temperatures with streamflow are shown to correspond to increases in steel production (fig. 6). When the steel-production index was 50 and streamflow was 300 cfs, the increase in water temperature from Leavittsburg to Lowellville was 16°F. At a production index of 175 and discharge of 300 cfs, the increase in water temperature was 42°F. At higher water discharges the temperature increase was less.

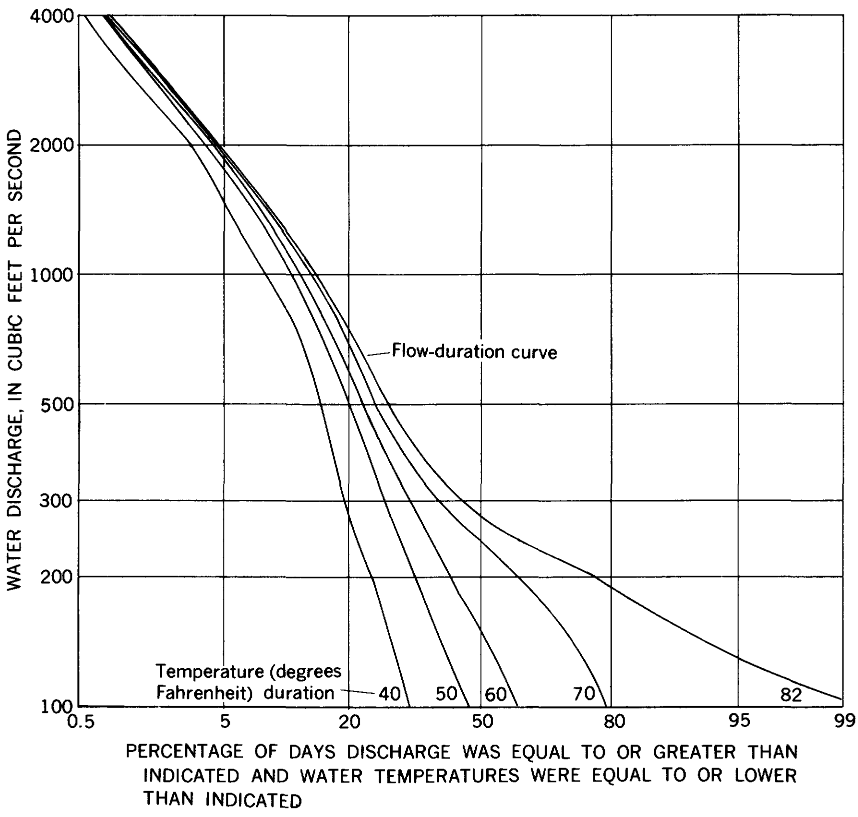

FIGURE 2.—Flow duration–water-temperature duration, Mahoning River at Leavittsburg, 1950–65 water years.

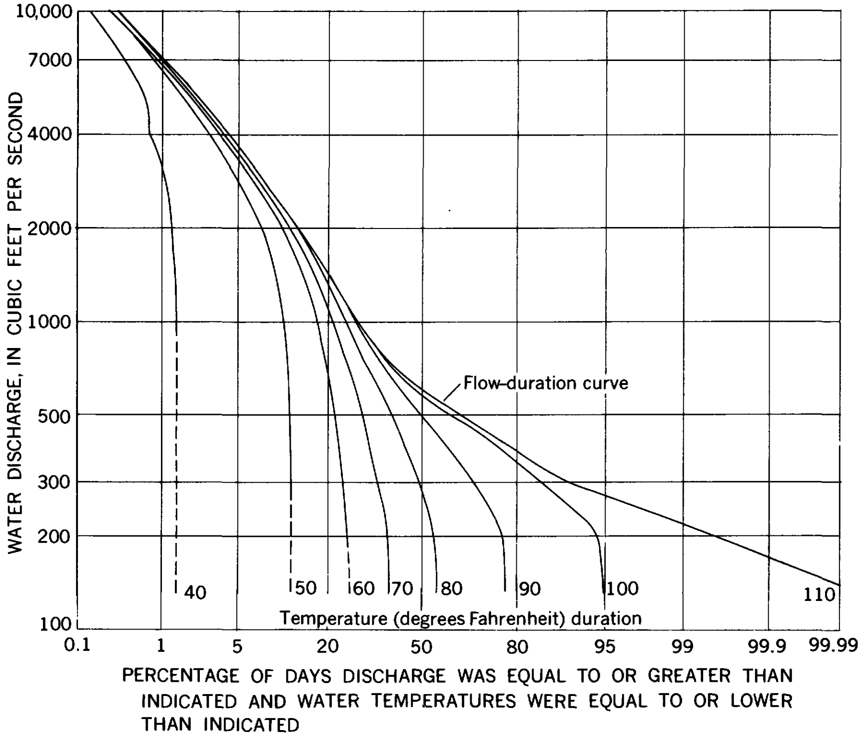

FIGURE 3.—Flow duration–water-temperature duration, Mahoning River at Lowellville, 1950–65 water years.

Higher water temperature is not only a problem for the industrial user because of increased quantities of water needed for cooling purposes, but it also has a marked influence on water quality. Higher water temperature reduces the quantity of oxygen that can be dissolved in water and therefore reduces the capacity of the stream to assimilate wastes and to support aquatic life.

DISSOLVED OXYGEN

Dissolved oxygen is one of the critical water-quality problems of the lower Mahoning River. At Pricetown and Leavittsburg the dissolved-oxygen concentration was generally sufficient for most uses, as shown by the concentration durations in table 3. Downstream from Warren to Lowellville, the discharge of oxygen-consuming materials such as organic matter and ferrous iron, along with thermal loading, reduced the river's capacity to maintain a natural dissolved-oxygen level. Between Warren and Niles and between Youngstown and Lowellville, the dissolved-oxygen concentration was only 1–3 ppm (parts per mil-

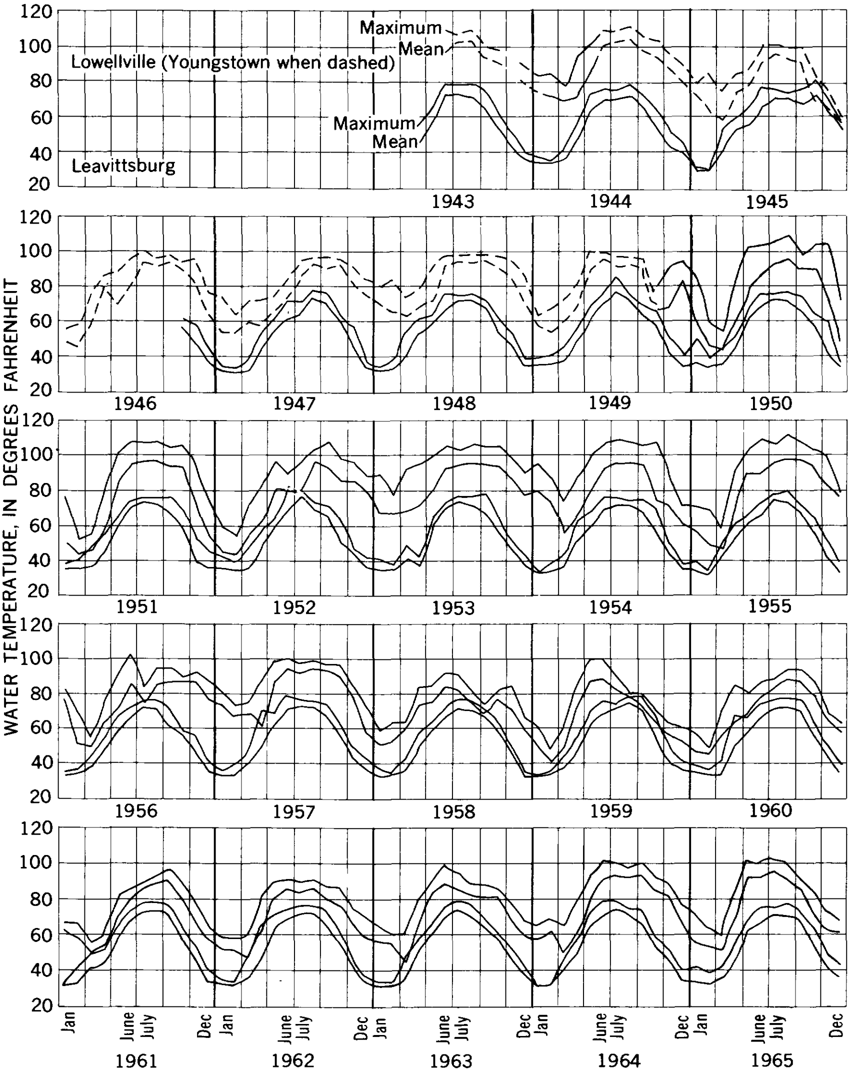

FIGURE 4.—Monthly maximum and mean water temperatures of the Mahoning River, 1943–65.

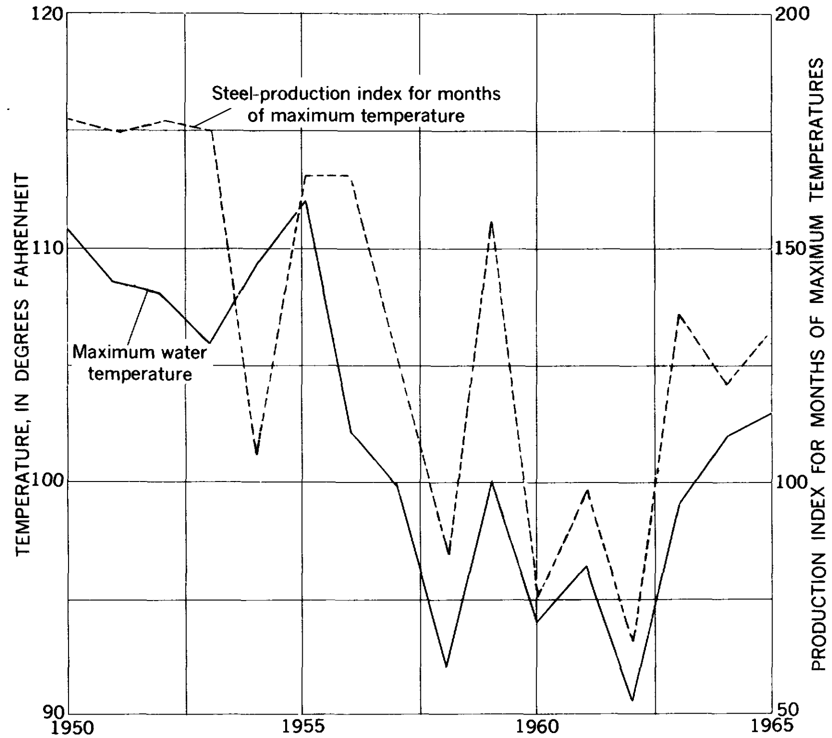

FIGURE 5.—Maximum observed water temperatures and steel-production indices for months of maximum temperature, Mahoning River at Lowellville.

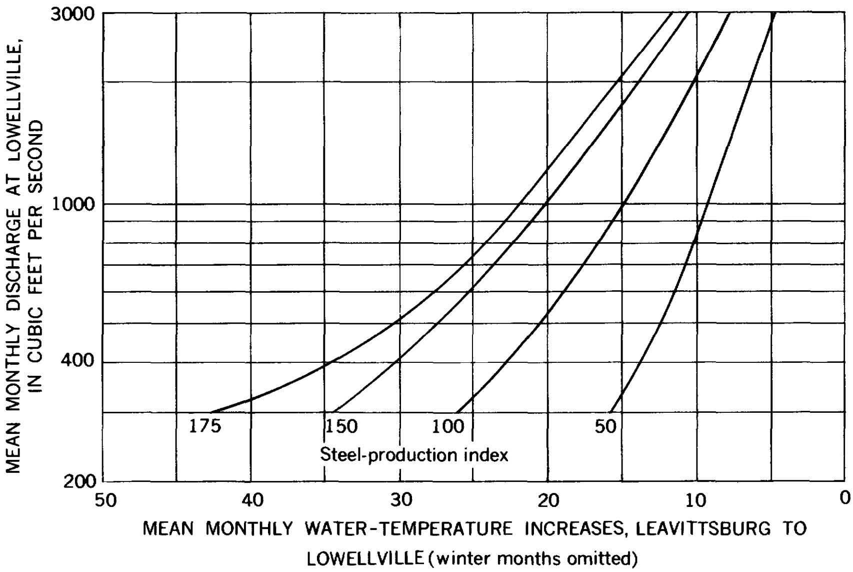

FIGURE 6.—Correlation of discharge, water-temperature increases, and steel production, Mahoning River from Leavittsburg to Lowellville.

lion) for 10 percent of the time, as shown on the map on plate 1. Inflow from Meander and Mosquito Creeks at Niles caused some recovery in dissolved-oxygen levels of the river; the concentration was between 3 and 5 ppm for 10 percent of the time.

The duration table of percentage of saturation (table 4) shows a similar condition. Relatively high percentage of saturation was maintained at Pricetown and Leavittsburg, whereas much lower levels of percentage of saturation occurred at the downstream sites.

There were seasonal variations in percentage of saturation of dissolved oxygen. At Pricetown and Leavittsburg a slightly higher level of percentage of saturation existed in the warm months, May through October (table 4, fig. 7). At Pricetown the percentage of saturation was generally 4 or 5 percent higher during the warm months than during the winter. Ice cover during the winter tended to reduce diffusion of oxygen in the water of Lake Milton above Pricetown and in the upper reach of the main stem of the Mahoning River. From Niles to Lowellville, however, the situation was reversed. Dilution of water by the higher streamflow, together with lower temperatures during the winter and spring in the lower reach, probably caused by the increased level of percentage of saturation.

SPECIFIC CONDUCTANCE—DISSOLVED-SOLIDS CONCENTRATION

Specific conductance is a measure of the dissolved-solids concentration in water. A duration table and extremes of specific conductance that occurred during the 1963–65 calendar years are shown in table 3 and figure 8 respectively. The specific conductances were very similar at Pricetown and Leavittsburg, at Niles and Youngstown, and at

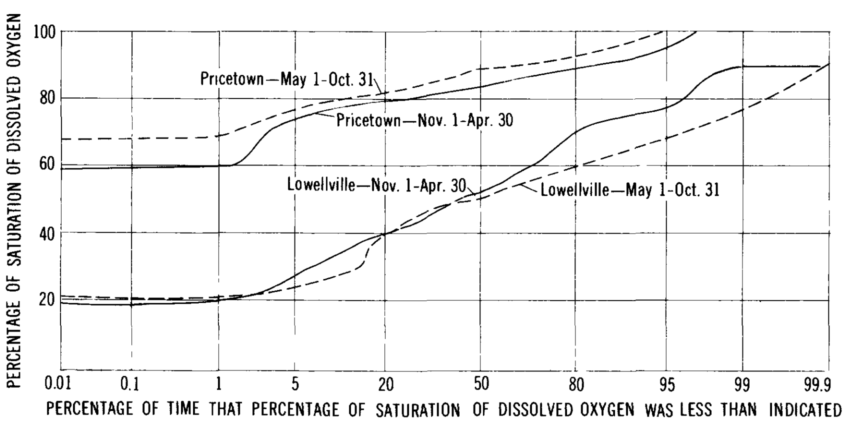

FIGURE 7.—Duration of percentage of saturation of dissolved oxygen, Mahoning River at Pricetown and Lowellville, May–October and November–April, 1963–65.

TABLE 4.—*Duration of percentage of saturation of dissolved oxygen in the Mahoning River for the period January 1, 1963, to December 31, 1965*

[Upper figures are for period Nov. 1 to Apr. 30; lower figures are for period May 1 to Oct. 31]

Percentage of time percentage of saturation of dissolved oxygen was equal to or less than that shown	Percentage of saturation of dissolved oxygen in Mahoning River at—					
	Pricetown	Leavittsburg	Niles	Youngstown	Struthers	Lowellville
1	60	25	10	30	18	20
	69	44	2	19	14	21
5	74	72	29	32	22	27
	77	68	9	34	22	24
10	78	74	34	36	30	34
	80	77	12	35	24	27
25	80	77	42	45	43	42
	84	83	27	43	33	44
50	84	82	61	59	55	53
	89	87	35	52	42	51
75	88	86	71	68	66	66
	92	90	49	65	53	58
90	92	90	80	77	75	75
	97	95	58	74	61	64
95	96	93	82	80	78	78
	100	100	68	84	66	69
99	100	100	91	91	81	90
	100	100	86	91	79	77
Maximum percentage of saturation	101	100	98	92	84	90
	106	120	87	101	107	106
Minimum percentage of saturation	59	24	5	28	17	19
	68	41	1	19	14	21

Struthers and Lowellville. This similarity indicates that significant loading of soluble waste materials occurred below Leavittsburg and Youngstown.

On the basis of measurements of specific conductance, converted to dissolved solids by multiplying by the factor 0.65, the dissolved-solids concentration of the Mahoning River increased downstream from Pricetown to Lowellville. During the 1963–65 calendar years the dissolved solids were less than 500 ppm all of the time in the Mahoning River upstream from Niles, 90 percent of the time at Niles and Youngstown, and 75 percent of the time at Struthers and Lowellville. Relatively large differences occurred at each site with changes in rates of streamflow. The dissolved-solids concentration ranged from about 150 to 450 ppm at Leavittsburg and from about 200 to 650 ppm at Lowellville.

During steel-mill shutdowns the chemical composition of the river at Lowellville assumed the general chemical character of the river at Leavittsburg. The change in the specific conductance and dissolved-solids concentration of the water at Lowellville during a steel-mill shutdown lasting from July 14 to November 7, 1959, is shown in figure 9. Prior to the shutdown the specific conductance averaged approximately 550 micromhos with a dissolved-solids concentration of about 360 ppm. During the shutdown the specific conductance decreased and averaged about 430 micromhos with a dissolved-solids concentration of 280 ppm. During the shutdown the chemical composition of the river at Lowellville was essentially the same as the chemical composition of the water at Pricetown and Leavittsburg. When steel production was resumed, the specific conductance and dissolved-solids concentration of the Mahoning River averaged about the same as before the shutdown.

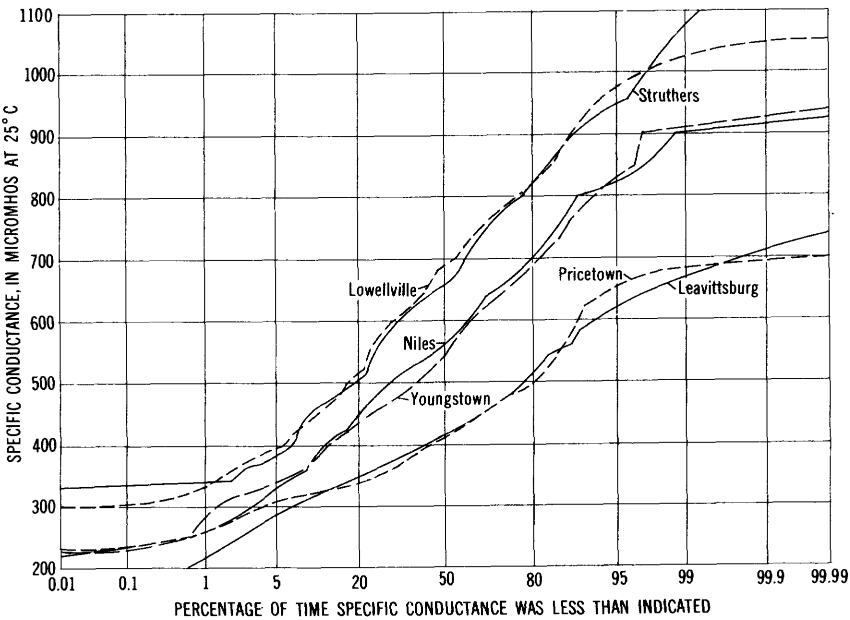

FIGURE 8.—Specific-conductance duration.

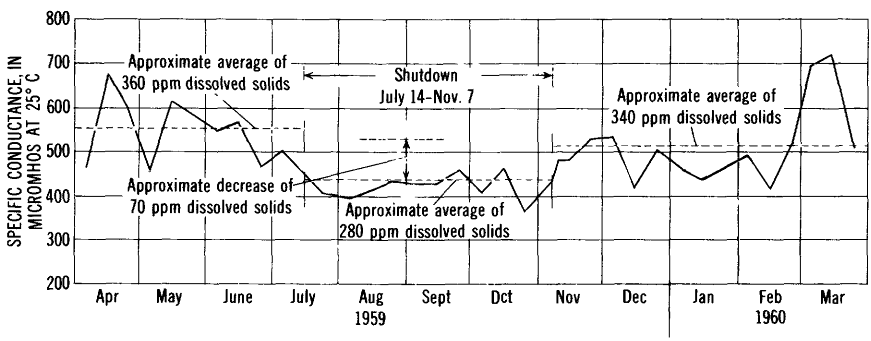

FIGURE 9.—Changes in specific conductance and dissolved-solids concentrations of the Mahoning River at Lowellville during steel-mill shutdown, 1959.

A significant change in the chemical characteristics of the river during this shutdown was the increase in percentage of bicarbonate (HCO_3) and the decrease in percentage of sulfate (SO_4), as shown in figure 10. Although the percentage of sulfate decreased during the shutdown, it was still the major constituent. This fact suggests that a large proportion of the sulfate in the Mahoning River at Lowellville was derived from sources other than steel-mill effluents. The most probable source of sulfate is from the chemical weathering and oxidation of iron sulfide minerals in the coal-mining regions of the basin. No other sulfate-bearing minerals, such as gypsum ($CaSO_4$), are major constituents of the rocks and soils in the area. Figure 10 also shows that the percentage of chloride (Cl) in the dissolved solids remained about the same during steel production as during steel-mill shutdown.

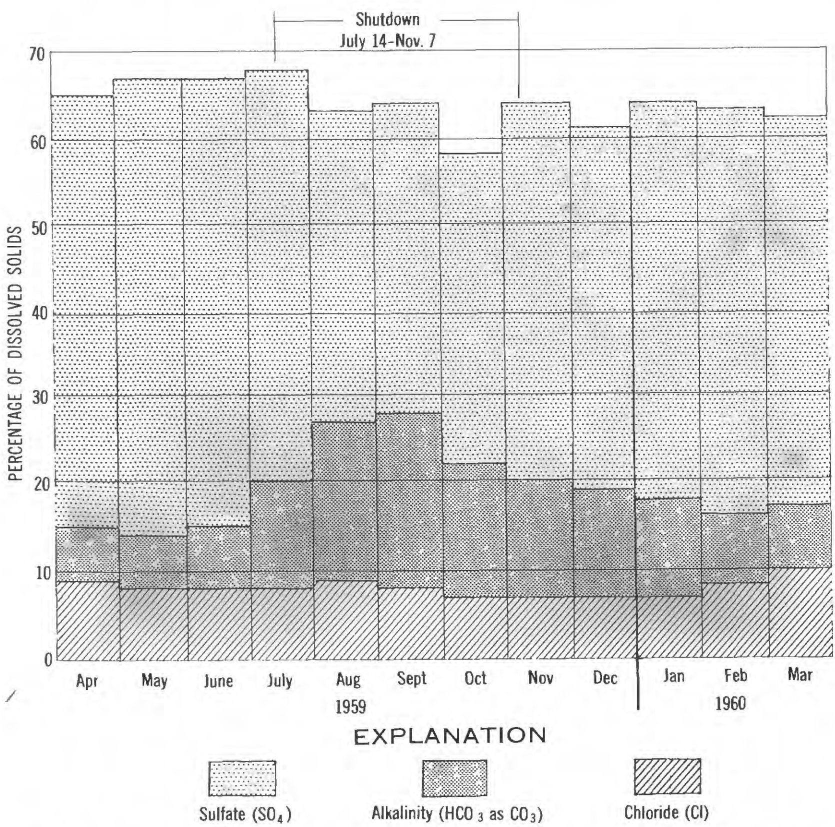

FIGURE 10.—Changes in the chemical composition of the Mahoning River at Lowellville during steel-mill shutdown, 1959.

pH

The alkaline-acid balance maintained by a stream is an important consideration for practically all users of water. In a chemical sense water having pH of 7.0 is neutral and is neither acid nor alkaline. In water-quality interpretations water having a pH of above 4.5 will be alkaline. Alkalinity decreases as pH decreases. When the pH of water approaches 4.5, the alkalinity content is depleted. A water that has a pH below 5.0 is considered by many authorities as unfit for many uses and harmful to aquatic life. The duration of pH of the Mahoning River is shown in table 3.

On occasion, the water of portions of the lower Mahoning River became significantly acidic primarily owing to acid wastes from steel-pickling processes and, to some extent, acid mine drainage. Increases in acid wastes emptying into the river between Niles and Lowellville caused the pH of the water of the river to fall below 5.0. The water of the Mahoning River at Niles and Youngstown had a pH of 5.0 or less for about 5 percent of the time. The pH of the river at Lowellville, and probably Struthers, at times also fell below 5.0. However, this probably occurred less than 1 percent of the time.

At Pricetown and Leavittsburg the pH of the river was near 7.0 or above for 10 percent of the time, as shown on plate 1. The decrease in the pH and the increase in acidity in the river from Warren to Lowellville are apparent in this figure. This condition is the result of acid wastes being discharged by the many industries along this stretch of the river.

The pH of the water of the river is lowest and the acidity is highest when there are insufficient quantities of alkalinity to neutralize the acid wastes. Sulfuric acid is a principal cause of acidity in both steel-pickling wastes and acid mine drainage. The end product of the neutralization of sulfuric acid by alkalinity is generally calcium sulfate ($CaSO_4$).

CHLORIDE

The chloride concentration of the Mahoning River was generally low. During 1963–65 the mean chloride content ranged from 24 ppm at Pricetown to 56 ppm at Lowellville (table 3). A maximum chloride concentration of 141 ppm was observed at Lowellville during 1963–65. The chloride concentrations and loads generally increased through the urban and industrial areas between Leavittsburg and Lowellville; however, they were generally at an acceptable level for practically all uses.

The relation of chloride concentrations with discharge at the sampling sites is shown in figure 11. Decreases in chloride concentrations

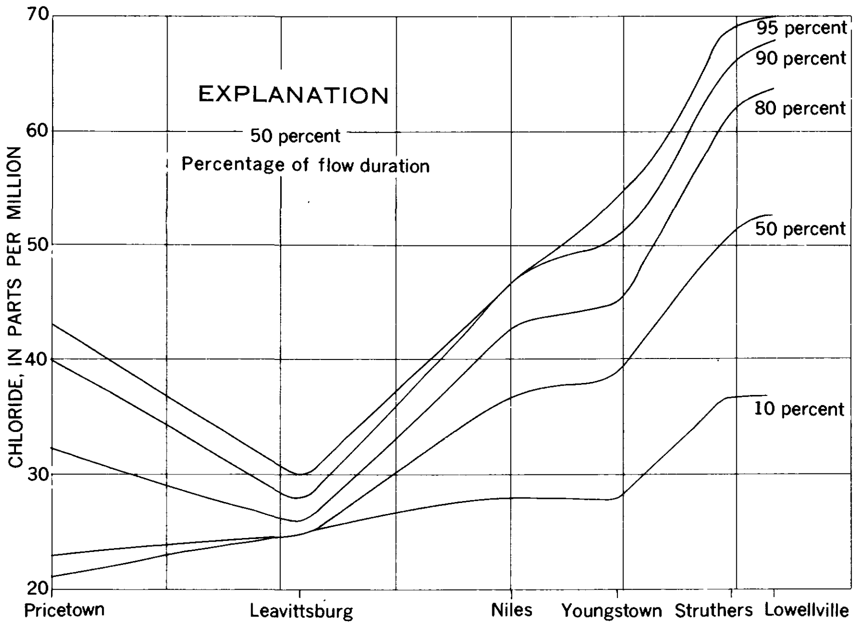

FIGURE 11.—Chloride concentration versus distance for indicated flow durations.

from Pricetown to Leavittsburg at lower flows were the result of dilution by tributary and ground-water inflow. From Niles to Lowellville the concentration increased as the river received municipal and industrial waste effluents. There was little change in chloride concentrations at 10-percent flow duration (high flow) except for a slight increase between Youngstown and Struthers.

The chloride load, however, markedly increased from Niles to Lowellville during high flow. At 10-percent flow duration the load increased from about 76 tons per day at Niles to nearly 180 tons per day at Lowellville, as shown in figure 12. At lower streamflow the chloride load increased gradually from Pricetown to Niles. From Niles to Lowellville the increase in load was greater due to waste discharged into the river. The duration table of daily chloride loads and the approximate extremes are shown in table 5.

The chloride concentration and load of the Mahoning River during low streamflow are further illustrated on plate 1. Upstream from West Branch Mahoning River the chloride concentration averaged 40 ppm at 90-percent flow duration. This concentration was reduced to 28 ppm by the inflow from West Branch Mahoning River and Eagle Creek. Downstream from Leavittsburg the chloride concentration of the Mahoning River gradually increased owing to the municipal and industrial wastes discharged to the river.

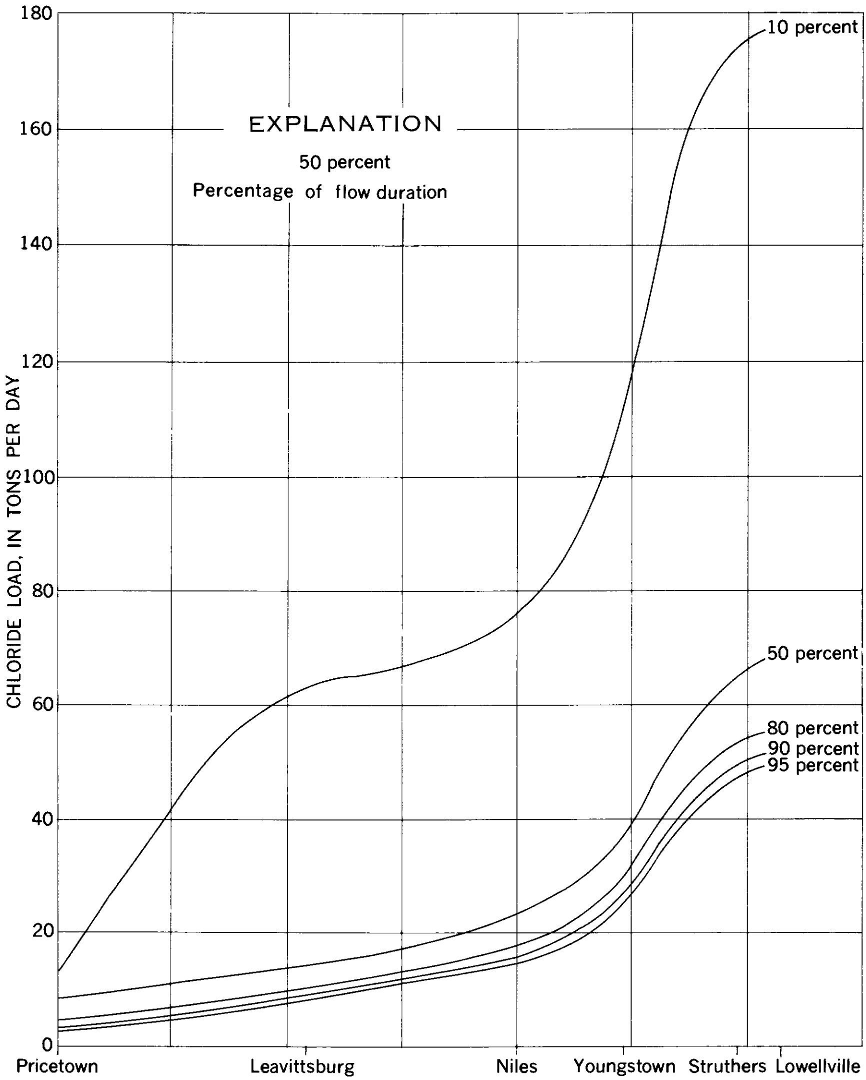

FIGURE 12.—Chloride load versus distance for indicated flow durations.

The chloride concentration of the Mahoning River has increased significantly since the late 1800's as a result of increased municipal- and industrial-waste disposal. Based on chemical analysis of five water samples collected monthly from July through November 1897, Foulk

TABLE 5.—*Duration of tons per day of water-quality parameters in the Mahoning River for the period January 1, 1963, to December 31, 1965*

[Figure in parentheses is number of observations]

Percentage of time parameter equaled or was less than that shown	Mahoning River at—					
	Pricetown	Leavittsburg	Niles	Youngstown	Struthers	Lowellville
	(144)	(149)	(146)	(141)	(148)	(142)
Alkalinity [1]:						
1 [2]	0.5	2.3	0	0	3.2	0
5	1.1	6.2	2.0	3.0	7.7	5.6
10	3.6	24	4.7	7.0	11	9.2
25	14	32	10	13	25	20
50	22	39	17	25	45	41
75	31	52	32	49	64	75
90	37	92	80	97	141	160
95	44	166	152	248	258	273
99 [3]	166	306	398	932	1,030	1,180
	(140)	(141)	(141)	(138)	(142)	(137)
Sulfate:						
1 [2]	2.5	16	12	80	116	106
5	6.9	31	77	101	165	170
10	12	35	91	118	194	200
25	24	48	114	153	238	255
50	38	54	148	198	205	310
75	55	84	191	242	360	380
90	84	171	282	399	535	630
95	124	308	418	687	825	940
99 [3]	587	816	1,480	2,090	2,110	2,420
	(154)	(153)	(154)	(151)	(154)	(151)
Chloride:						
1 [2]	0.4	4.3	10	20	36	37
5	1.8	7.9	14	24	40	43
10	2.7	8.5	15	25	46	48
25	4.4	11	18	28	53	56
50	8.3	13	24	37	66	68
75	11	20	36	51	91	97
90	14	28	48	89	157	146
95	22	40	61	158	219	252
99 [3]	90	198	287	350	689	601

[1] Alkalinity as $CaCO_3$.
[2] Approximately equal to the minimum load of the listed parameter.
[3] Approximately equal to the maximum load of the listed parameter.

(1925, p. 174) reported an average chloride content of 12.6 ppm at Niles and 7.5 ppm at Youngstown. During the 1963–65 period the average chloride concentrations were 38 ppm at Niles and 40 ppm at Youngstown. The chloride concentrations ranged from 2.1 to 42.5 ppm at Niles and from 0.3 to 15.2 ppm at Youngstown in 1897. During 1963–65 the ranges in chloride concentrations were 10–68 ppm at Niles and 11–79 ppm at Youngstown.

Although chloride is not now a problem constituent in the water of the Mahoning River, in future years more steel mills may convert from sulfuric acid pickling to hydrochloric acid pickling. Without proper controls, there could then be a serious increase in chloride concentration in the river.

SULFATE

Several relations were developed to define changes in the sulfate concentration and load in the lower reach of the Mahoning River. The sulfate-concentration durations in table 3 show that significant changes occurred between the upstream and downstream stations. The durations for Pricetown and Leavittsburg were nearly the same—equal to or less than 100 ppm and 98 ppm, respectively, for 50 percent of the time. From Youngstown to Lowellville the sulfate concentration at 50 percent duration was about twice as high and ranged from 190 to 230 ppm.

The relations between water discharge and sulfate concentration were defined for each station. The average sulfate concentration for each of five flow rates representing 10-, 50-, 80-, 90-, and 95-percent flow duration was plotted in downstream order (fig. 13). The flow, in cubic feet per second, represented by these percentages is shown on each curve. The reasons for changes in the sulfate concentrations from station to station are now apparent.

The sulfate concentration decreased from Pricetown to Leavittsburg. Upstream from Pricetown acid mine drainage contributed appreciable quantities of sulfate to the Mahoning River, so that during low flow (upper two curves) the river had about 200–250 ppm sulfate at Pricetown. These concentrations were diluted by water from West Branch Mahoning River and from Eagle Creek, which enter the Mahoning River upstream from Leavittsburg. At Leavittsburg the sulfate concentration at the 90- and 95-percent flow durations was 150 ppm or slightly less.

From Leavittsburg to Niles, through the Warren area, the sulfate concentration increased to more than 300 ppm during low flow. No major tributary enters the Mahoning River between these cities, so there is little increase in water discharge. The increase in sulfate concentration was the result of the sulfate contributed by industrial- and municipal-waste water discharged to the river.

Downstream from the Niles sampling station, inflow from Meander and Mosquito Creeks again reduced the sulfate concentration of the Mahoning, except at extremely low flows (95-percent flow duration). From Youngstown to Struthers and Lowellville, the concentration again increased as more industrial and municipal waste was received. At the higher water discharges, 50- and 10-percent durations, a similar trend is evident but it is of a smaller magnitude.

Each tributary and each major water-use area had an effect on the sulfate concentration of the river. However, further analysis is needed to determine the magnitude of the sulfate load and the variations in load from station to station. The curves for sulfate load are

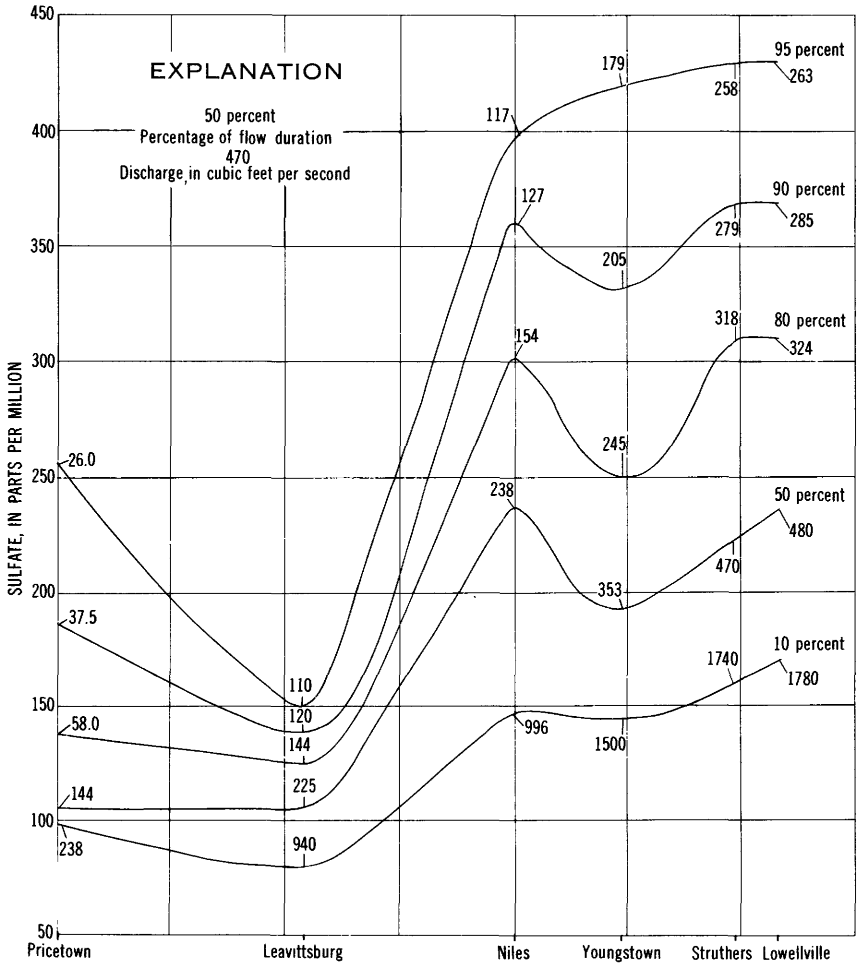

Figure 13.—Sulfate concentration versus distance for indicated flow durations.

shown in figure 14. This figure, similar to figure 13, is a plot of the loads for several flow rates, representing different flow durations for each sampling station. The resulting curves are quite different from those for concentration because there was a continuous increase in sulfate load throughout the reach.

During low flows, shown by the lower curves, the sulfate loads increased slightly between Pricetown and Leavittsburg. Although inflow from West Branch Mahoning River and Eagle Creek caused a lower sulfate concentration in the Mahoning River at Leavittsburg, the inflow did contain some sulfate and contributed a small sulfate load to the river. Downstream from Leavittsburg the sulfate load increased. During high streamflow, shown by the upper curve, the sulfate loads were much higher, although the sulfate concentrations at these flows were lower. From Pricetown to Niles the load during high flow increased gradually in the downstream direction and indicated a continuous pickup of sulfate through this reach of river. The appreciable increase in flow between Niles and Struthers, with Meander, Mosquito, and Mill Creeks all contributing calcium sulfate, caused a greater increase in sulfate load in this reach.

The variations in the sulfate concentration and load during low flow are illustrated on plate 1. The sulfate concentration varied as water was contributed by the several tributaries and by the industrial- and municipal-waste outfalls. The sulfate load, however, increased significantly from one sampling station to the next downstream station. This increase in sulfate load in the downstream direction is also shown by the duration of the daily loads in table 5. For each percentage of time, the loads progressively increased from station to the next down-

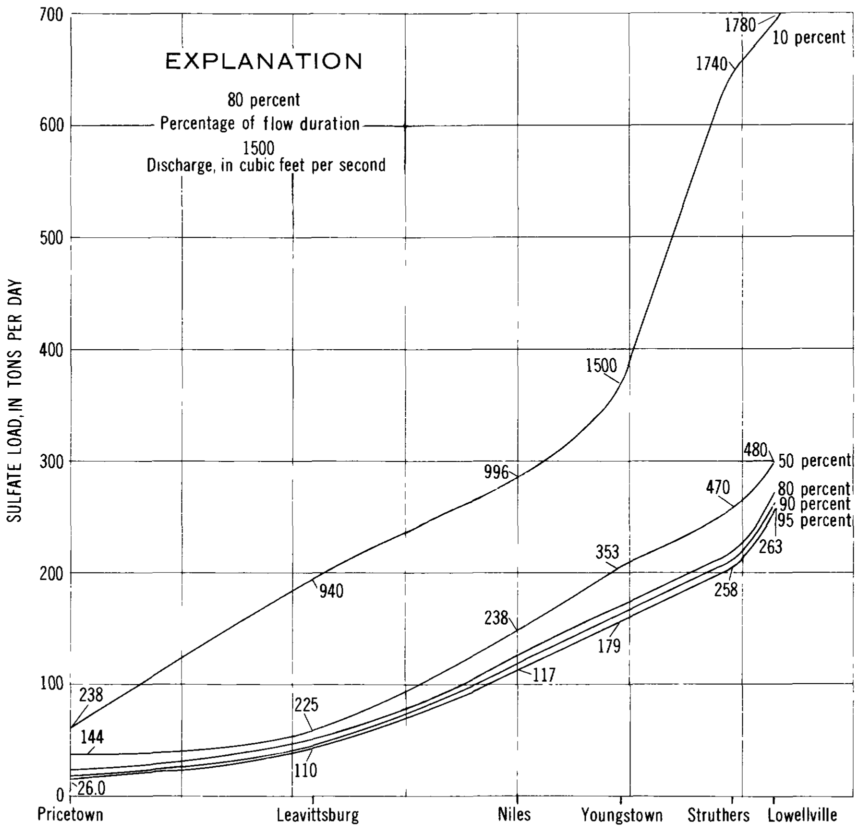

FIGURE 14.—Sulfate load versus distance for indicated flow durations.

stream station. The maximum daily sulfate load at Pricetown was nearly 600 tons, or about one-fourth of the maximum daily load at Lowellville.

The plot of the cumulative sulfate load for each station (fig. 15) shows seasonal variations as well as the increase in sulfate load in the

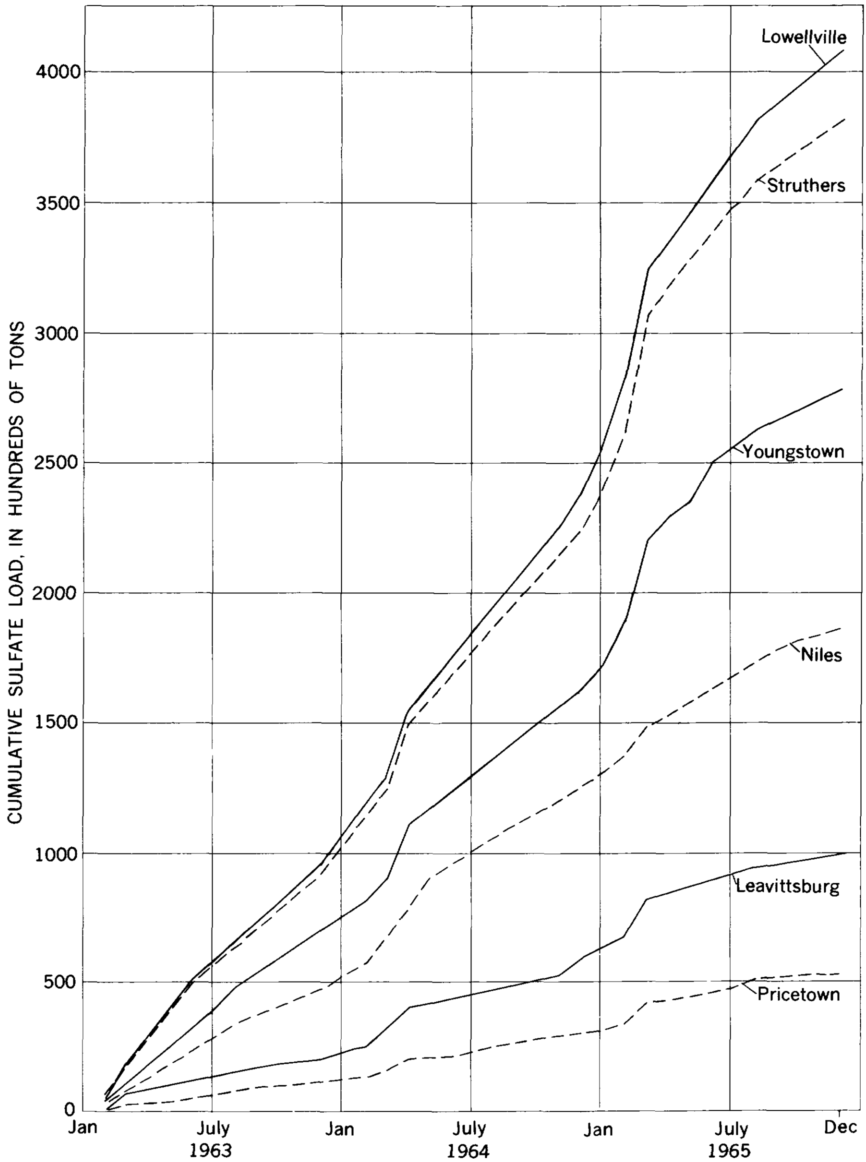

FIGURE 15.—Cumulative sulfate load.

downstream direction. Increased loads during the high flows caused the curves to steepen for each winter period. The industrial and municipal outfalls contributed a relatively uniform sulfate load; the increased load during high flows was contributed by the tributaries.

To further define the proportion of the sulfate load contributed by tributary streams and by industry along the Mahoning River, the sulfate loads and concentrations at various water discharges at Lowellville were plotted with the corresponding monthly steel-production index (fig. 16). Although there are some exceptions, there is a correlation between production index and sulfate load. Notice, too, that during the steel-mill shutdowns from June 3 to July 24, 1952, and from July 14 to November 7, 1959, the sulfate load decreased considerably.

To show the relation between steel production and sulfate, the average sulfate concentration was plotted against the mean-water discharge for each month for the Mahoning River at Lowellville, and the monthly production index was noted (fig. 17). Curves were then drawn for production indices of 50, 100, and 175 and for months the mills were shut down. The dashed and dotted lines indicate the scatter of the points for the 175 index. The two dashed lines indicate the standard deviation from the mean curve. The upper (dotted) line indicates the upper limit of plotted points.

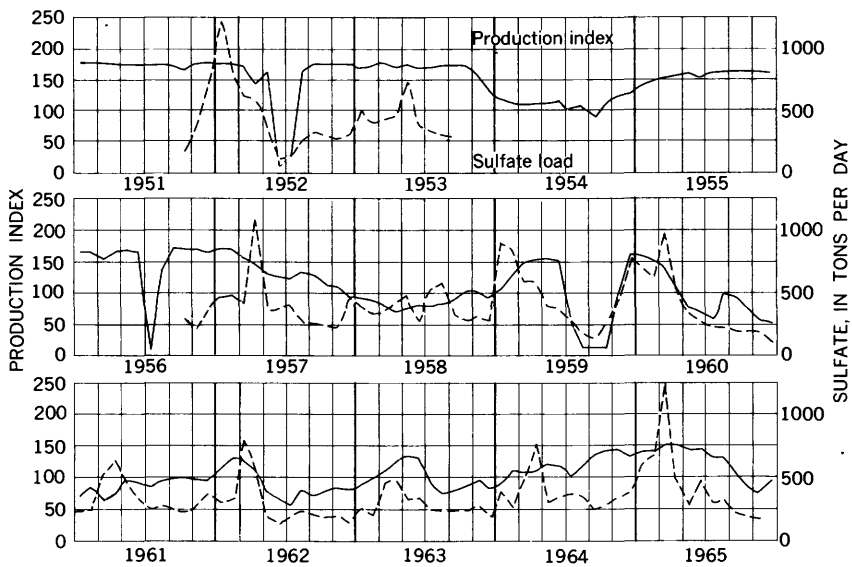

FIGURE 16.—Sulfate loads and steel production, Mahoning River at Lowellville, 1951–65. Solid line, production index; dashed line, sulfate load.

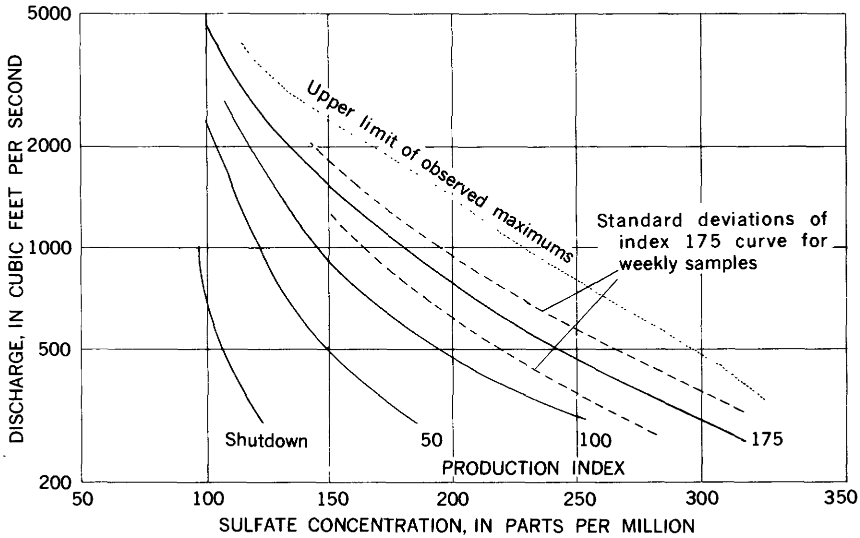

FIGURE 17.—Correlation of sulfate concentration, stream discharge, and steel production, Mahoning River at Lowellville.

The curves show that as the production index increased, the sulfate concentration at Lowellville increased. However, at higher streamflows, the curves tend to converge. At flows of more than about 2,000 cfs, the concentrations tend to level off at about 100 ppm regardless of the production index. Notice, also, that even during periods of steel-mill shutdown, shown by the left-hand curve, the sulfate concentration ranged from 100 to 120 ppm, which is one-third to one-half the sulfate concentration at the 175 production index.

Similar correlations using sulfate load are shown in figure 18. Curves for production indices of 50, 100, and 175 and for steel-mill shutdown are shown as in the previous figure. There was a noticeable increase in sulfate load as steel production increased, particularly at lower flows. However, the load contributed from other sources accounted for more than half the load at Lowellville when the production index was 100 or less. At a mean monthly flow of 600 cfs, for example, the daily sulfate load was about 165 tons at Lowellville when the mills were shut down, about 220 tons when production was at an index of 50, and 360 tons when at an index of 175. During months of high water discharge, the portion of the sulfate load contributed by natural sources and by acid mine drainage was greater, and the contribution by the steel industry was proportionately less than during low-flow months.

A plot of cumulative sulfate load versus cumulative water discharge (fig. 19) indicates that there has been no significant change in this

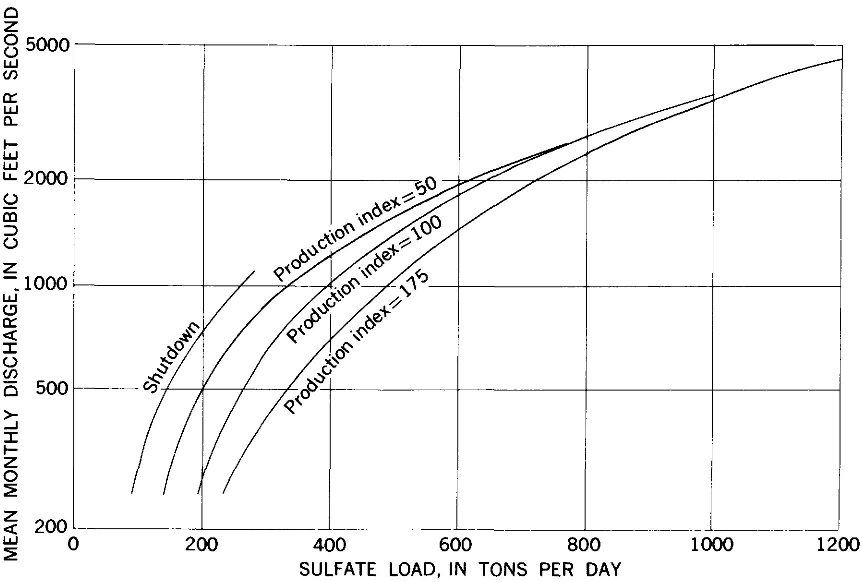

FIGURE 18.—Correlation of sulfate load, stream discharge, and steel production, Mahoning River at Lowellville.

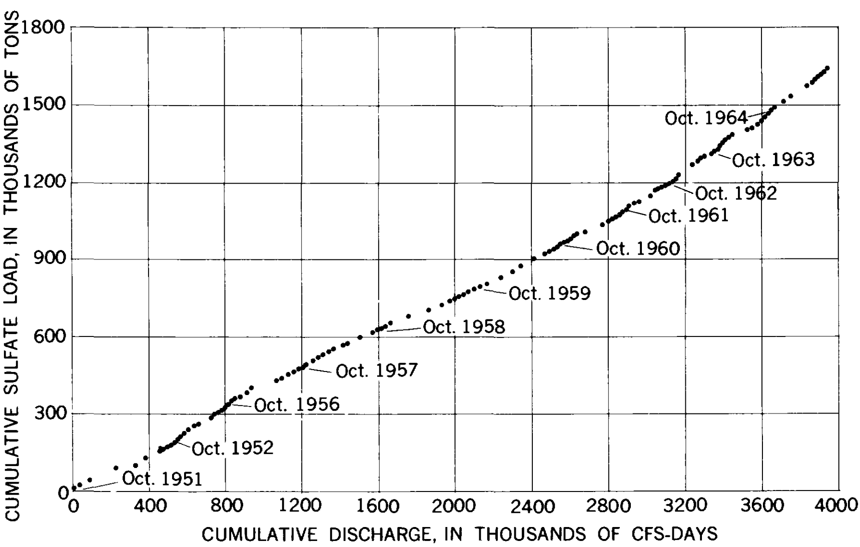

FIGURE 19.—Cumulative sulfate load versus cumulative discharge for the Mahoning River at Lowellville for water years 1951–52 and 1957–65.

relation during the indicated periods of record. From early 1962 through late 1964, the slope of the curve is steeper and indicates an increase sulfate load compared to discharge. This increase in slope, however, is probably due to the relatively low flows and corresponding higher sulfate concentrations which prevailed during this time.

ALKALINITY AS $CaCO_3$

The alkalinity of the Mahoning River was generally low through the Pricetown-Lowellville reach owing to the acid mine drainage and industrial discharges which the river received. The alkalinity was highest at Leavittsburg and Pricetown upstream from the industrialized area. At Niles, Youngstown, Struthers, and Lowellville, the alkalinity as $CaCO_3$ was less than 70 ppm for 90 percent of the time (table 3).

At Pricetown and Leavittsburg the alkalinity concentration varied inversely with water discharge (fig. 20). At Pricetown, for example, the concentration ranged from 128 ppm during low flow to 53 ppm during high flow. However, the alkalinity was reduced through the

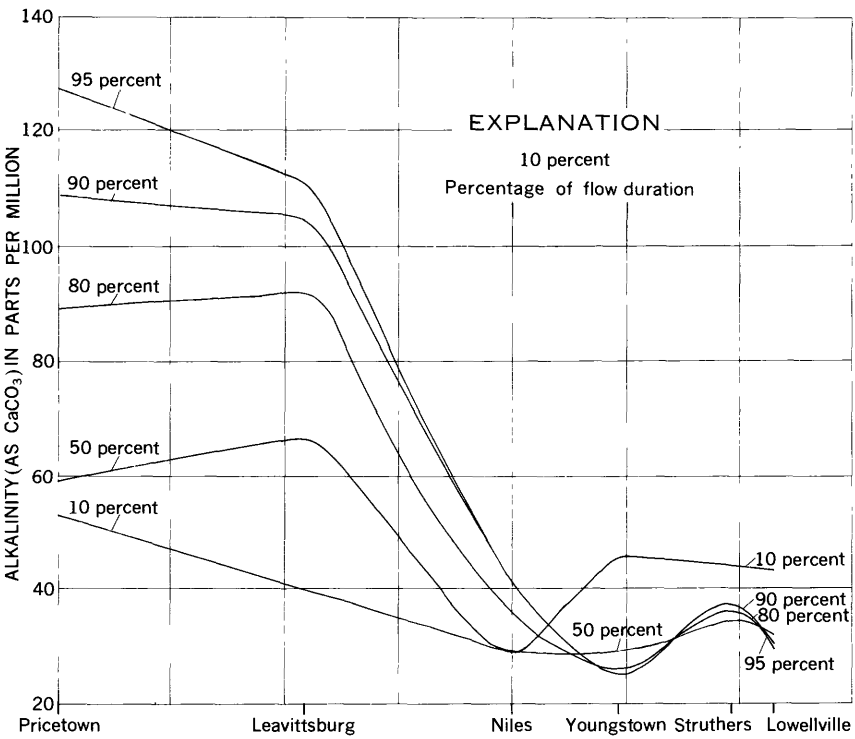

FIGURE 20.—Alkalinity concentration versus distance for indicated flow durations.

industrial area downstream from Leavittsburg and ranged from about 25 to 45 ppm. It did not vary appreciably with water discharge in this reach.

The effect of industrial wastes and tributary inflow on alkalinity loads is shown by figure 21. Between Pricetown and Leavittsburg alkalinity was contributed by Kale Creek, Eagle Creek, and West Branch Mahoning River. Between Leavittsburg and Niles the alkalinity was reduced by pickle-liquor waste effluent. During high flow (10-percent flow duration) inflow from Meander and Mosquito Creeks caused an increase in the alkalinity load from 78 tons at Niles to 185 tons at Youngstown. Alkalinity load was also increased by the washing out of softening sludges disposed of in Meander Creek and by the seepage from slag dumps. At medium and low flows, when ground-water inflow is the predominant source of streamflow, the alkalinity load increased from 15 to 30 tons per day between Niles and Struthers and

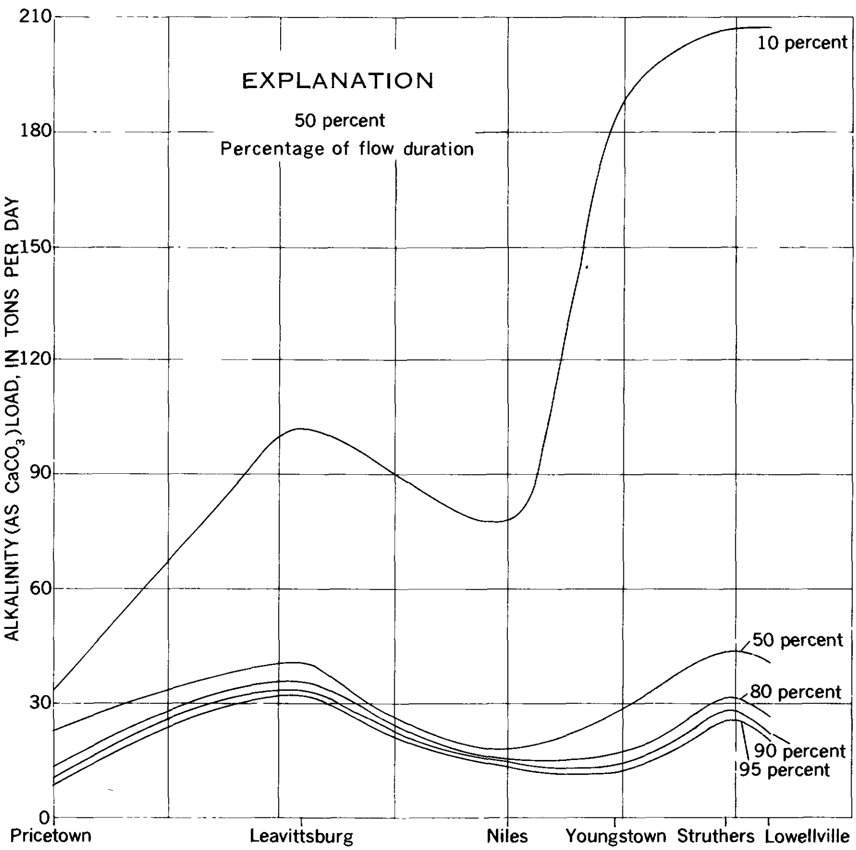

FIGURE 21.—Alkalinity load versus distance for indicated flow durations.

declined again at Lowellville. A comparison of alkalinity concentrations and loads in the Mahoning River during periods of low streamflow is shown on plate 1. The highest load and highest concentrations occurred upstream from the industrial reach during low flow.

The duration table of daily alkalinity loads again shows that, up to 25 percent of the time, the highest loads occurred at Leavittsburg, upstream from the industrialized area. (See table 5.) Also, the effect of inflow from Meander and Mosquito Creeks is shown by the large increases in the daily alkalinity load that occurred between Niles and Youngstown.

IRON

Steel-pickling liquors contain large amounts of iron in the soluble ferrous state. To date, the pickling has been principally with sulfuric acid. When steel-pickling liquors containing ferrous sulfate are discharged into a stream, there is an immediate chemical reaction. Through hydrolysis and oxidation, the ferrous iron is converted to an insoluble ferric salt, which precipitates and is deposited in the channel or is carried in suspension by the river. Ferric iron is also contributed in the waste waters containing flue dust and mill scale. Portions of the Mahoning River channel have been dredged for the recovery of the deposited iron.

At Pricetown and Leavittsburg the concentration of total iron was less than 1.5 ppm for 90 percent of the time (table 3). From Niles to Lowellville the iron concentration increased markedly and concentrations in excess of 50 ppm were measured frequently.

The iron concentrations shown in table 3 are for total iron and include the iron in solution and in suspension. Total iron concentrations were not reported when less than 1 ppm occurred.

CONCLUSIONS

Although water quality is influenced to some extent by acid mine drainage, the Mahoning River at Pricetown and Leavittsburg is relatively unaffected by industrial and domestic wastes. Therefore, the water-quality data for these sites can be compared with data for the reach from Niles to Lowellville to determine the effect of municipal and industrial wastes on the water quality of the river. Consideration of the water-quality data with the hydrologic conditions and water use will aid materially in the understanding of the chemical system and the selection of reasonable water-quality criteria.

Streamflow during 1963–65 was generally less than during the long-term period. However, minimum flows during the 3-year period were greater than those experienced in the long-term period.

Thermal loading in the industrial reach of the Mahoning River commonly caused water temperatures to exceed 100°F during the summer months. However, flow augmentation and modification of industrial processes have improved the water-temperature conditions in recent years. Water temperatures increased with higher steel-production indices but were lower during high water discharge.

Dissolved-oxygen content was less than 5.0 ppm in some reaches of the lower Mahoning River for extended periods as a result of the disposal of municipal and industrial wastes and thermal loading.

The municipal and industrial wastes also caused an increase in the dissolved-solids concentration, particularly the sulfate concentration, in the lower Mahoning River. A correlation of sulfate concentration with the steel-production index and water discharge showed that during low flow about half the sulfate load at Lowellville was derived from steel-mill wastes when production was at an index of 100. During a steel-mill shutdown the water in the lower Mahoning River had the same general chemical character as the river upstream from Leavittsburg. Chloride was of minor importance and averaged 56 ppm at Lowellville during the 1963-65 period.

The acid mine drainage and pickle-liquor wastes received by the Mahoning River decreased the alkalinity and lowered the pH to below 7.0 most of the time downstream from Leavittsburg. Significant quantities of iron were received by the river from steel-mill production, and total iron concentrations were frequently in excess of 20 ppm between Leavittsburg and Lowellville.

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