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WATER RESOURCES OF DELAWARE COUNTY, INDIANA

BY

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WATER RESOURCES OF DELAWARE COUNTY, INDIANA

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ABSTRACT

In Delaware County, Indiana, water of sufficient quantity and quality is available with proper development in the streams and in the aquifers for the expected increase of most agricultural, domestic, industrial, and municipal uses in the foreseeable future.

Water use in Delaware County totals about 18.5 mgd (million gallons per day) of which 63 percent is from surface water and 37 percent from ground water. Muncie uses about 80 percent of the total water used in the county.

The White River at Muncie yields a natural flow (after adjustment for diversion) of more than 20 cfs (cubic feet per second) (13 mgd) 90 percent of the time from a drainage area of 242 square miles. Low flow in White River is augmented by releases from Prairie Creek Reservoir for the Muncie water supply.

The Mississinewa River offers good development potential, although the low flow is not as well sustained as in the White River. By way of comparison, the Mississinewa River 3 miles upstream from Eaton, drainage area 304 square miles, yields more than 8 cfs (5 mgd) 90 percent of the time.

Many small streams in the northern half of the county frequently go dry, while most streams in the southern half of the county, regardless of size, yield more than 0.013 mgd per square mile 90 percent of the time. Buck Creek has the highest low-flow yield of all the small streams in the county. At the stream-gaging station on Buck Creek near Muncie, drainage area 36.7 square miles, the flow exceeds 10 cfs (6.5 mgd) 90 percent of the time.

Nearly all the available ground water occurs within 400 feet of the land surface. Wells utilizing all available water-bearing zones could probably yield as much as 1,000 gpm (gallons per minute) in the south central and southeastern parts of the county.

The upper 100 feet of dolomite of Silurian Age, at the bedrock surface, is one of the two principal aquifers in the county. It underlies the entire county at depths ranging from 0 to about 300 feet. The most permeable parts of this aquifer could yield as much as 500 gpm to individual wells.

Sand and gravel in and near buried valleys yield water for domestic and industrial use. The areal extent and potential of this unit are not well known.

The principal Pleistocene aquifer is composed chiefly of glacio-fluvial sand and gravel up to 80 feet thick and underlies most of the county at depths of 0 to about 140 feet. The thicker parts of this aquifer could yield as much as 500 gpm to individual wells.

The surface and ground waters in Delaware County are generally a calcium bicarbonate type with moderate amounts of sulfate and hardness. The ground water may contain objectionable concentrations of iron. The chemical quality of the ground water is similar in all important aquifers in the county. The quality of the streams at about 90 percent flow duration approximates that of the ground water except where activities of man have increased the mineralization of the streams.

PURPOSE AND SCOPE

The purpose of this report is to describe for those concerned with water development and use in Delaware County (1) the sources of available water for current and future uses, (2) the quantity, distribution, and quality of the resource, and (3) some of the significant relations in the hydrologic system between precipitation, geology, ground water, surface water, and water quality.

This purpose was accomplished by analyzing information based on (1) well data and aquifer characteristics collected from drillers, water works superintendents, industries and others, (2) streamflow data based on 7 stream-gaging station records, 4 partial-record station measurements and base-flow measurements at miscellaneous sites, (3) quality-of-water data based on samples collected from the streams during low flows, from wells, and at water quality monitoring stations, and (4) field investigation of the surficial geology of the county.

This report provides information that will be useful in planning the development, control, and utilization of surface and ground waters in Delaware County. Some of the problems to be considered by the water user in the development of the resource are discussed.

COOPERATION AND ACKNOWLEDGEMENTS

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The authors thank all persons and State Agencies who contributed time, information, and assistance during the preparation of this report. We especially thank the well drillers who furnished well logs and other

information, as well as the Muncie Water Works Company, industries, firms, and water works superintendents who contributed information. The Indiana State Highway Commission supplied locations and logs of test borings and the Indiana State Board of Health and Stream Pollution Control Board furnished water-quality data at monitoring stations on the Mississinewa and White Rivers.

WATER USE

Water use in Delaware County is presently about 18.5 mgd (million gallons per day) or 155 gpd (gallons per day) per person. Water use has been increasing at the rate of about 2 gallons per person per year since 1950. It is estimated that by 1980 the requirements will be nearly 190 gpd per person or a total of 31.5 mgd for the county.

An inventory of municipal and industrial water consumption was made in order to obtain information on present water use in the county and to outline future water needs. These data and records, obtained from water users, the Indiana Public Service Commission, Indiana State Board of Health, and other sources, were utilized in formulating an estimate of the amount of water used in the county.

A compilation of these data along with projected estimates of water use in 1980 are shown in table 1. The estimates for 1980 are made on the assumption that the use of surface water and ground water will have the same ratio as at the present time and that Muncie will be the only surface water user. A small amount of surface water has been used in time past for irrigation, probably less than 0.1 mgd. A larger amount will probably be used in the future when climatic factors are unfavorable during the growing season. As water used for irrigation is such a nebulous figure to estimate in Delaware County, no estimate has been entered in table 1 for either 1964 or 1980.

Table 1. Estimates of water use in Delaware County in millions of gallons per day, for 1964 and 1980.

Source and use	1964	1980
Surface Water		
Industrial	5.8	9.8
Municipal	5.9	10.0
Self-supplied domestic	0	0
Total	11.7	19.8
Ground Water		
Industrial	3.7	6.4
Municipal	.6	1.0
Self-supplied domestic	2.5	4.3
Total	6.8	11.7
Grand Total	18.5	31.5

Water use today is the highest in the history of Delaware County, and the trend has been upward for many years with no indication of leveling off. Of the 18.5 mgd used at present, industry uses about one-half, with the remaining part divided between municipal (Albany, Eaton, Gaston, Muncie and Yorktown) and self-supplied domestic use (table 1). Most municipal and industrial use is not consumptive, and used water is disposed of in the streams usually after treatment.

Industrial and municipal use is concentrated in the Muncie area, where the combined use is about 14.7 mgd, or 80 percent of the total water used in the county. This 14.7 mgd includes water taken from White River, Prairie Creek Reservoir, Buck Creek, and wells. Of the total used in the county, about 11.7 mgd, or 63 percent, is taken from surface water sources, with the remainder, 37 percent, being obtained from numerous municipal, industrial and domestic ground-water supplies.

Population trends have likewise been progressing upward. With an expected increase in population from 120,000 (estimated) in 1964 to about 167,000 by 1980 (Hannaford, 1960, p. 7), water consumption is expected to increase from the present 155 gpd per person (18.5 mgd) to about 190 gpd per person (31.5 mgd). Of this estimated total volume, about 19.8 mgd will probably be taken from surface water sources, primarily White River, Prairie Creek Reservoir and Buck Creek, and the remainder from well supplies.

PHYSICAL FEATURES AFFECTING WATER SUPPLY

Climate

Precipitation, temperature, and wind are climatic factors directly affecting surface and ground-water supplies. Precipitation adds water to the streams and ground-water reservoirs causing water levels to rise. During dry periods water used or flowing out of an area is not replenished, and water levels fall. High temperature and wind cause water levels to fall by increasing the amount of water returned to the atmosphere by evaporation (from exposed water surfaces) and transpiration (from plants). High temperatures likewise cause water levels to fall by increasing the withdrawals by man for both his personal comfort and industry.

In east-central Indiana, which embraces Delaware County, precipitation averages about 39 inches per year, with monthly averages ranging from 2.37 inches for February to 4.50 inches for June. Much of the precipitation that replenishes the ground-water supply occurs during the early spring and late fall months. Although precipitation is slightly less during these periods, recharge is greater than during the growing season, when monthly precipitation averages are higher. During the growing season, the evaporation and the transpiration losses are large and percolation of precipitation to the ground-water reservoirs is greatly decreased. The average monthly, annual, and seasonal (April through September) precipitation and temperature of east-central Indiana for the period 1931-60 are shown in table 2.

Table 2. Average monthly, annual, and seasonal (April through September) precipitation and temperature of east-central Indiana, 1931-60.

Month	Average Precipitation (inches)	Average Temperature (^{o}F)
January	3.03	29.4
February	2.37	30.9
March	3.35	38.8
April	3.78	50.5
May	4.13	60.9
June	4.50	70.7
July	3.60	74.2
August	2.98	72.5
September	3.31	65.5
October	2.77	54.5
November	2.93	41.1
December	2.52	31.1
Annual	39.27	51.7
April through September	22.30	65.7

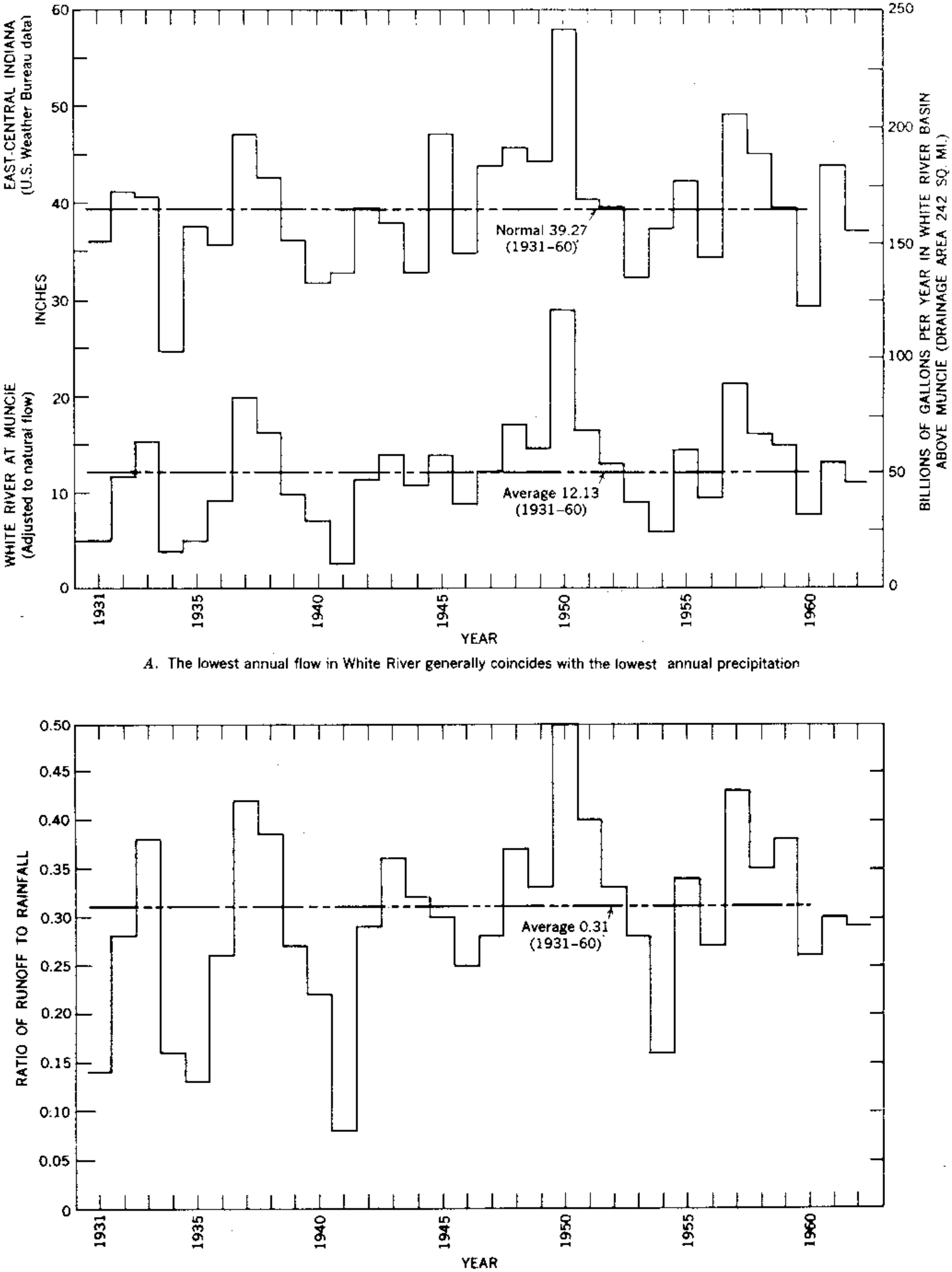
From U. S. Weather Bureau Data

The annual runoff of the White River at Muncie, adjusted to natural flow, is compared with the annual precipitation of east-central Indiana for the period of 1931-62 in figure 1. The similarity between the two graphs (A of fig. 1) is apparent, with the lowest annual flows in White River generally coinciding with periods of lowest precipitation. The ratio of runoff to precipitation is not constant, however, (B of fig. 1) varying from 0.08 in 1941 to 0.50 in 1950. Soil moisture, amount of precipitation, intensity of precipitation, distribution of precipitation throughout the year, and water levels in ground-water aquifers, as well as other factors, have their effect on the proportion of precipitation that runs off into the stream by either overland or underground flow.

Topography and Drainage

The topography of Delaware County is flat to gently rolling with a dendritic drainage pattern.

Land elevations are highest in the southeastern part of the county where the maximum is about 1,100 feet above mean sea level. The land slopes downward gradually from this area towards the northwest and west. The lowest elevation is 835 feet above mean sea level in the northwestern part where the Mississinewa River flows from the county. Maximum local relief of approximately 80 feet occurs near the south-central edge of the county.



A. The lowest annual flow in White River generally coincides with the lowest annual precipitation

B. The ratio between rainfall and runoff is not constant

Figure 1.—About one-third of the precipitation that falls on Delaware County runs off in the streams.

Delaware County lies within the White River and Mississinewa River drainage basins. Of the 392 square miles of area in the county, approximately two-thirds is drained by the White River system which includes Prairie, Buck, York Prairie, Killbuck and Pipe Creeks. The Mississinewa River and its tributaries drain the northeastern part of the county.

The White River flows generally westward through the county, and the Mississinewa flows in a northwesterly direction. The slopes of the stream channels are about 3.3 and 3.9 feet per mile for the Mississinewa and White Rivers, respectively, as they flow through the county. Several of the smaller streams have been dredged to improve the surface drainage.

Surficial Geology

The land surface of Delaware County is almost entirely covered by a relatively impermeable layer of glacial till and some silt. This deposit limits the amount of ground-water recharge and the amount of ground-water discharge to streams. The unit helps prevent the direct contamination of aquifers by man-made wastes.

Differences in base flow of the streams of Delaware County are caused by: (1) the unequal distribution and hydraulic properties of sand and gravel deposits beneath the surface till, (2) variations in thickness and permeability of the till, and (3) variations of the heights of the piezometric surfaces of the till and of the underlying saturated material above or below the level of the streams. The pick up of base flow in the streams compared with the size of the drainage area indicates the relative availability of ground water in the drift upstream from the points of measurement.

SOURCES OF WATER SUPPLY

The major sources of water in Delaware County are the streams, the upper 400 feet of the glacial drift, and the bedrock. The streams supply the largest amount of water and this amount could be increased by impoundments. The rocks generally provide adequate amounts of water and this amount could be increased by additional wells.

Streams

The average annual precipitation for the county is 39 inches. Of this amount about 12 inches, or 82 billion gallons, drains out of the county through the stream system. The quantity of water in the streams at any given time varies considerably from flood to drought. The amount that can be obtained as a dependable supply is highly variable from stream to stream, as well as at different locations on the same stream.

Application of Streamflow Data

The water available in the streams without impoundment has been evaluated by three techniques: (1) flow duration, (2) low-flow frequency, and (3) base-flow discharge measurements. The water that would be available by impoundment in the vicinity of the stream-gaging stations has been evaluated by a fourth technique: determination of draft-storage requirements. The first two techniques are statistical studies based on records of daily discharges collected at stream-gaging stations. The third technique is the comparison of base-flow (ground-water runoff) increase or decrease from various streams by obtaining discharge measurements when there is no overland runoff into the streams. The fourth technique is based on the low-flow frequency analysis and is used as a design tool. The two statistical studies were developed for a common time interval of 1924-63 by correlation of short-term with long-term water discharge records. A common reference period tends to equalize or make homogeneous climatic experiences.

These studies were based on records from 7 stream-gaging stations and measurements at 4 partial-record stations and 69 miscellaneous sites (including some observations of no flow) in the upper Mississinewa and White River basins embracing Delaware County. A list of the stations and sites is given in table 3, and the location of each is shown on plate 1.

The works of man have greatly altered the discharge of some streams or certain reaches of the channels. Most of these man-made effects are much more pronounced during low flows. At these times a considerable percentage of the total flow may be man supplied through waste or sanitary systems and reservoir releases, or man deleted or detained, through water supplies including reservoir storage. Adjustments have been made to some of the observed data to approach natural flow. Where observed data have been adjusted, this has been noted on the figures and in the tables.

Flow duration. Flow characteristics of a stream throughout its range in discharge may be shown by the flow-duration curve. A flow-duration curve shows the percentage of time discharges have been equaled or exceeded during a given period without regard to the sequence of occurrence. If the period upon which the curve is based represents a long-term flow of a stream, the curve may be used to estimate distribution of future flows for water supply and pollution studies. The slope of the duration curve is a quantitative measure of the variability of the streamflow and a flat slope on the lower end depicts well sustained flow.

The variation in flow at the 7 gaging stations is illustrated in figure 2. These flow-duration curves have been expressed in cubic feet per second per square mile (cfsm) so that they might be compared on a unit basis.

Table 3.--List of stream-gaging stations, partial-record stations, and miscellaneous sites used in this report and shown on Plate 1

Reference no.	Stream and location	Drainage area (sq mi)	Type of collection point	Reference no.	Stream and location	Drainage area (sq mi)	Type of collection point
1	Mississinewa River near Salem	25.0	M. S.	41	Cunningham ditch near New Burlington	1.95	M. S.
2	Harshman Creek near Salem	13.2	M. S.	42	Prairie Creek near Muncie (Reservoir release)	17.0	M. S.
3	Mississinewa River near Ridgeville	130	S. G. S.	43	Medford drain near Muncie	2.14	M. S.
4	Bear Creek near Ridgeville	15.0	M. S.	44	White River tributary near Muncie	3.83	M. S.
5	Platt Nibarger ditch near Redkey	5.81	M. S.	45	Muncie Creek near Desoto	3.82	M. S.
6	Mississinewa River near Albany	228	M. S.	46	Muncie Creek near Muncie	5.50	M. S.
7	Mud Creek near Albany	11.7	M. S.	47	White River at Muncie	242	S. G. S.
8	Halfway Creek near Albany	21.8	M. S.	48	White River near Yorktown	246	M. S.
9	Campbells Creek near Parker City	10.2	M. S.	49	Buck Creek near Oakville	27.1	M. S.
10	Campbells Creek near Desoto	20.4	M. S.	50	Buck Creek near Muncie	36.7	S. G. S.
11	Mississinewa River tributary near Albany	2.35	M. S.	51	Buck Creek near Yorktown	48.5	M. S.
12	Mississinewa River tributary near Royerton	.93	M. S.	52	Bell Creek near Cross Roads	16.0	M. S.
13	Bosman ditch near Albany	3.12	M. S.	53	Williams Creek near Cross Roads	11.7	M. S.
14	Bosman ditch tributary near Albany	1.56	M. S.	54	No Name Creek near Progress	7.55	M. S.
15	Bosman ditch near Eaton	6.10	M. S.	55	Little No Name Creek near Progress	2.63	M. S.
16	Mississinewa River near Eaton	304	S. G. S.	56	York Prairie Creek near Muncie	3.43	M. S.
17	Rees ditch near Dunkirk	6.43	M. S.	57	York Prairie Creek near Cammack	9.70	M. S.
18	Rees ditch near Millgrove	8.07	M. S.	58	York Prairie Creek near Yorktown	16.2	M. S.
19	Rees ditch near Eaton	13.5	M. S.	59	White River near Daleville	383	M. S.
20	Mississinewa River near Wheeling	348	M. S.	60	White River at Anderson	401	S. G. S.
21	Big Lick Creek near Hartford City	32.9	M. S.	61	Killbuck Creek near Anthony	7.35	M. S.
22	Bick Lick Creek near Wheeling	76.4	P. R. S.	62	Mud Creek near Anthony	6.52	M. S.
23	Studebaker ditch near Wheeling	10.5	M. S.	63	Killbuck Creek near Bethel	26.1	M. S.
24	Hayden ditch near Wheeling	4.45	M. S.	64	Thurston ditch near Bethel	1.63	M. S.
25	Hedgeland ditch near Wheeling	2.76	M. S.	65	Jakes Creek near Cammack	8.64	M. S.
26	Pike Creek at Wheeling	21.5	M. S.	66	Eagle Branch near Cammack	5.01	M. S.
27	Hoppas ditch at Matthews	8.14	M. S.	67	Jakes Creek near Bethel	18.5	M. S.
28	Lake Branch near Upland	9.15	M. S.	68	Pleasant Run Creek near Gilman	4.91	M. S.
29	Barren Creek near Upland	20.7	M. S.	69	Killbuck Creek near North Anderson	74.4	M. S.
30	Mississinewa River near Upland	515	M. S.	70	Killbuck Creek near Anderson	98.0	P. R. S.
31	Mississinewa River at Marion	677	S. G. S.	71	White River at Perkinsville	557	M. S.
32	White River near Harrisville	21.3	P. R. S.	72	Pipe Creek at Gaston	1.30	M. S.
33	White River at Winchester	34.1	M. S.	73	Yeager, Finley, Manard ditch near Gaston	7.43	M. S.
34	White River tributary near Maxville	1.15	M. S.	74	Steel ditch near Gaston	.67	M. S.
35	Eightmile Creek near Maxville	8.06	M. S.	75	Pipe Creek near Gaston	18.3	M. S.
36	White River near Farmland	84.5	M. S.	76	Pipe Creek near Alexandria	44.7	P. R. S.
37	Stoney Creek near Blountsville	18.7	M. S.	77	Pipe Creek near Frankton	108	M. S.
38	Stoney Creek tributary near Blountsville	1.03	M. S.	78	White River near Noblesville	814	S. G. S.
39	White River near Selma	179	M. S.	79	Fall Creek near Cross Roads	4.97	M. S.
40	Mud Creek near Selma	6.27	M. S.	80	Brandon ditch near Middleton	5.42	M. S.

S. G. S. - Stream-gaging station P. R. S. - Partial-record station M. S. - Miscellaneous site

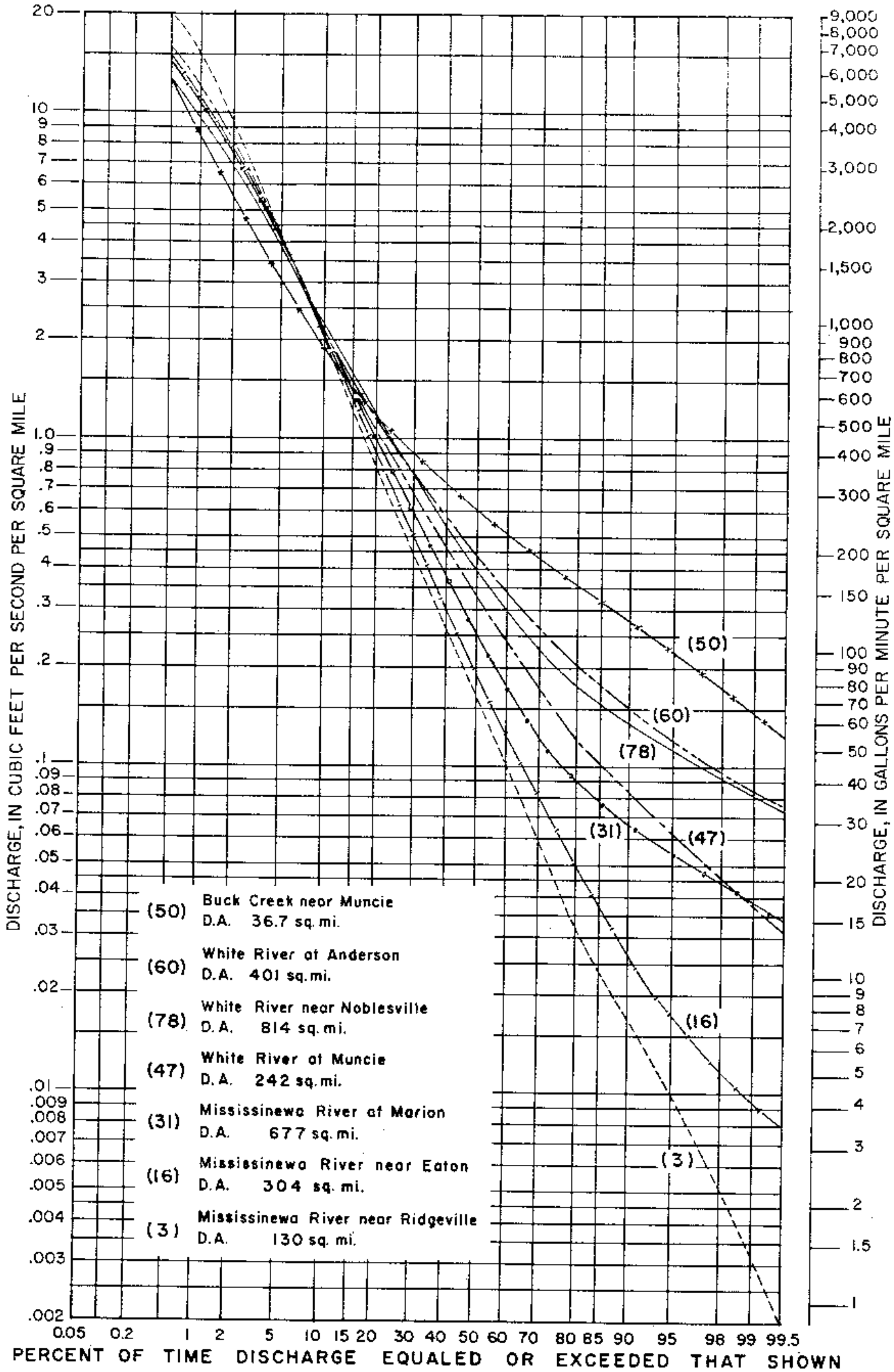


Figure 2 - Duration curves of daily flows at seven gaging stations on the Mississinewa River, White River and Buck Creek (adjusted to period, 1924— 1963)

Discharges of equal percent duration for the lower half of the flow-duration curves, which contain larger percentages of ground-water runoff as the flow decreases, have been tabulated and shown both in terms of cubic feet per second (cfs) and cfsm in table 4. As a means of comparing the inflow between gaging stations, table 4 also contains computed runoff figures for the intervening drainage areas.

To supplement the flow-duration data for the stream-gaging stations, the 90 and 95 percent flow-duration discharges at 4 partial-record stations and 11 miscellaneous sites have been estimated by correlation and are tabulated in table 5.

Low-flow frequency. Since the flow-duration curve does not show the frequency with which any given discharge can be expected to occur on the average, it is necessary to know more about low-flow characteristics of the stream. The low-flow frequency curve is an excellent tool for estimating how frequently a certain average low-flow discharge for a given period of consecutive days will occur. It can also be used in the analysis of storage requirements. The shapes of low-flow frequency curves, like the flow duration curves, reflect the hydrogeologic and hydraulic characteristics of the upstream basin.

Low-flow frequency data for the 3-, 7-, 14-, 30-, 60-,120-, 183-, and 274-day consecutive periods are presented in table 6 for the same 7 stream-gaging stations for which flow-duration data are tabulated and illustrated. The 7-day low-flow frequency curve for each of these stream-gaging stations is illustrated in figure 3. These low-flow frequency curves have been expressed in cfsm so that they might be compared on a unit basis.

To avoid misuse of these data it might be well to discuss recurrence interval (frequency), as used in this study. By definition, the recurrence interval, given in years, is the long-term average interval between annual minimum discharges equal to or less than the given minimum. For example, inference should not be made that the 3-day 10-year minimum will occur once, and only once during a 10-year period. It may occur in any year or successive years, but its chance of occurring as an annual 3-day minimum in any year is 1 in 10, or 10 percent.

To supplement the low-flow frequency data for the stream-gaging stations, the 7-day 2-year and 7-day 10-year low-flow have been estimated for the 4 partial-record stations and 11 miscellaneous sites where several base-flow measurements have been made and tabulated in table 5.

As with flow-duration studies, estimates of average low-flow frequency are based on records of past events and it is impossible to foresee what the future works of man will do to alter the natural flow.

Table 4.--Discharge of equal percent flow duration as taken from stream-gaging station flow-duration curves and computed for intervening areas (adjusted to the period 1924-63)

Reference no.	Gaging station and intervening areas	Drainage area (sq mi)	Discharge of indicated percent time duration (cubic feet per second, over cubic feet per second per square mile)								
			99.5	99	98	95	90	80	70	60	50
3	Mississinewa River near Ridgeville	130	0.2 .002	0.4 .003	0.7 .005	1.3 .010	2.2 .017	4.2 .032	7.8 .060	13 .100	22 .169
	Intervening - Ridgeville to Eaton	174	2.1 .012	2.3 .013	2.8 .016	4.0 .023	5.8 .033	10.8 .062	17.2 .099	25 .144	36 .207
16	Mississinewa River near Eaton	304	2.3 .008	2.7 .009	3.5 .012	5.3 .017	8.0 .026	15 .049	25 .082	38 .125	58 .191
	Intervening - Eaton to Marion	373	20.7 .055	23.3 .062	26.5 .071	31.7 .085	37 .099	47 .126	60 .161	82 .220	117 .314
31	Mississinewa River at Marion (adjusted for low flow regulation)	677	23 .034	26 .038	30 .044	37 .055	45 .066	62 .092	85 .126	120 .177	175 .258
47	White River at Muncie (adjusted to natural flow by adding diversion for water supply)	242	7.6 .031	9.0 .027	11 .045	15 .062	20 .083	29 .120	42 .174	59 .244	80 .331
50	Buck Creek near Muncie	36.7	4.5 .23	5.3 .144	6.2 .69	8.0 .218	10 .272	13 .354	16 .436	19 .518	22 .599
	Intervening - Muncie to Anderson excluding Buck Creek	122	18 .148	20 .164	21 .172	25 .205	30 .246	38 .311	47 .385	57 .467	73 .598
60	White River at Anderson (adjusted to natural flow by correlation with White River near Noblesville)	401	30 .075	34 .085	38 .095	48 .120	60 .150	80 .200	105 .262	135 .337	175 .436
	Intervening - Anderson to Noblesville	413	29 .070	31 .075	35 .085	42 .102	50 .121	60 .145	80 .194	110 .266	155 .375
78	White River near Noblesville	814	59 .072	65 .080	73 .090	90 .111	110 .135	140 .172	185 .227	245 .301	330 .405

Table 5.--Selected low-flow frequency and flow-duration data for partial-record stations and miscellaneous sites in the upper Mississinewa and White River basins embracing Delaware County (Data adjusted to period 1924-63 on basis of correlation with stream-flow records at stream-gaging stations).

Reference no.	Stream and location	Drainage area (sq mi)	Annual low-flow, in cfs, for indicated period of consecutive days and for indicated recurrence interval, in years		Flow, in cfs, which was equaled or exceeded for indicated percent of time	
			7 day		90	95
			2 yr	10 yr		
10	Campbells Creek near Desoto	20.4	0.2	0	0.3	0.2
19	Rees ditch near Eaton	13.5	1.1	.5	1.0	.8
22	Big Lick Creek near Wheeling 1/ 2/	76.4	3.2	1.4	4.0	3.0
23	Studebaker ditch near Wheeling	10.5	.2	0	.1	.1
32	White River near Harrisville 1/	21.3	.5	.2	.5	.3
37	Stoney Creek near Blountsville	18.7	1.4	.6	1.4	.9
41	Cunningham ditch near New Burlington	1.95	.6	.4	.6	.5
52	Bell Creek near Cross Roads	16.0	1.2	.6	1.2	.8
53	William Creek near Cross Roads	11.7	.6	.2	.6	.3
54	No Name Creek near Progress	7.55	.2	0	.2	.1
57	York Prairie Creek near Cammack	9.70	2.6	1.8	2.4	2.0
63	Killbuck Creek near Bethel	26.1	2.0	.8	1.8	1.2
67	Jakes Creek near Bethel	18.5	.5	0	.5	.2
70	Killbuck Creek near Anderson 1/	98.0	14	6.7	13	9.5
76	Pipe Creek near Alexandria 1/	44.7	3.6	1.6	3.4	2.4

1/ Partical-record station

2/ Adjusted to natural flow

Table 6.--Low-flow frequency as taken from stream-gaging station low-flow frequency curves (adjusted to the period 1924-63)

Reference no.	Station	Drainage area (sq mi)	Consecutive days	Recurrence Interval in Years											
				2		5		10		20		30		40	
				cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm
3	Mississinewa River near Ridgeville	130	3	1.1	0.003	0.3	0.002	0.2	0.002	0.2	0.002				
			7	1.4	.011	.4	.003	.3	.002	.2	.002				
			14	1.6	.012	.5	.004	.3	.002	.2	.002				
			30	2.3	.018	.8	.006	.5	.004	.4	.003				
			60	4.1	.032	1.3	.010	.7	.005	.5	.004				
			120	9.0	.069	2.8	.022	1.6	.012	1.0	.008				
			183	18	.138	5.9	.045	3.3	.025	2.0	.015				
			274	50	.385	18	.138	10	.077	6.3	.048				
16	Mississinewa River near Eaton	304	3	4.6	.015	2.1	.007	1.5	.005	1.3	.004				
			7	5.5	.018	2.5	.008	1.8	.006	1.5	.005				
			14	6.4	.021	2.8	.009	2.0	.007	1.7	.006				
			30	7.9	.026	3.4	.011	2.5	.008	2.0	.007				
			60	11	.036	4.5	.015	3.0	.010	2.3	.008				
			120	23	.076	8.7	.029	5.7	.019	4.1	.013				
			183	47	.155	16	.053	9.7	.032	6.6	.022				
			274	120	.395	47	.155	28	.092	18	.059				
31	Mississinewa River at Marion	677	3	36	.053	25	.037	21	.031	19	.028	18	0.026	17	0.025
	(adjusted for low-flow regulation)		7	38	.056	27	.040	22	.032	20	.030	19	.028	18	.026
			14	41	.060	29	.043	24	.035	21	.031	20	.030	19	.028
			30	47	.069	33	.049	28	.041	24	.035	22	.032	21	.031
			60	61	.090	39	.058	32	.047	26	.038	24	.035	23	.034
			120	96	.142	54	.080	42	.062	35	.052	32	.047	31	.046
			183	135	.199	70	.103	54	.080	44	.065	39	.058	37	.055
			274	300	.443	140	.207	96	.142	74	.109	64	.095	59	.087
47	White River at Muncie	242	3	17	.070	11	.045	8.3	.034	6.7	.028	5.9	.024	5.4	.022
	(adjusted to natural flow by add-		7	18	.074	11	.045	8.8	.036	7.0	.029	6.2	.026	5.7	.024
	ing diversions for water supply)		14	20	.083	12	.050	9.3	.038	7.4	.031	6.5	.027	6.0	.025
			30	22	.091	14	.058	11	.045	8.6	.036	7.6	.031	7.0	.029
			60	27	.112	17	.070	13	.054	10	.041	9.3	.038	8.6	.036
			120	40	.165	24	.099	19	.078	15	.062	14	.058	13	.054
			183	59	.244	33	.136	25	.103	20	.083	18	.074	17	.070
			274	110	.454	57	.236	42	.174	34	.140	31	.128	29	.120

Table 6.--Low-flow frequency as taken from stream-gaging station low-flow frequency curves (adjusted to the period 1924-63)

Reference no.	Station	Drainage area (sq mi)	Consecutive Days	Recurrence Interval in Years											
				2		5		10		20		30		40	
				cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm	cfs	cfsm
50	Buck Creek near Muncie	36.7	3	10	0.272	8.1	0.221	7.0	0.191	6.4	0.174				
			7	11	.300	8.4	.229	7.4	.202	6.7	.183				
			14	11	.300	8.8	.240	7.8	.212	7.0	.191				
			30	12	.327	9.6	.262	8.4	.229	7.6	.207				
			60	13	.354	10	.272	9.0	.245	8.2	.223				
			120	16	.436	12	.327	10	.272	9.5	.259				
			183	18	.490	14	.382	12	.327	11	.300				
			274	24	.654	16	.436	13	.354	12	.327				
60	White River at Anderson (adjusted to natural flow by correlation with White River near Noblesville)	401	3	54	.135	38	.095	32	.080	28	.070				
			7	58	.145	41	.102	34	.085	29	.072				
			14	61	.152	43	.107	36	.090	30	.075				
			30	67	.167	48	.120	39	.097	33	.082				
			60	77	.192	54	.135	44	.110	38	.095				
			120	100	.249	68	.170	56	.140	48	.120				
			183	130	.324	80	.200	64	.160	54	.135				
			274	220	.549	125	.312	91	.227	72	.180				
78	White River near Noblesville	814	3	99	.122	68	.084	56	.069	48	.059	44	0.054	42	0.052
			7	105	.129	73	.090	60	.074	51	.063	47	.058	44	.054
			14	110	.135	76	.093	62	.076	53	.065	49	.061	46	.056
			30	125	.154	85	.104	70	.086	59	.072	53	.065	50	.061
			60	140	.172	97	.119	79	.097	66	.081	60	.074	57	.070
			120	180	.221	115	.141	95	.117	82	.101	75	.092	71	.087
			183	240	.295	145	.178	115	.141	99	.122	91	.112	86	.106
			274	410	.504	230	.282	165	.203	130	.160	120	.147	110	.135

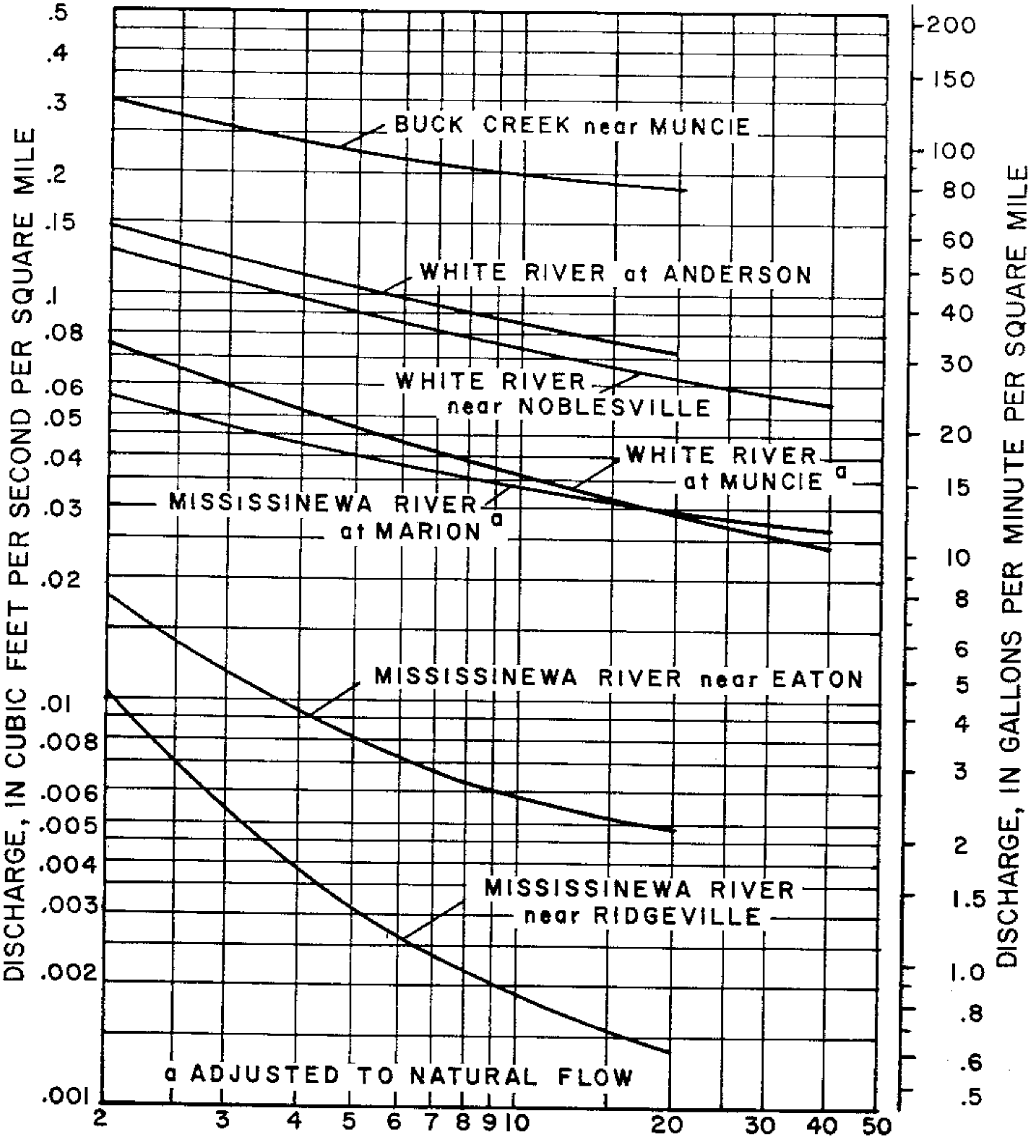


Figure 3—Magnitude and frequency of 7-day low flow at seven gaging stations on the Mississinewa River, White River, and Buck Creek (adjusted to period, 1924-62)

Base-flow measurements. The third technique used to analyze the quantity of water available in the streams and also to define areas of good or poor ground water possibilities is the base-flow measurement run. In this technique numerous discharge measurements are made over a short period of time throughout an area so that comparisons of flow in streams may be made at approximately equal flow durations. This method is useful in assessing the relative yields of different drainage basins. A word of caution is needed. Because there is only one measurement of flow made at one particular time, there is the possibility that the discharge may be affected by some temporary or permanent work of man. This may be in the form of diversions, depletions, or regulations of the streamflow, or addition to the flow by sewage effluents. Such alterations are not always readily apparent in a reconnaissance type survey which involves collection of base-flow measurements. Also, streams in a certain area may be severely affected by a series of extreme hydrologic events.

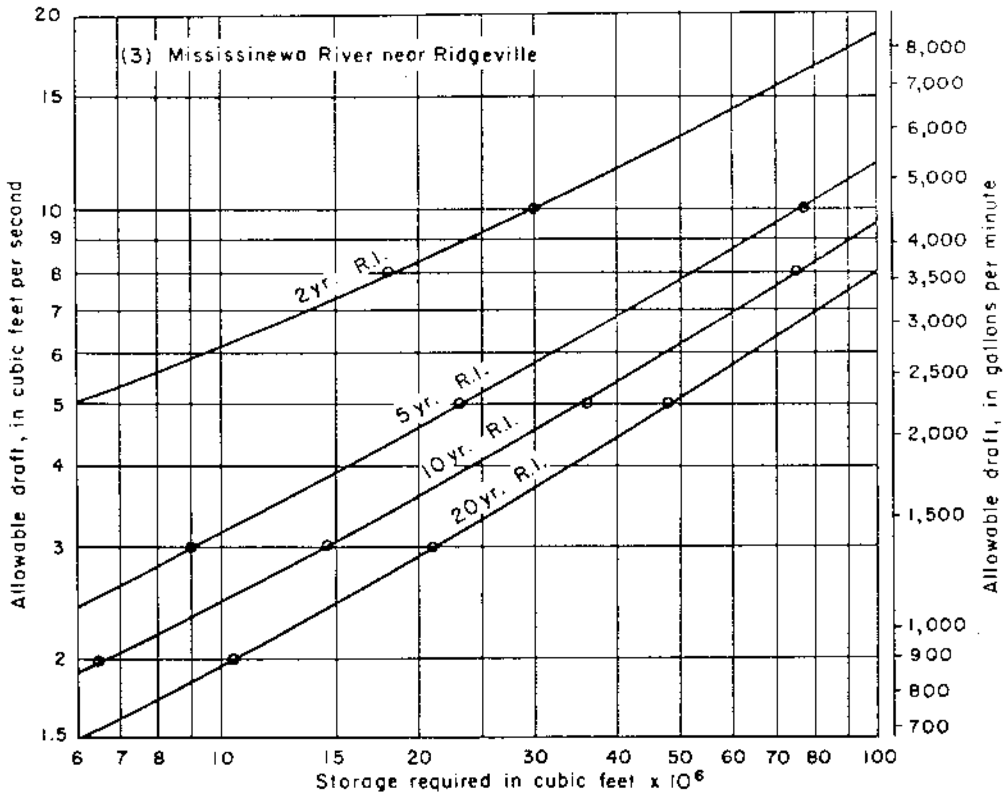
A group of 73 base-flow measurements were made the week of November 11, 1963, when the base flow throughout the study area was very close to the 90 percent flow duration. Although most measurements were made within Delaware County, they were not limited to this political unit. Measurements were made in the entire drainage system embracing the county. The measured discharges have been shown on plate 1, as well as the flow in cfsm of areas between the measured sites.

Draft-storage requirements. The natural flow of a stream during low flow is often not sufficient to meet all the demands of water supply. It then becomes necessary to search out other ways of overcoming the deficiency. One solution to the problem is storing water during periods of excess flow and releasing it during times of deficient flow. In order to determine the amount of storage necessary to maintain certain draft rates, storage-required graphs for various frequency recurrence intervals have been computed from the low-flow frequency data and shown as figures 4 and 5 for the following gaging stations: Mississinewa River near Ridgeville, Mississinewa River near Eaton, White River at Muncie, White River at Anderson and Buck Creek near Muncie.

In using the storage-required frequency curves for estimates of storage, it must be kept in mind that such graphs have not been corrected for reservoir seepage and evaporation.

Summary of Low-flow Stream Characteristics

Results obtained by use of flow duration and low-flow frequency analyses and base-flow discharge measurements show that the low-flow yield per square mile of the Mississinewa and White Rivers generally increases progressively downstream as they pass through Delaware County. Also, low flow is better sustained in the White River than in the Mississinewa River. The low flows of tributary streams are variable at about 90 percent flow duration and range from no flow for most streams in the northern half of the county having less than 10 square miles of drainage area, including the headwaters of larger streams, to the



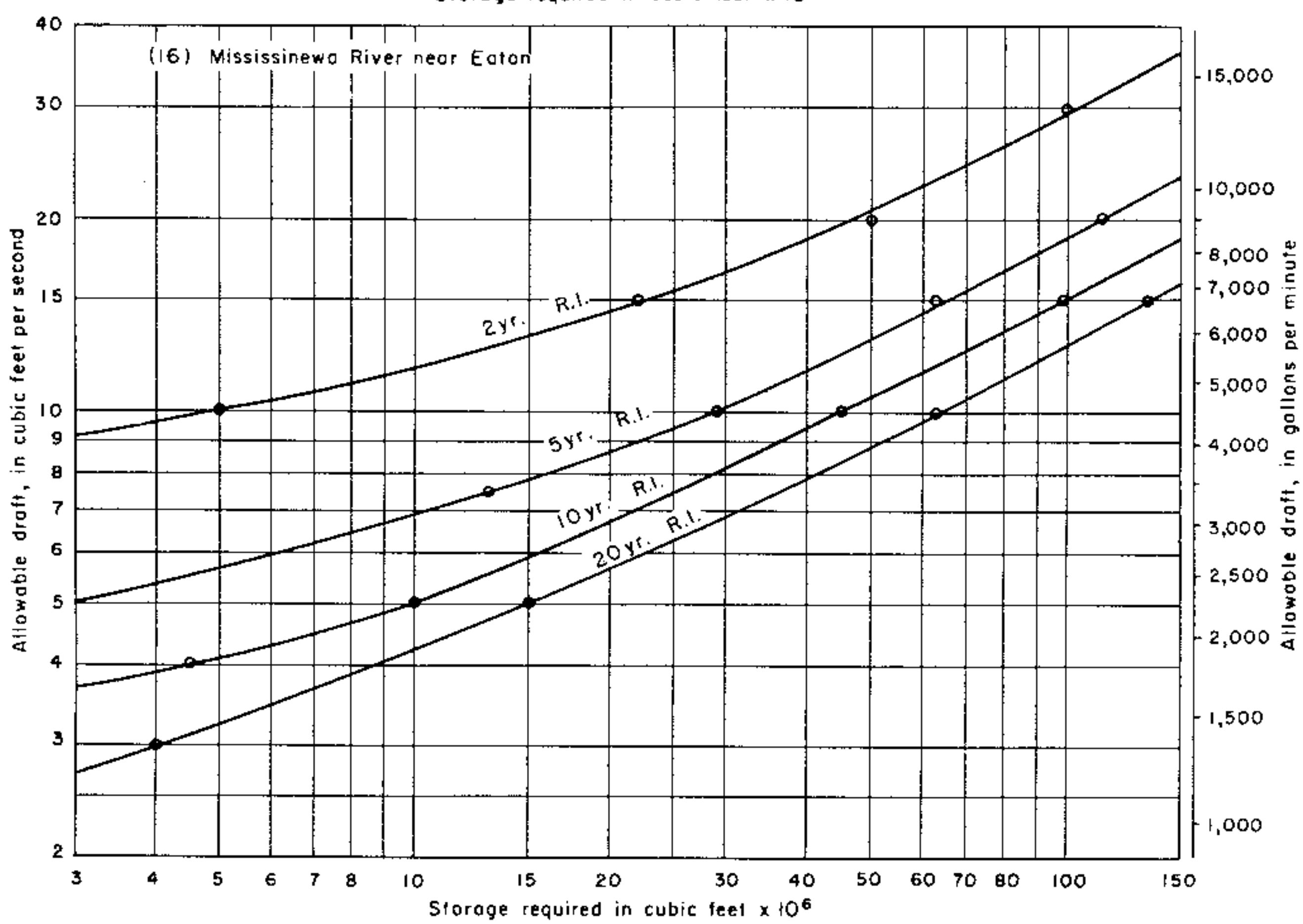


Figure 4.-- Storage-required graphs for 2, 5, 10 and 20-year recurrence intervals for the Mississinewa River near Ridgeville and Mississinewa River near Eaton. (Storage is uncorrected for reservoir seepage and evaporation)

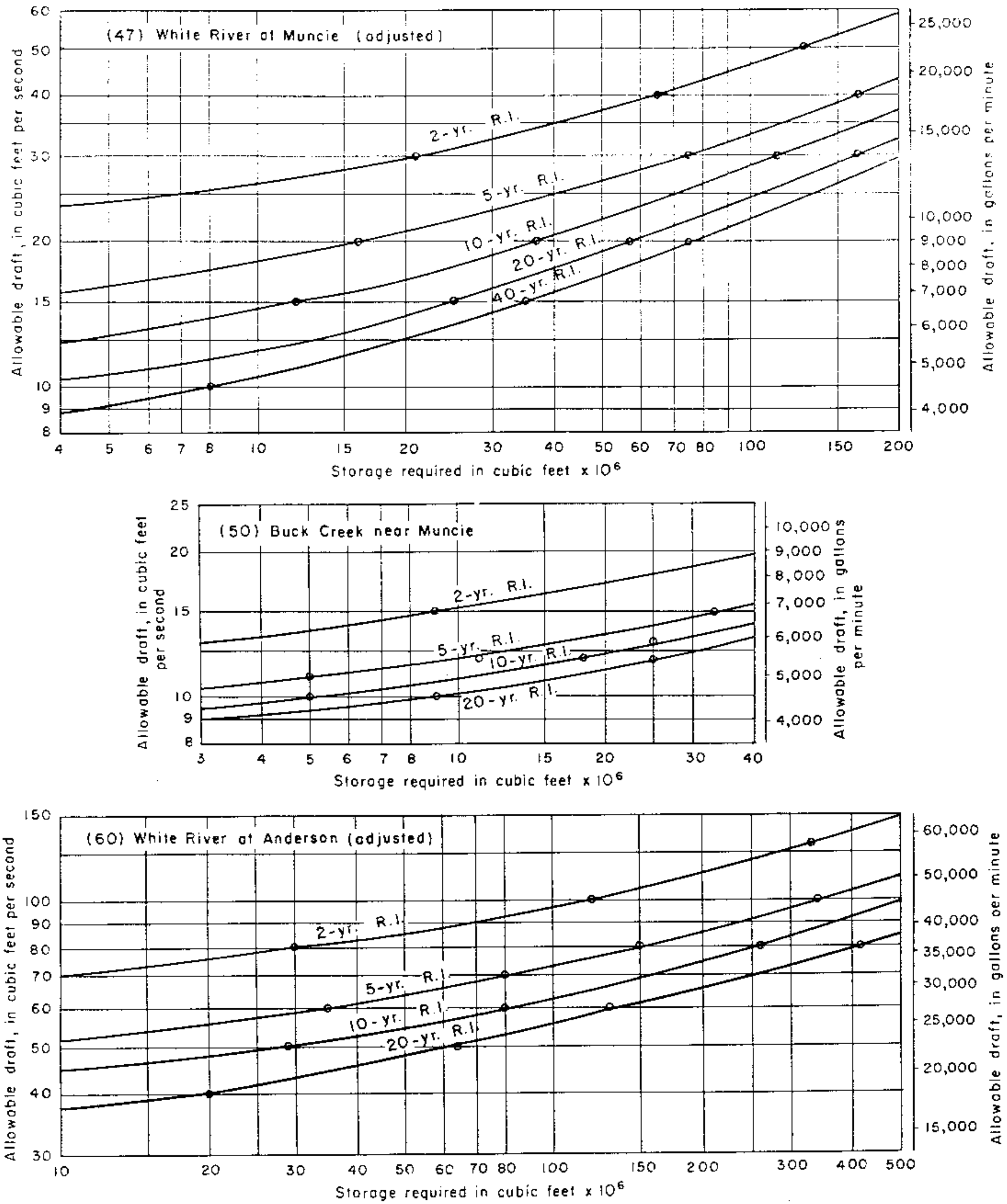


Figure 5 .-- Storage-required graphs for 2, 5, 10, 20 and 40-year reccurence intervals for the White River at Muncie and 2, 5, 10 and 20-year recurrence intervals for Buck Creek near Muncie and White River at Anderson. (Storage is uncorrected for reservoir seepage and evaporation.

excellent sustained flow of 0.26 cfsm (0.17 mgd per square mile) for the upper part of Buck Creek (Plate 1).

The flow-duration and low-flow frequency data for the 7 stream-gaging stations show Buck Creek near Muncie to have the highest sustained low-flow yield per square mile and the Mississinewa River near Ridgeville to have the lowest. The relatively flat slopes of the duration and frequency curves, with the exception of that for the Ridgeville station, indicate that a considerable quantity of ground-water discharge is available to sustain low flow.

At the 90 percent flow duration, the flow in the Mississinewa River at Marion is 2.5 times as great per square mile as that upstream near Eaton, and 3.9 times as great as that further upstream near Ridgeville. The spread is even larger at the 95 and 98 percent duration values. Data in table 4 indicate that the flow from the intervening area between the gages at Marion and near Eaton at 90 percent flow duration is 3.0 times as great as the intervening area between the gages near Eaton and near Ridgeville and 5.8 times as great as the area upstream from the near Ridgeville gage.

Carrying the comparison to the White River at 90 percent flow duration, the natural (adjusted) flow per square mile of the White River at Muncie is 3.2 times as great as the Mississinewa River near Eaton, but 0.8 as large as the flow from the intervening area between the Eaton and Marion gages. The 90 percent flow duration from the intervening area between the White River at Anderson and the White River at Muncie, excluding the area above the Buck Creek near Muncie gage, is 3.0 times the flow contributed from the area above the Muncie gage, but 0.9 times the flow from the area above the Buck Creek near Muncie gage. Although the drainage area for the stream-gaging station on Buck Creek near Muncie equals only 15 percent of the drainage area above the stream-gaging station on White River at Muncie, the discharge is 50 percent as large at 90 percent flow duration.

The low-flow characteristics at the 7 stream-gaging stations may be examined further by analyzing the minimim observed flows that have occurred during their period of record. Table 7 shows the instantaneous minimum flow, and the lowest two minimum average flows for 1-day, 3-day, 7-day, 14-day, 30-day and 60-day consecutive periods with the beginning month of the period. The values in this table when compared with the low-flow frequency data in table 6 make it possible to estimate the severity of the observed low flows during the period of records, excepting for the stream-gaging stations that have pronounced regulation or diversion. Example: The lowest 3-day average flow on the Mississinewa River near Eaton during the period from 1952-63 is 2.1 cfs (table 7). This flow will occur on the average 1 time in every 5 years (table 6).

In reviewing the low-flow characteristics it is interesting to compare the runoff map (Plate 1) with the shape of the piezometric water surfaces in the glacial drift (fig. 8) and bedrock (fig. 13). Where contours on the piezometric surface are parallel to the streams, flow is sustained by ground-water discharge. It is possible that some of the flow does not appear in the streams but rather occurs as underflow beneath the stream channels. This may be the case in the reach of the White River from Yorktown to Daleville.

Application of Techniques to Water Planning

Application of the four foregoing techniques to water planning is demonstrated by the following hypothetical example. A new industrial plant desires to locate on the Mississinewa River at Eaton, where the drainage area is about 310 square miles. It is determined that the water supply obtainable from the town of Eaton's wells is more than adequate to meet anticipated future needs. However, in the absence of a sewage disposal plant at Eaton, it will be necessary to have a minimum flow of 6 cfs, or 3.9 mgd, for dilution of plant waste products as predetermined by the Indiana Stream Pollution Control Board.

Observed minimum flows (at the gage upstream near Eaton) (table 7) are less than the required flows; therefore, it is necessary to know the probable percent of time there will be a shortage of water. From figure 2, it is determined that the flow of 6 cfs, or 0.02 cfsm, will be available about 93 percent of the time, or about 7 percent of the time the flow would be less than that required for dilution.

A management decision could be made at this point as to whether or not plant operation can be economically reduced or shut down 7 percent of the time.

If management decides that plant operation cannot be shut down 7 percent of the time, then arrangements for storage or a supplemental supply must be considered and planned.

To assist further in the water planning, the low-flow frequency data for the gaging station near Eaton indicates the frequency at which the discharge falls below 6 cfs. Table 6 shows that on the average, about once every 2 years for a 14-day consecutive period, or once every 10 years for a 120-day consecutive period, or once every 20 years for a 183-day consecutive period, the average natural flow in the Mississinewa River would be less than that needed for plant operations. To continue the plant in operation during these periods of insufficient streamflow, it would be necessary to supplement the natural streamflow with dilution water from a standby facility such as private wells, the Eaton water supply system, or upstream surface storage on the Mississinewa River or on one of its tributaries.

The base flow measurements would be used to determine which of the Mississinewa River tributaries might offer the best potential for off channel storage should it be decided to go to a small storage dam to supplement the natural flow of the Mississinewa River. An examination of plate 1 indicates that both Bosman and Rees ditches offer good possibilities for low-flow yield in their lower reaches.

Table 7.--Average discharge, instantaneous minimum, and lowest two minimum average flows for 1-, 3-, 7-, 14-, 30-, and 60-day consecutive periods for stream-gaging stations on the Mississinewa River, White River, and Buck Creek

Reference no.	Station	Drainage area (sq mi)	Period of record	Average discharge (cfs)	Instantaneous minimum (cfs)	1-day (cfs)	3-day (cfs)	7-day (cfs)	14-day (cfs)	30-day (cfs)	60-day (cfs)
3	Mississinewa River near Ridgeville	130	Aug. 1946 to Sept. 1963	132	0.1 (10/24/46)	0.1 (10/46)	0.2 (10/46)	0.2 (10/46)	0.3 (10/46)	0.6 (9/54)	0.9 (9/46)
						.3 (9/54)	.3 (9/54)	.3 (9/54)	.5 (9/54)	1.0 (9/46)	1.7 (9/53)
16	Mississinewa River near Eaton	304	Mar. 1952 to Sept. 1963	282	2.0 (9/23,27/54)	2.0 (9/54)	2.1 (9/54)	2.2 (9/54)	2.3 (9/54)	2.3 (9/54)	4.3 (8/53)
						2.2 (10/53)	2.2 (10/53)	2.5 (9/53)	2.5 (9/53)	2.9 (9/53)	6.8 (8/54)
31	Mississinewa River at Marion	677	Sept. 1923 to Sept. 1963	641	[a] 1.1 (4/17/59)	[a] 3.8 (10/40)	[a] 5.1 (10/43)	[a] 8.4 (10/40)	[a] 12.0 (11/28)	[a] 16.4 (10/28)	[a] 20.2 (9/28)
						[a] 3.8 (10/43)	[a] 5.4 (10/40)	[a] 12.0 (11/28)	[a] 18.9 (10/40)	21.7 (8/40)	22.8 (8/40)
47	White River at Muncie	242	Nov. 1930 to Sept. 1963	[b] 217	[c] .6 (9/16/37)	[c] 1.1 (9/54)	[c] 1.1 (9/54)	[c] 1.2 (9/54)	[c] 1.2 (9/54)	[c] 1.5 (9/54)	[c] 2.9 (9/56)
						[c] 1.1 (10/56)	[c] 1.3 [d]	[c] 1.4 (8.34)	[c] 1.4 (7.34)	[c] 2.2 (9/56)	[c] 3.8 (8/40)
50	Buck Creek near Muncie	36.7	Oct. 1954 to Sept. 1963	35.9	----------------	5.8 (9/56)	6.1 (9/56)	[e] 7.3 (12/62)	8.0 (9/60)	9.1 (9/56)	9.8 (9/56)
						[e] 6.0 (12/62)	[e] 6.3 (12/62)	7.7 (9/60)	8.6 (9/56)	9.4 (8/60)	10.3 (8/60)
60	White River at Anderson	401	July 1925 to Sept. 1926, Oct. 1931 to Sept. 1963	375	[c] 8.8 (9/24/40)	[c] 9.1 (9/40)	[c] 12.3 (9/41)	[c] 13.0 (9/41)	[c] 13.9 (9/41)	[c] 20.5 (9/40)	[c] 22.1 (8/41)
						[c] 12.0 (9/41)	[c] 13.0 (8/40)	[c] 15.7 (9/40)	[c] 18.9 (9/40)	[c] 20.8 (9/41)	[c] 22.2 (8/40)
78	White River near Noblesville	814	May 1915 to Sept. 1926, Oct. 1928 to Sept. 1963	803	36 (9/25/41)	39 (9/41)	41.3 (9/41)	42.0 (9/41)	43.9 (9/41)	55.1 (9/41)	59.8 (8/41)
						46 (9/40)	51.0 (9/40)	53.1 (9/40)	53.1 (9/40)	57.2 (9/40)	62.6 (8/40)

a Regulated

b Adjusted for diversion after September 1937

c Diversion for water supply above gage, returned to stream through sewage treatment plant below gage

d 8/34 and 10/56

e Ice effect

To determine the approximate amount of storage necessary to maintain a 6 cfs draft rate from a channel-storage reservoir on the Mississinewa River itself, storage-required frequency curves for the near Eaton gage as presented in figure 4 may be used. A reservoir of 16 million cubic feet, or 120 million gallons, capacity would be needed to maintain a 6 cfs flow for a 10-year frequency recurrence interval. To maintain this draft rate to overcome a 20-year frequency drought, 23 million cubic feet, or 172 million gallons, of storage would be necessary. Additional storage would be necessary to overcome water loss by seepage and evaporation.

Development Potential

The available water supply potentials of the several streams in Delaware County are an index of their development potential. Many of the streams flow with fairly well sustained low flows during dry weather. An excellent example of development is Prairie Creek, a tributary to White River, which was put to use in 1961 for water supply by the Muncie Water Works Company by construction of a 7.2 billion gallon reservoir.

The variation in low flow is illustrated by plate 1. The color lines along the streams indicate the range of flow into which the measured discharges fell during the week of November 11, 1963, at about 90 percent flow duration. The color lines between the measured locations are estimates based on flows at measured points.

From a practical standpoint, the low flow available 90 percent of the time may be considered the maximum dependable supply that can be obtained without storage in reservoirs. The other 10 percent of the time the flow is less than this amount.

The average discharges for the period of record at each of the 7 stream-gaging stations are included in table 7. The average discharge divided by the drainage area equals about 1 cfsm at each gage. The average discharge represents the absolute limit of the potential surface-water supply available, if it were possible to store in reservoirs and release at uniform rate the total water that flows from the area above the gage. To carry this reasoning one step further to ungaged sites, an estimate of the absolute limit of the potential surface-water supply available on any stream in Delaware County, regardless of size, would be the product of the drainage area, in square miles, times 1 cfsm.

Mississinewa River and tributaries. The flow in the Mississinewa River increases from a yield of 0.008 cfsm at the Ohio-Indiana state line, to 0.03 cfsm, at about 90 percent flow duration before it leaves Delaware County (pl. 1). On the basis of the streamflow data, the Mississinewa River offers a better development potential downstream from about the mouth of Campbells Creek than it does above this point. This increase in base flow is due to better yields of ground-water discharge from (1) the till and (2) probably the valley train and outwash plain sediments beginning on the main channel a little upstream from Eaton and continuing downstream. Another feature of the surficial geology in the area of increased base flow yields is the presence of large sand and gravel deposits in the forms of kames and eskers in the till.

A large user of water considering the Mississinewa River as a supply will have to depend on an impoundment if his activity requires 9 mgd or more, more than 90 percent of the time.

The tributaries in Delaware County offer various development potentials at about 90 percent flow duration. Mud Creek, Halfway Creek, the upper reaches of Bosman ditch, Rees ditch, Pike Creek, as well as a few smaller unnamed tributaries, were either dry or contained very little flow during the week of November 11, 1963. Some of these streams had excellent amounts of flow for their size in their lower reaches.

Most of the tributaries having less than 10 square miles of drainage area, including the headwaters of larger streams, go dry frequently. Impoundments would be necessary if these sources were developed. If a supply of 0.6 mgd, or more, was required more than 90 percent of the time from any of the aforementioned tributaries, an impoundment would be necessary.

White River and tributaries. The flow in the White River increases from a yield of 0.03 cfsm in its headwaters in Randolph County to 0.10 cfsm in Delaware County at about 90 percent flow duration (pl. 1). This increase in base flow is due to better yields of ground-water discharge from (1) the till and (2) probably the valley train and outwash plain sediments, beginning on the main channel of White River at about Mud Creek and continuing downstream.

Below Muncie, the White River meanders through the outwash sediments, and although the flow in the reach from below Muncie to the county line nearly doubles at 90 percent flow duration, the increase is due largely to the entrance of Buck Creek and York Prairie Creek. The White River from below Mud Creek to the mouth of Buck Creek would offer the best potential development under natural flow conditions. However, the flow in this reach is altered by the water supply for the city of Muncie. Water is taken out above Muncie and sewage effluent is returned below Muncie.

A large user of water considering the White River as a supply will have to depend on an impoundment if his activity requires 25 mgd or more, more than 90 percent of the time.

The tributaries in Delaware County offer various development potentials at about 90 percent flow duration. The upper portions of Muncie Creek, and some of the small tributaries of Killbuck and Pipe Creek were either dry or contained practically no flow during the week of November 11, 1963. Flows in Stoney Creek, Mud Creek, Medford drain, the middle portion of Muncie Creek, Bell Creek, the upper portions of Killbuck Creek and Pipe Creek are fairly well sustained. The tributaries of the White River offering the best potential development are Cunningham ditch (tributary to Prairie Creek Reservoir and thus already used in water supply development), Buck Creek (used for water supply by the Muncie Water Works Company without impoundment), York Prairie Creek and Brandon ditch (tributary to Fall Creek).

Most of the tributaries in the northern half of the county having less than 10 square miles of drainage area, including the headwaters of larger streams, go dry frequently. Impoundments would be necessary if these sources were developed. Most of the tributaries in the southern half of the county, regardless of size, can be depended on to yield more than 9 gpm (0.013 mgd) per square mile 90 percent of the time. Buck Creek, in the upper part of its basin, can be depended on to yield more than 120 gpm (0.170 mgd) per square mile 90 percent of the time.

Glacial Deposits

Delaware County is underlain by glacial drift that ranges in thickness from 0 to about 300 feet. The principal sources of ground water in the drift are two sand and gravel aquifers (fig. 6). Nearly all the ground water in these deposits must percolate through the confining layer that covers almost the entire land surface of the county (fig. 6). Some water can be recovered by dug wells in the surficial confining layer, but usually these wells are not adequate even for domestic supplies.

Sand and Gravel Aquifers

One of the two important water-bearing zones underlies nearly the entire county and is referred to as the "principal Pleistocene aquifer" (fig. 6). The other zone lies beneath the principal Pleistocene aquifer, usually within or near buried bedrock valleys and is referred to as the "deeper sand and gravel aquifers".

The principal Pleistocene aquifer consists chiefly of sand and gravel as much as 80 feet thick, with some areas of sand alone. It extends beyond the boundaries of Delaware County, and is an important aquifer in surrounding areas. The aquifer is artesian except for a few scattered areas of water-table conditions in the central part of the county. Its stratigraphic position is shown on figure 6.

The deeper sand and gravel aquifers occur principally in the southern third of the county in the thicker parts of the glacial drift. The thickness and configuration of these aquifers are not well known.

Recharge and Discharge

Most of the inflow to the shallow glacial deposits of Delaware County is derived from precipitation within the county. Some water enters the county by underground flow, most of which occurs along the eastern and southern boundaries. Average inflow and outflow in the shallow glacial deposits are symbolized by figure 7. Recharge and discharge of the deeper sand and gravel aquifers are illustrated along with the Silurian Dolomite (p. 34).

EXPLANATION

System	Series	Symbol on cross section	Lithology	Thickness (feet)	Areal extent	Importance for water supply
QUATERNARY	Pleistocene and Recent, undifferentiated	Confining layer	Clay and silt; sandy, gravelly, calcareous, brown to yellowish-brown, occasionally blue. Mostly till	0-110	Underlies entire county except for a few very small isolated areas	A few dug wells for livestock. Limits recharge to aquifers and ground-water discharge to streams
		Aquifer	Sand and gravel; silty, often clayey, tan to brown	0-40	Underlies most of the county. Cannot be distinguished from principal Pleistocene aquifer where the till below is missing	Some domestic and stock wells
		Confining layer	Clay; silty, sandy, gravelly, usually brown or blue. Till	0-100	Same as above unit	Confining layer for part of principal Pleistocene aquifer
		Aquifer	Sand and gravel; silty, often clayey	0-100	Underlies the entire county (fig. 9)	Principal Pleistocene aquifer. Domestic and industrial use
		Confining layer	Clay; silty, sandy, gravelly, usually blue or brown, sometimes red in lower part; with occasional sand and gravel lenses. Till	0-240	Underlies most of the county. Missing on bedrock highs	Confining layer for most of the Silurian Dolomite
		Aquifer	Sand and gravel; often interbedded with clay	0-70+	Occurs in and near most buried valleys (fig. 11)	Domestic and industrial use
SILURIAN		Aquifer	Mostly dolomite. Drillers occasionally report shale and, rarely, sandstone	200-500	Underlies the entire county	Domestic, industrial, and municipal use

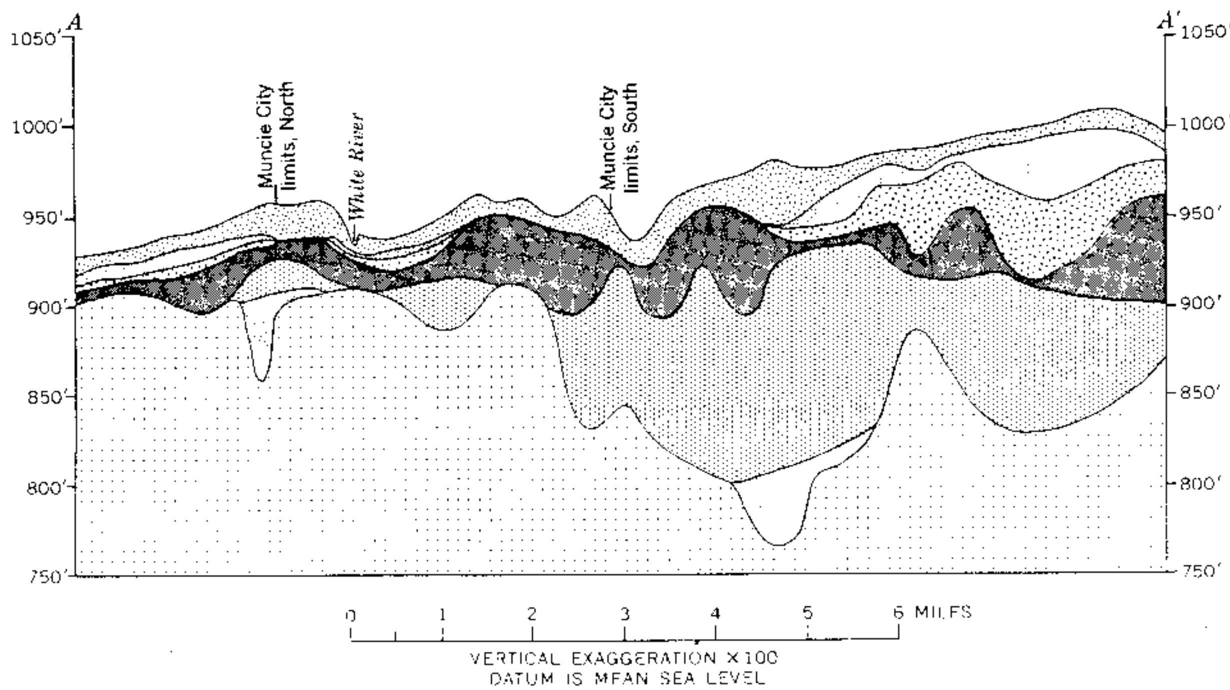
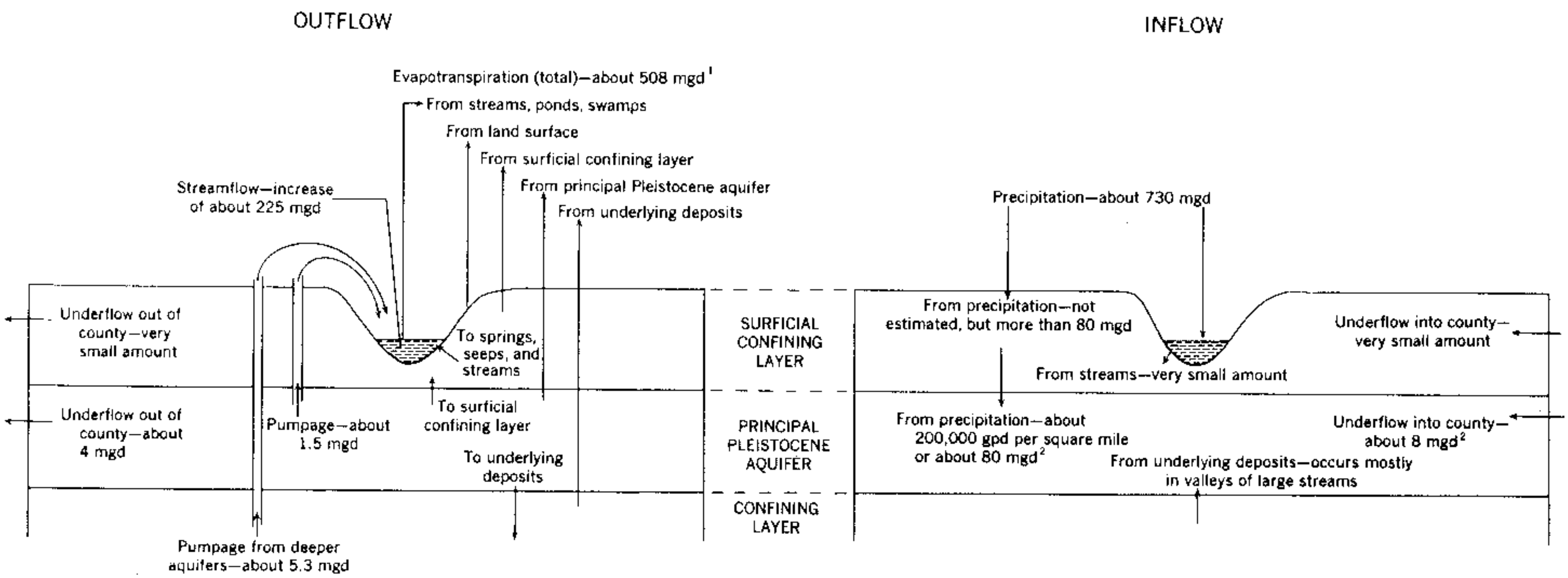


Figure 6.—Generalized cross section showing aquifers and confining layers of Delaware County. Line of cross section is shown on figure 9.



	Average amount (mgd)
Increase of streamflow	about 225
Evapotranspiration	about 509[1]
Underflow	about 4
Total	about 738

[1] By subtraction. Includes consumptive use by man

	Average amount (mgd)
Precipitation	about 730
Underflow	about 8[2]
Total	about 738

[2] See text

Figure 7.—Average recharge and discharge of the shallow glacial deposits.

Inflow from deeper sand and gravel aquifers and from the Silurian Dolomite occurs principally as upward flow toward the larger streams. This inflow occurs in areas where contours on the piezometric surface of the Silurian Dolomite (fig. 13, p. 37) are approximately parallel to the streams.

The estimates of recharge from precipitation to the principal Pleistocene aquifer shown on figure 7 were obtained from parts of the piezometric surface and the hydraulic characteristics of the aquifer, using Darcy's Law. These estimates are only approximations because of limited knowledge of the hydraulic properties of the aquifer and should not be used to extrapolate into other apparently similar areas. They are adequate, however, to show the relative importance of direct recharge and underflow in the hydrologic cycle in Delaware County. The estimates of underflow may be misleading unless compared with the configuration of the piezometric surface. Ground-water flow along the county boundaries is nearly parallel to the boundaries in many places. Only a small amount of ground water flows across the boundaries. The eastern and southern boundaries together are about 40 miles long. The quantity of water flowing through an aquifer of similar hydraulic properties directly across a line 40 miles long would be about 14 mgd, assuming a hydraulic gradient of about 10 feet per mile. Even this hypothetical figure is small compared with the amount of recharge from precipitation within the county.

Ground water is discharged to the streams in the county through the surficial confining layer. This discharge constitutes most of the base flow of the streams. Figure 8 shows the stream runoff per square mile at near 90 percent flow duration for small drainage basins within the county, and contours on the piezometric surface of the principal Pleistocene aquifer, drawn from water-well data. Ground water flows approximately at right angles to the contour lines and down the hydraulic gradient. Where the contour lines are approximately parallel to the streams, ground water is being discharged into the streams. The figure shows a general correlation between gain in base flow of the streams and direction of ground-water flow. The principal Pleistocene aquifer supplies most of the base flow; however, some ground water is discharged to streams from the bedrock, from the sand and gravel unit overlying the principal Pleistocene aquifer (fig. 6), and from the surficial confining layer each of which has its own piezometric surface. Although there is usually some difference in head between these surfaces at any particular place their configurations are similar to the configuration of the piezometric surface of the principal Pleistocene aquifer.

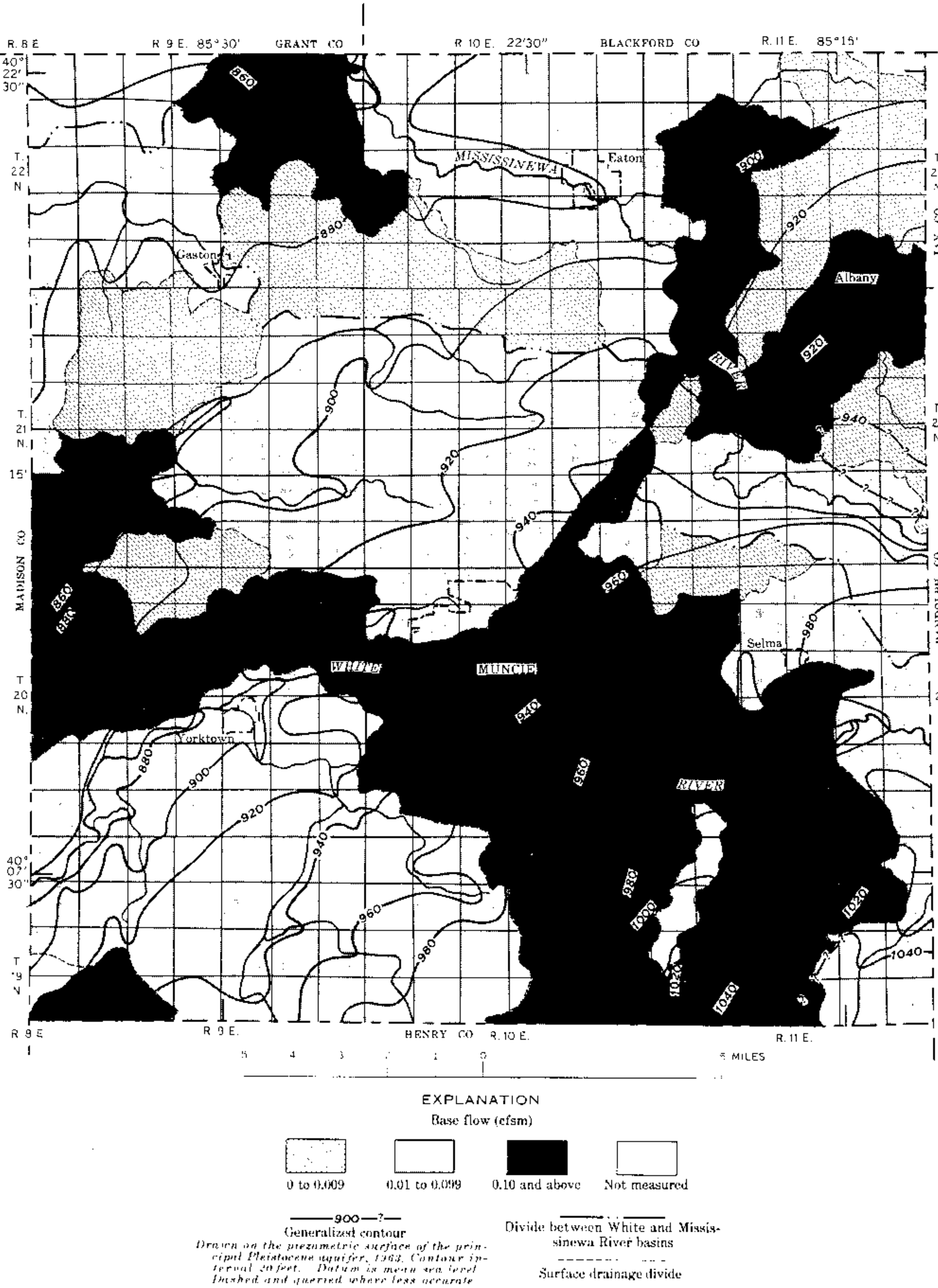


Figure 3.—Ground water supplies most of the base flow of streams of Delaware County. Streamflow was measured at near 90 percent flow duration, when nearly all of the flow of the streams was base flow.

Development and Potential

Principal Pleistocene Aquifer. This aquifer is capable of yielding as much as 500 gpm to individual wells in the south-central and southeastern parts of the county (fig. 9). These areas probably will not be extensively developed in the foreseeable future. Figure 9 shows expected one-day specific capacities and possible yields of 12-inch wells screened the full thickness of the aquifer. Screen diameter, length, and slot size must be chosen carefully in order to obtain the yields indicated on figure 9. Wells require development to remove the clay, silt, and very fine sand from the immediate vicinity of the screen. For domestic and farm supplies, screens are generally not used in Delaware County, and the possible yields shown are not applicable.

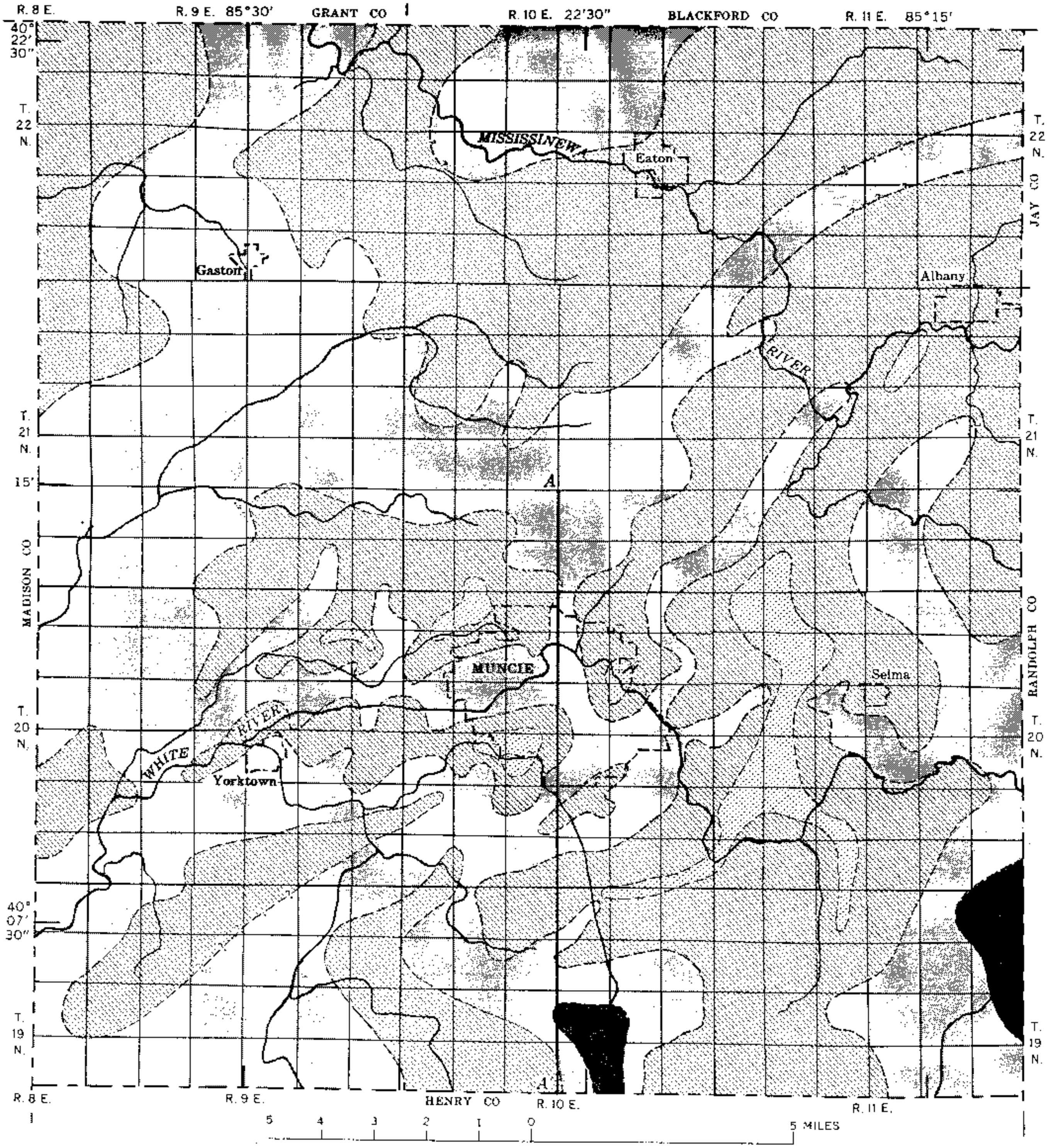
The yield of a well for a specified drawdown will decrease with time of pumping, and will be greater for a larger diameter well. Because of these limitations, and because of the lack of carefully controlled pumping data, the map shows only an approximation of the capability of the aquifer, and will probably need refining in the future.

The depth to the top of this aquifer can be estimated from figure 10. This depth, used along with figure 9, can be used to estimate the well depth necessary to develop a water supply in the aquifer.

The potential of the principal Pleistocene aquifer for future development depends to a large extent upon its rate of recharge, which is determined partly by the difference between the hydraulic head in the aquifer and the head in the surficial confining layer. If the head in the aquifer is lowered by pumping, recharge to the aquifer will increase until the water level is lowered to the top of the aquifer.

Deeper sand and gravel aquifers. Figure 11 shows the known areal extent of these aquifers and gives selected data on depth to the water-bearing zone, thickness penetrated, and pumping data where available. Saturated thickness and areal extent of these aquifers are not well known; however, the potential yield of these aquifers is much less than the potential of the principal Pleistocene aquifer.

Total potential of glacial deposits. For maximum yields, the entire thickness of the glacial deposits should be penetrated, and all major aquifers should be screened. By this method, yields of as much as 600 to 700 gpm might be obtained where the principal Pleistocene aquifers are most productive (fig. 9).



EXPLANATION

Anticipated range of maximum yields and anticipated one-day specific capacities of 12-inch wells that penetrate and screen the full thickness of the aquifer

Maximum yields 300 to 500 gpm (gallons per minute). Specific capacities 25 to 40 gpm/ft. (gallons per minute per foot of drawdown). Aquifer usually consists of 40 to 80 feet of sand and gravel

Maximum yields 150 to 300 gpm. Specific capacities 12 to 25 gpm/ft. Aquifer usually consists of 20 to 70 feet of sand and gravel

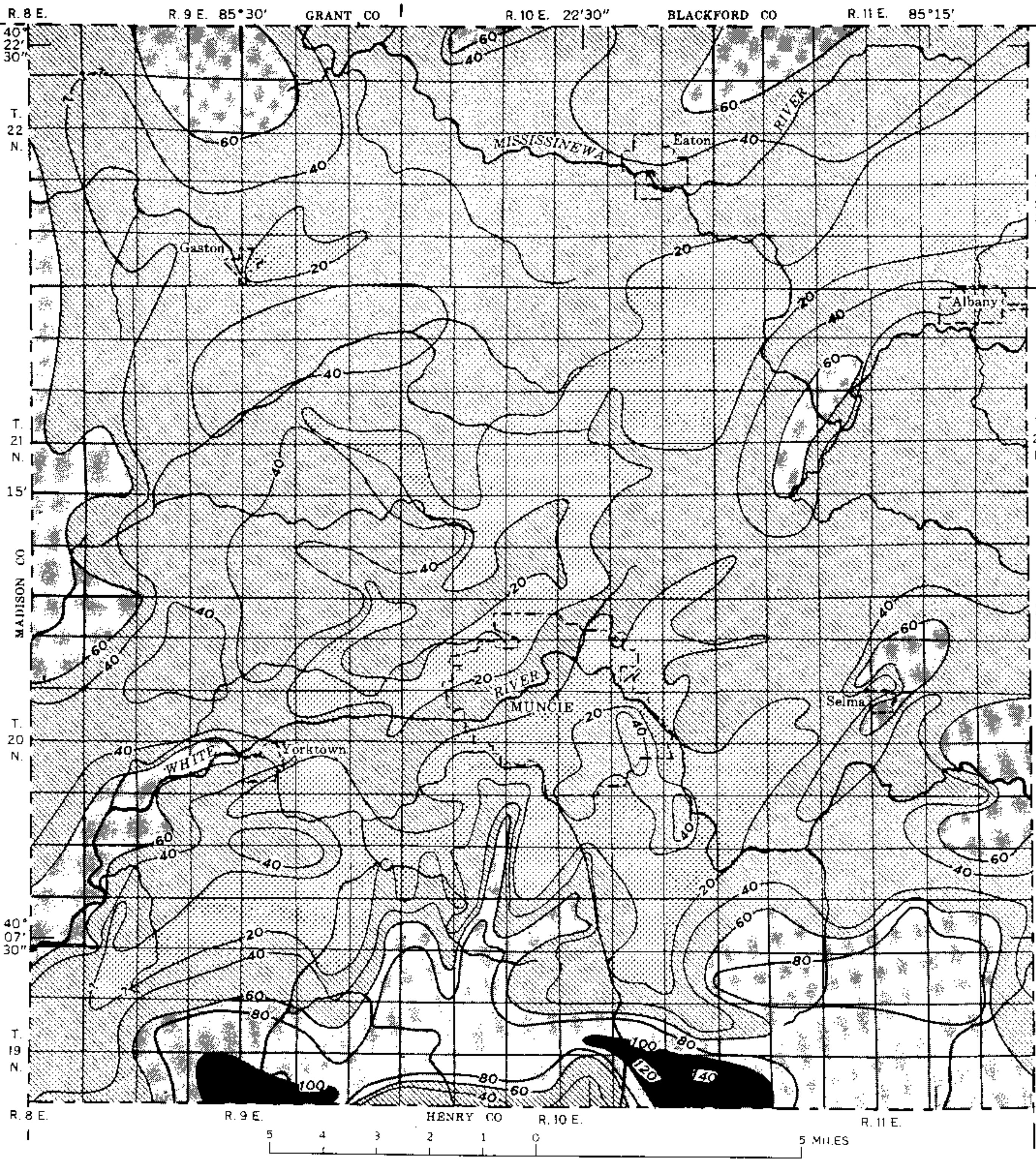
Maximum yields 150 gpm or less. Specific capacities 1.5 to 12 gpm/ft. Aquifer usually consists of sand up to 50 feet thick, or sand and gravel up to 15 feet thick

Aquifer very thin or missing. Deeper aquifers are usually better sources of water

A —— A'
Line of cross section (fig. 6)

— — — ?— ?— —
Approximate boundary
Queried where less accurate

Figure 9.—The principal Pleistocene aquifer is capable of supplying as much as 500 gpm to individual wells.



EXPLANATION

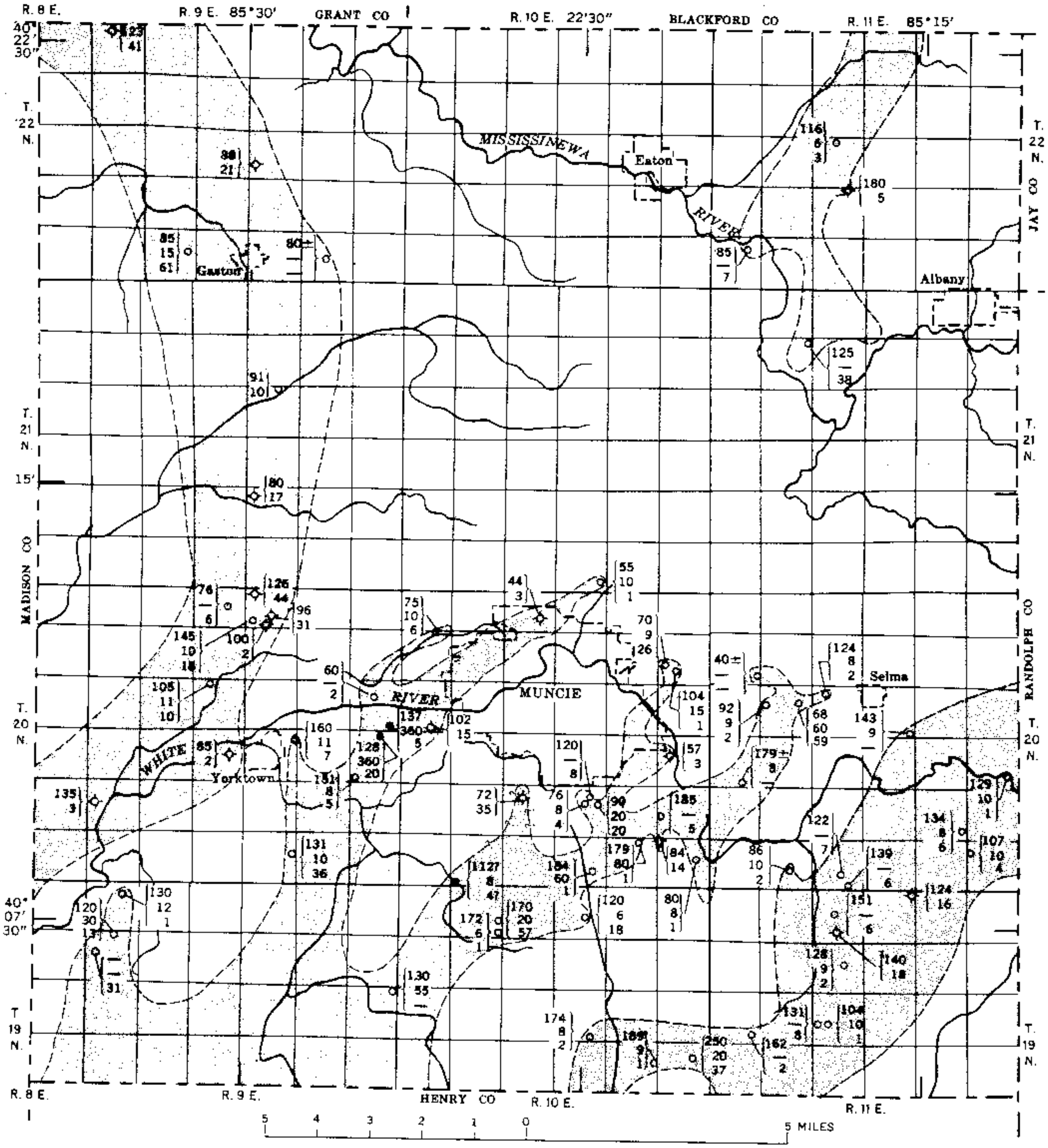
Approximate depth to top of aquifer below land surface (feet)

Less than 20	20 to 60	60 to 100	More than 100

—20—
Contour

Showing approximate depth to top of aquifer. Contour interval 20 feet

Figure 10.—The principal Pleistocene aquifer lies at depths of less than 20 to more than 140 feet below land surface.



EXPLANATION

Areal extent of deeper sand and gravel aquifers

Approximate boundary

170—depth to top of water-bearing zone
10—reported yield, gpm
5—thickness of sand and gravel penetrated

4-inch open-end well producing water from this unit

137—depth to top of water-bearing zone
360—reported yield, gpm
5—thickness of sand and gravel penetrated

12- to 16-inch industrial well

160—depth to top of water-bearing zone
16—total thickness of sand and gravel within the unit

Well, completed in Silurian Dolomite, penetrates the entire unit

Figure 11.—Sand and gravel below the principal Pleistocene aquifer usually occurs in bedrock valleys. Saturated thickness and potential of the unit are not well known.

Bedrock Formations

The principal bedrock aquifer of Delaware County is dolomite of Silurian age. It underlies the entire county at depths of 0 to about 300 feet. Drillers report some shale and occasionally sandstone, but these reports are too widely distributed to permit adequate mapping at the present time. The Trenton limestone of Ordovician age is a potential source of saline water. The Trenton is reached at depths of 900 to 1,000 feet below the land surface in Delaware County. The quantity of water available is uncertain.

Additional sources of saline water probably occur below the Trenton limestone in the Chazyan Series of Ordovician age, the Knox dolomite of Cambrian and Ordovician age and possibly the Mt. Simon sandstone of Cambrian age. Little is known about these sources and the quality or quantity of the water.

Silurian Dolomite

Water-bearing characteristics. The natural porosity and permeability of the dolomite are relatively small and most ground water occurs chiefly in the joints, fractures, and solution openings in the rock. Most of these openings were produced by chemical and physical weathering during pre-Pleistocene time, when the bedrock was exposed at the surface.

The permeability of the dolomite decreases rapidly with depth. Most of the water produced from the dolomite is obtained from the upper 50 feet; however, drillers occasionally report water-bearing zones after penetrating as much as 100 feet. These deeper zones yield generally less than 15 gpm to individual wells.

In other parts of the state, areas of high permeability in the Silurian dolomite have been found to coincide with bedrock uplands and upper parts of buried valley walls (Watkins and Rosenshein, 1963; Watkins and Ward, 1962; Rosenshein and Hunn, 1964). This relationship is probably valid in Delaware County; however, it cannot be fully substantiated with data presently available.

Recharge and discharge. Most of the inflow to the dolomite is precipitation that percolates through the overlying glacial deposits. Some water enters the county by underground flow, mostly along the eastern and southern boundaries. Average inflow and outflow in the dolomite and the deeper sand and gravel aquifers is symbolized by figure 12. The rate of recharge to the deeper sand and gravel aquifers must be about the same as the rate of recharge to the dolomite, because of the similarity of the overburden.

Very little or no inflow to the dolomite from underlying rocks is believed to occur in Delaware County. No saline water contamination has been reported, except as surface contamination in the vicinity of some pumping oil wells. Fresh ground water flows from some abandoned oil or gas wells during periods of high water levels. Locations of some of

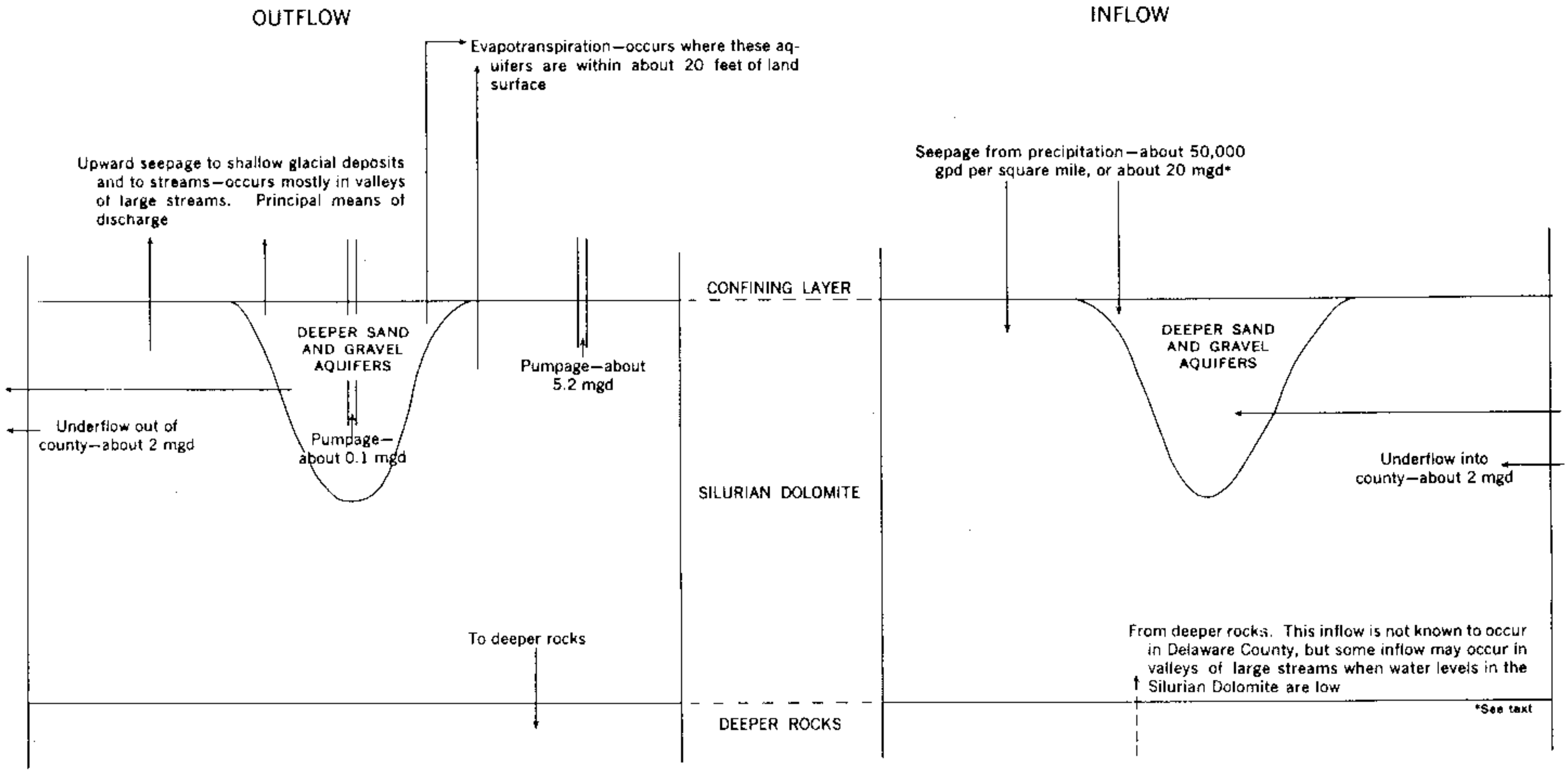


Figure 12.—Average recharge and discharge of the Silurian dolomite and the deeper sand and gravel aquifers.

these wells and field-chemical analyses of the water are shown in the quality of water section (p. 39).

The principal means of discharge from the dolomite and from the deeper sand and gravel aquifers is seepage to the overlying glacial drift in the valleys of the larger streams. Areas where this seepage occurs can be inferred from the piezometric surface of the dolomite (fig. 13). Discharge by evapotranspiration can occur in areas where the dolomite is within about 20 feet of the surface (fig. 14, p. 38).

The estimates of recharge from precipitation and underflow in and out of the dolomite were obtained by the same methods used for the principal Pleistocene aquifer, and the same limitations are applicable.

The rate of recharge of the dolomite and of the deeper sand and gravel aquifers determines to a large extent their potential for future development. Recharge to the aquifers will increase as the hydraulic head of the aquifer is lowered by pumping, until the water level reaches the top of the aquifer.

Development and potential. This aquifer is capable of yielding as much as 500 gpm to individual wells in the southeastern part of the county. Figure 13 shows expected one-day specific capacities and possible yields of 12-inch wells that penetrate the upper 100 feet of dolomite. Wells may require surging and chemical treatment to develop their maximum yields.

The pumping level of a well should not be continuously lowered below the top of the aquifer, where the more permeable zones occur. Lowering of the water level below these zones could cause precipitation of dissolved solids in openings in the rock, resulting in decreased well yields. In some areas this condition is unavoidable if the aquifer is to be developed at all. These areas are included within the areas of lowest potential on figure 13. Chemical treatment may improve the performance of wells whose yields have decreased for the above reason. Csallany and Walton (1963, p. 20, 21) report successful results of hydrochloric acid treatment for developing new wells in dolomite and for rehabilitating old wells.

The depth to the top of the aquifer can be estimated from figure 14. This depth, along with figure 13, can be used to estimate the well depth necessary to develop a water supply in the dolomite. The map and the associated data are subject to the same limitations as those applied to the capability map of the principal Pleistocene aquifer.

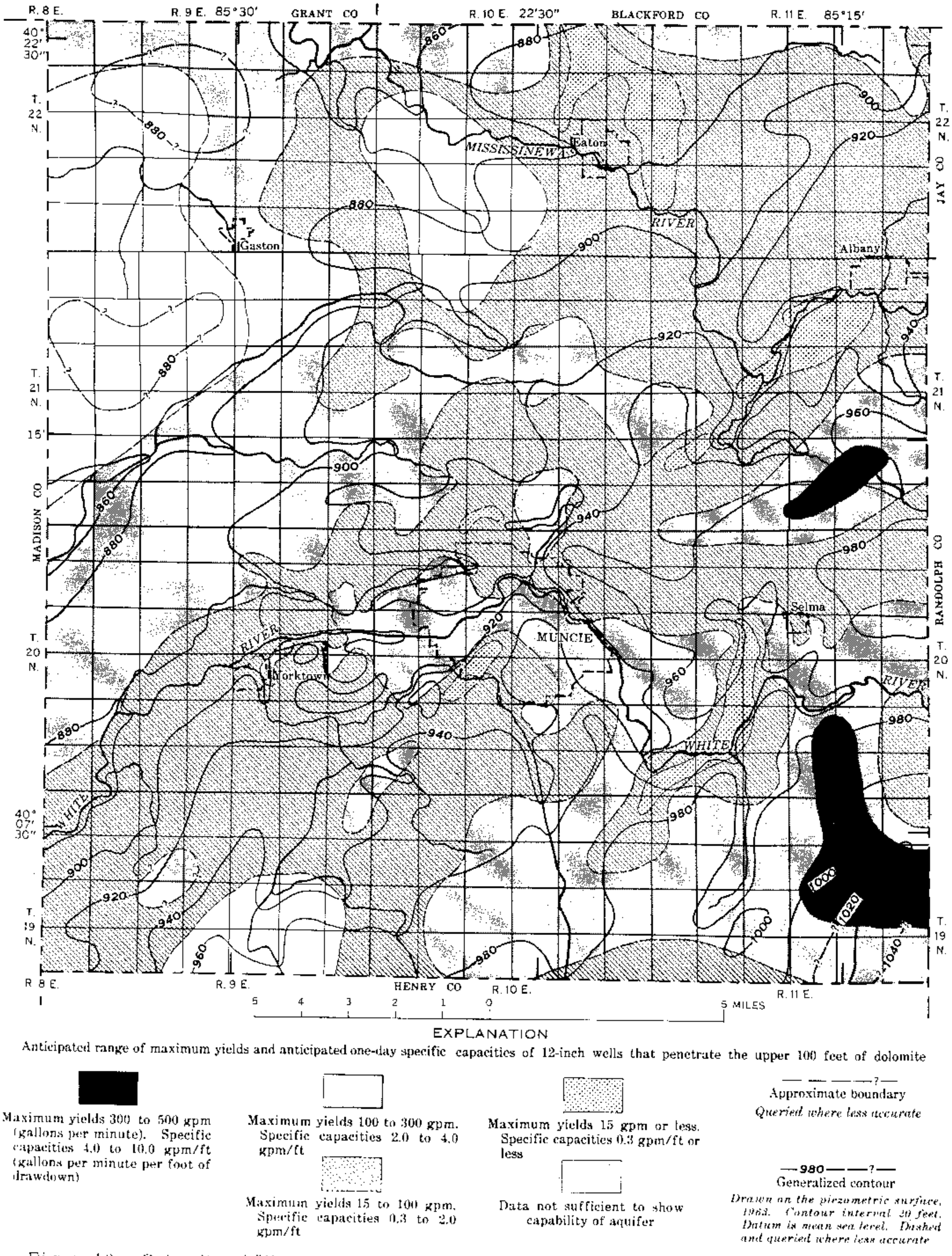


Figure 13.—Dolomite of Silurian age is capable of supplying as much as 500 gpm to individual wells.

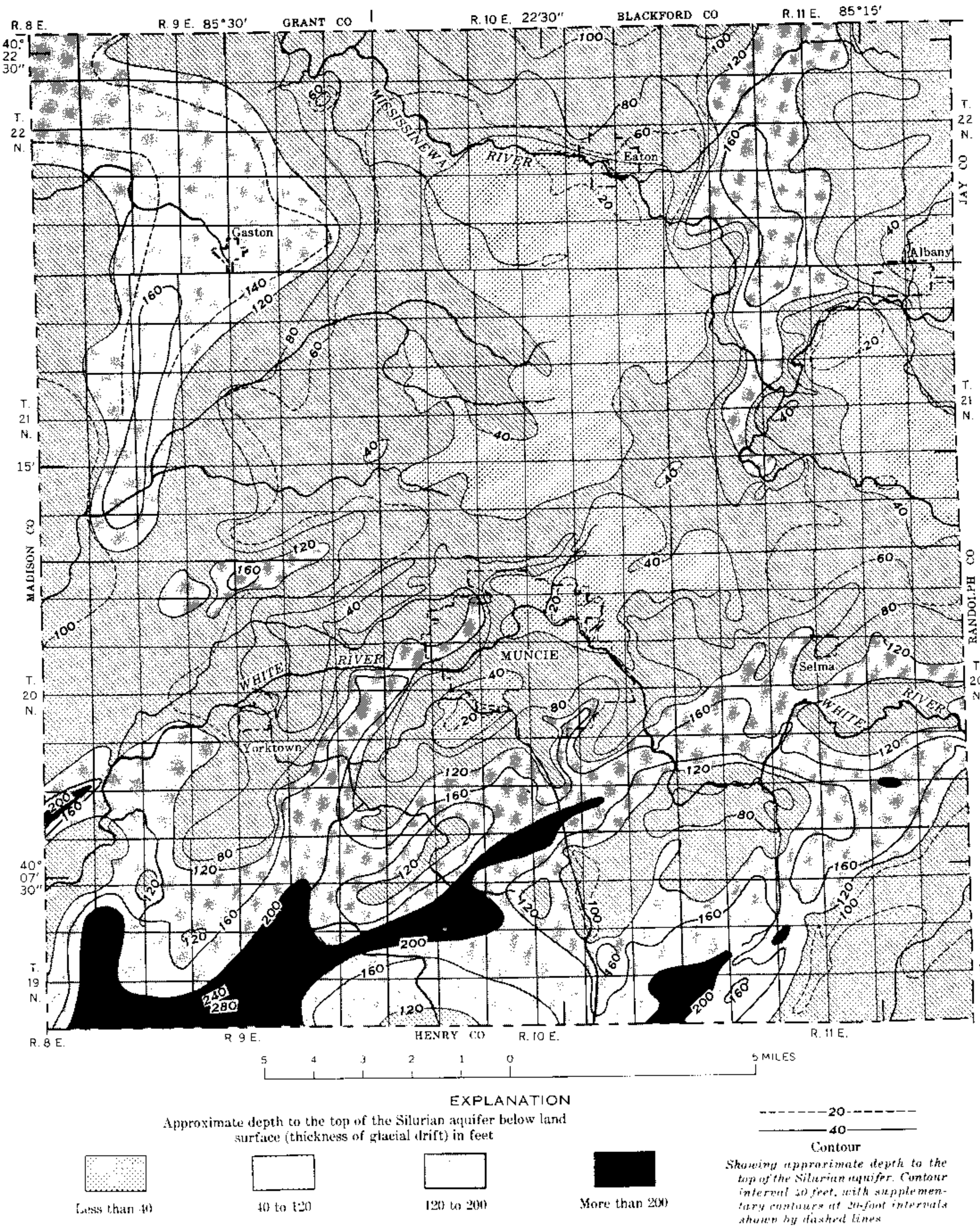


Figure 14.—The Silurian aquifer underlies the entire county at depths of 0 to about 300 feet below land surface. The top of the aquifer is the bedrock surface.

QUALITY OF THE WATER SUPPLY

The quality of the water in the aquifers and in the streams during low flow in Delaware County is generally acceptable for most uses. The concentration of dissolved chemical constituents are generally within the limits recommended by the U. S. Public Health Service (1962, p. 7) for drinking water. Iron content in the ground water, and hardness in both ground and surface water are generally present in undesirable quantities.

The ideal quality of water requirements for industrial use vary widely for the many purposes to which water is put. In fact, within any given industrial plant, water may have several functions for which the quality requirements vary considerably. To illustrate some of the quality standards necessary to meet those generally acceptable for drinking water and for certain industries, bar graphs are shown in figure 15 giving the acceptable, marginal, and undesirable ranges.

Chemical and Physical Quality of the Surface Water

The chemical quality of the surface water in Delaware County at about 90 percent flow duration is generally acceptable for most uses. Most of the water is hard and will require softening.

Water samples were collected for chemical analysis at the 7 stream-gaging stations, 4 partial-record stations and nearly every site where base-flow measurements were made, during the week of November 11, 1963. Generalized maps showing concentration of chloride, sulfate, and total dissolved solids are presented as figures 16, 17, and 18. The figures illustrate the variation of concentrations of these three chemical constituents at about 90 percent flow duration. The abrupt changes in concentration are due to the activities of man, mainly by the introduction of sewage effluents.

The surface waters are generally too hard for most industrial uses and would need to be softened. Hardness concentrations range from 258 ppm to 716 ppm, with most of the analyses ranging between 300 and 400 ppm. Water in Prairie Creek, below the Reservoir, contains less hardness (214 ppm) than other surface waters in the area. This better quality is due principally to the fact that the reservoir is filled during periods of high-water flow when the water has less dissolved solids than the mineralized ground waters that sustain dry-weather streamflows.

The bicarbonate concentration varied from 200 to 435 ppm with most of the waters ranging between 300 and 400 ppm, during the week of November 11, 1963, when the streams were at 90 percent flow duration.

When base-flow conditions end because of precipitation entering the stream by overland runoff, the chemical quality changes. The surface runoff dilutes most chemical constituents, and adds certain dissolved minerals and suspended sediments from the ground surface over which the water flows. The effect of increasing flow from combined underground and

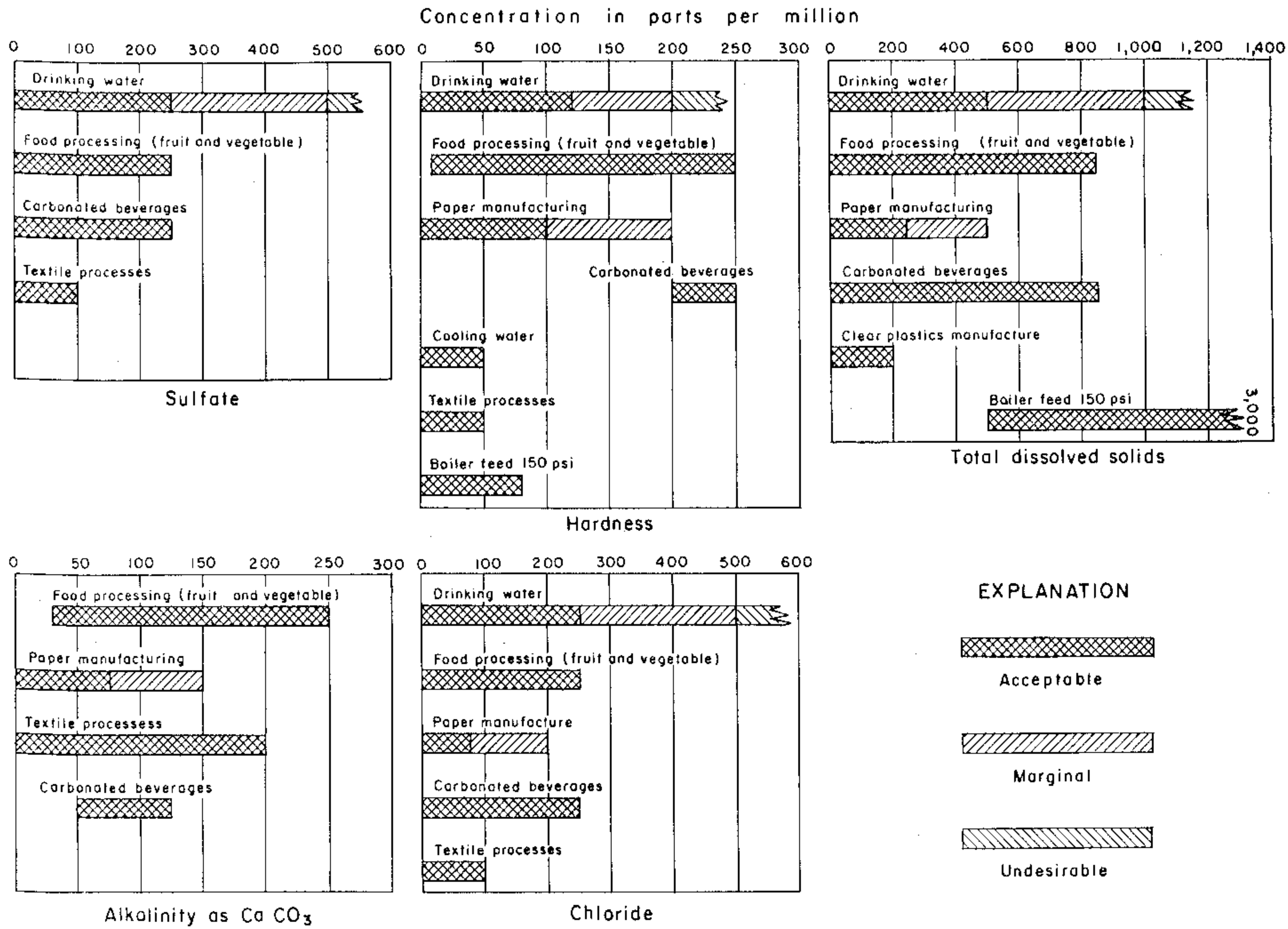


Figure 15. -- General raw water criteria for significant chemical constituents for drinking water and several industrial uses.

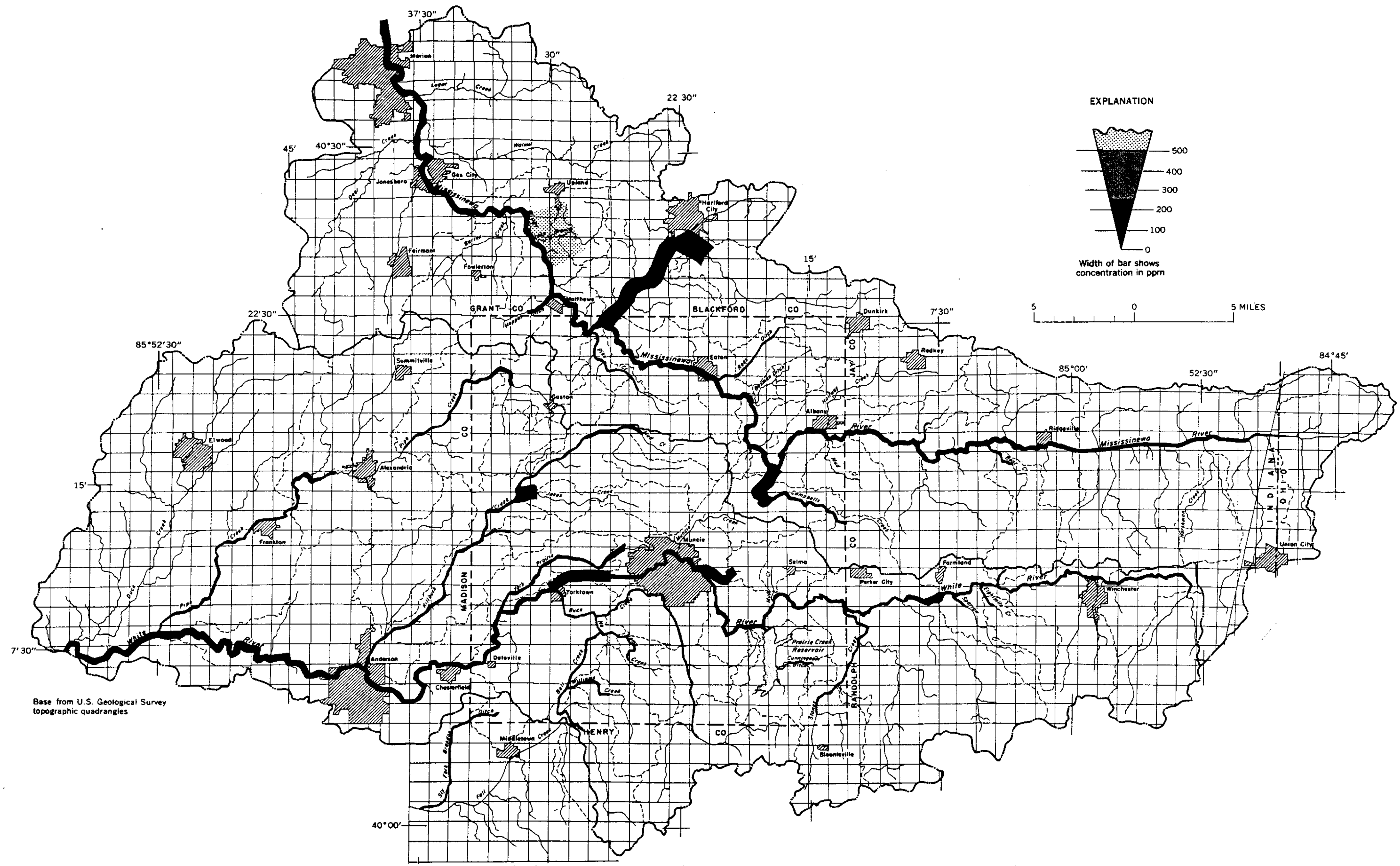


Figure 16.—Concentration of chloride in the streams of Delaware County at about 90 percent flow duration (week of Nov. 11, 1963) was generally less than 10 ppm excepting downstream from points of man-made effects.

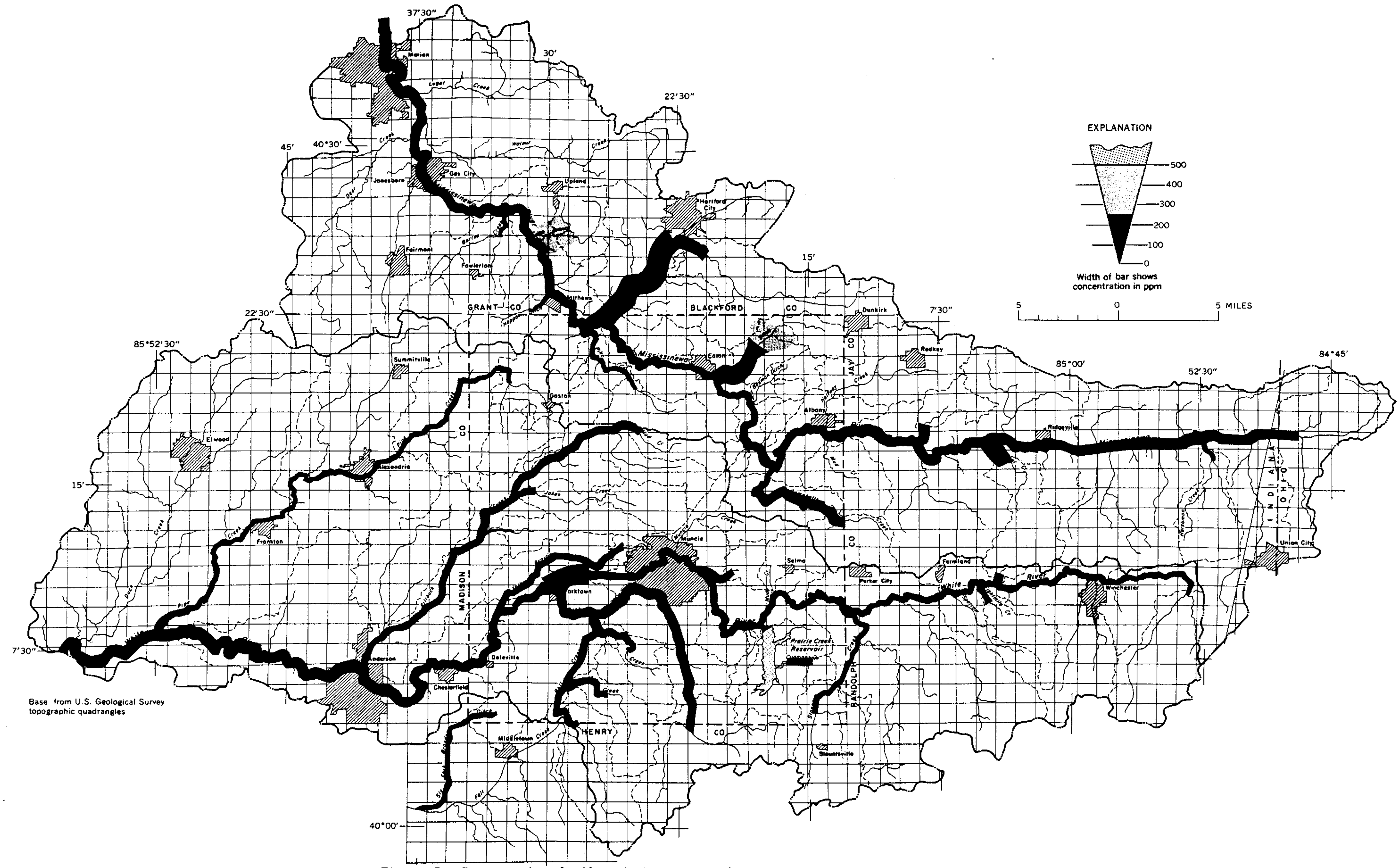


Figure 17.—Concentration of sulfates in the streams of Delaware County at about 90 percent flow duration (week of Nov. 11, 1963) was generally less than 100 ppm excepting downstream from points of man-made effects.

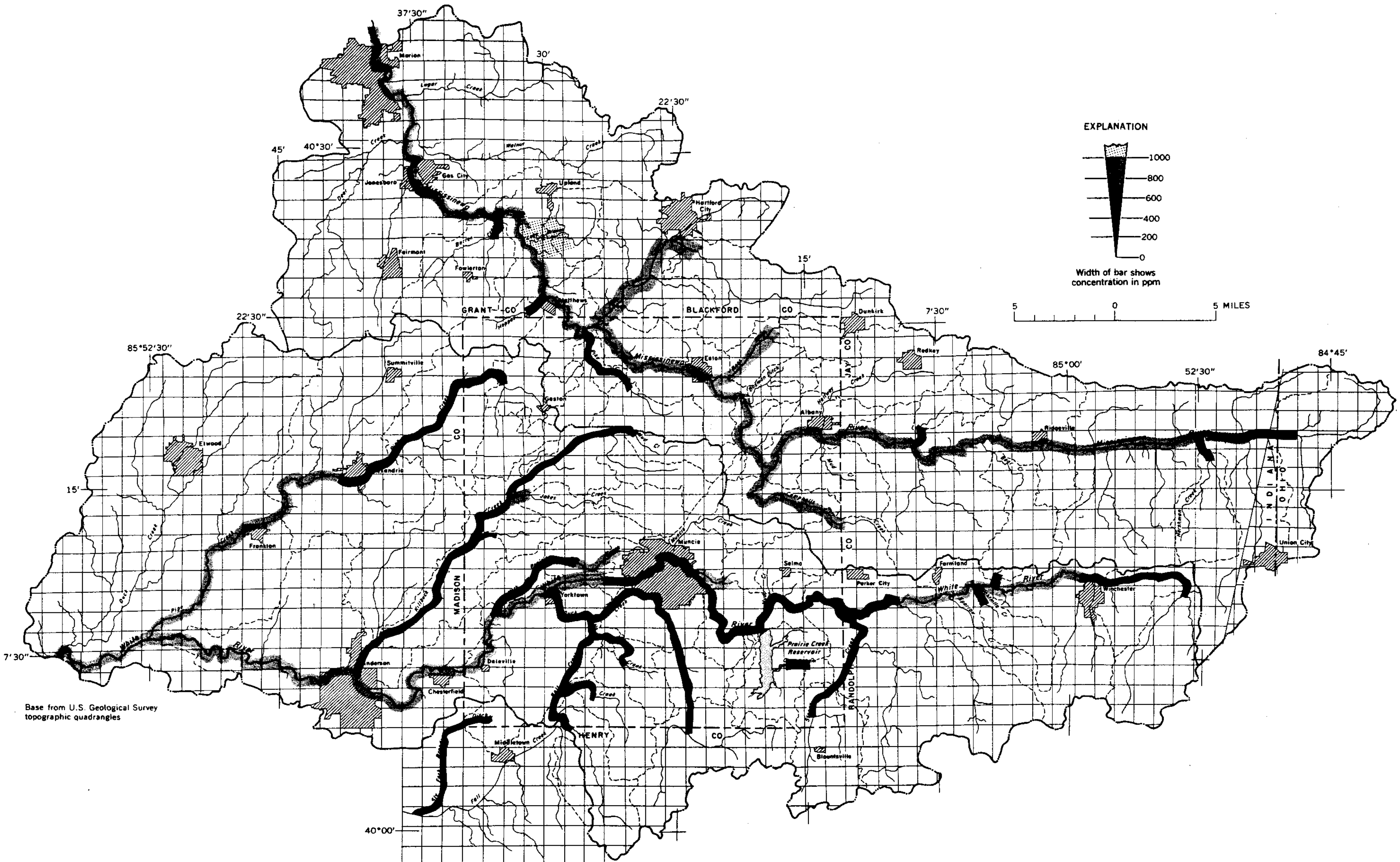


Figure 18.—Concentration of total dissolved solids in the streams of Delaware County at about 90 percent flow duration (week of Nov. 11, 1963) was generally less than 500 ppm excepting downstream from points of man-made effects.

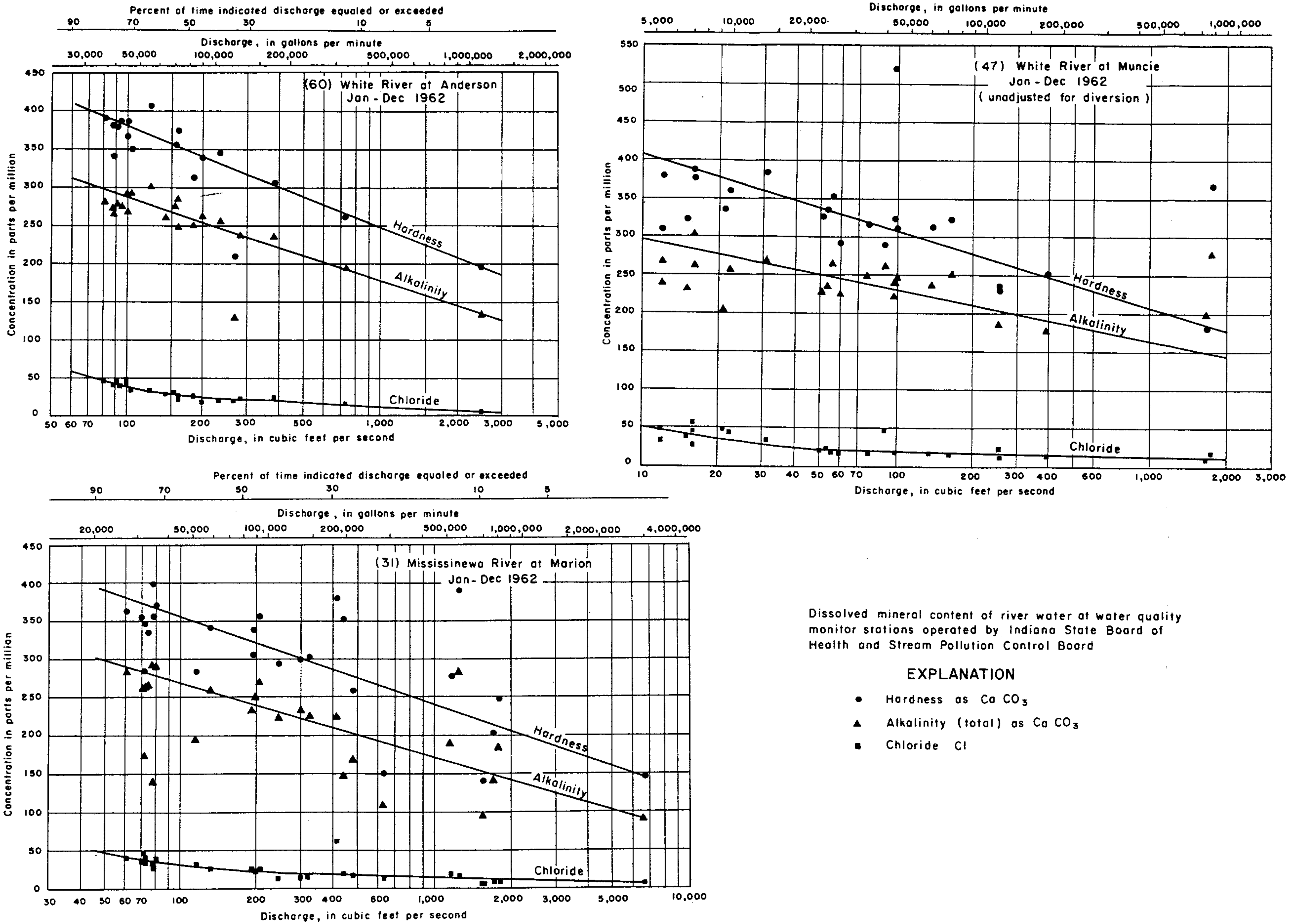


Figure 19 . -- Relation of mineral concentration to river discharge showing how quality of water varies with changing discharge.

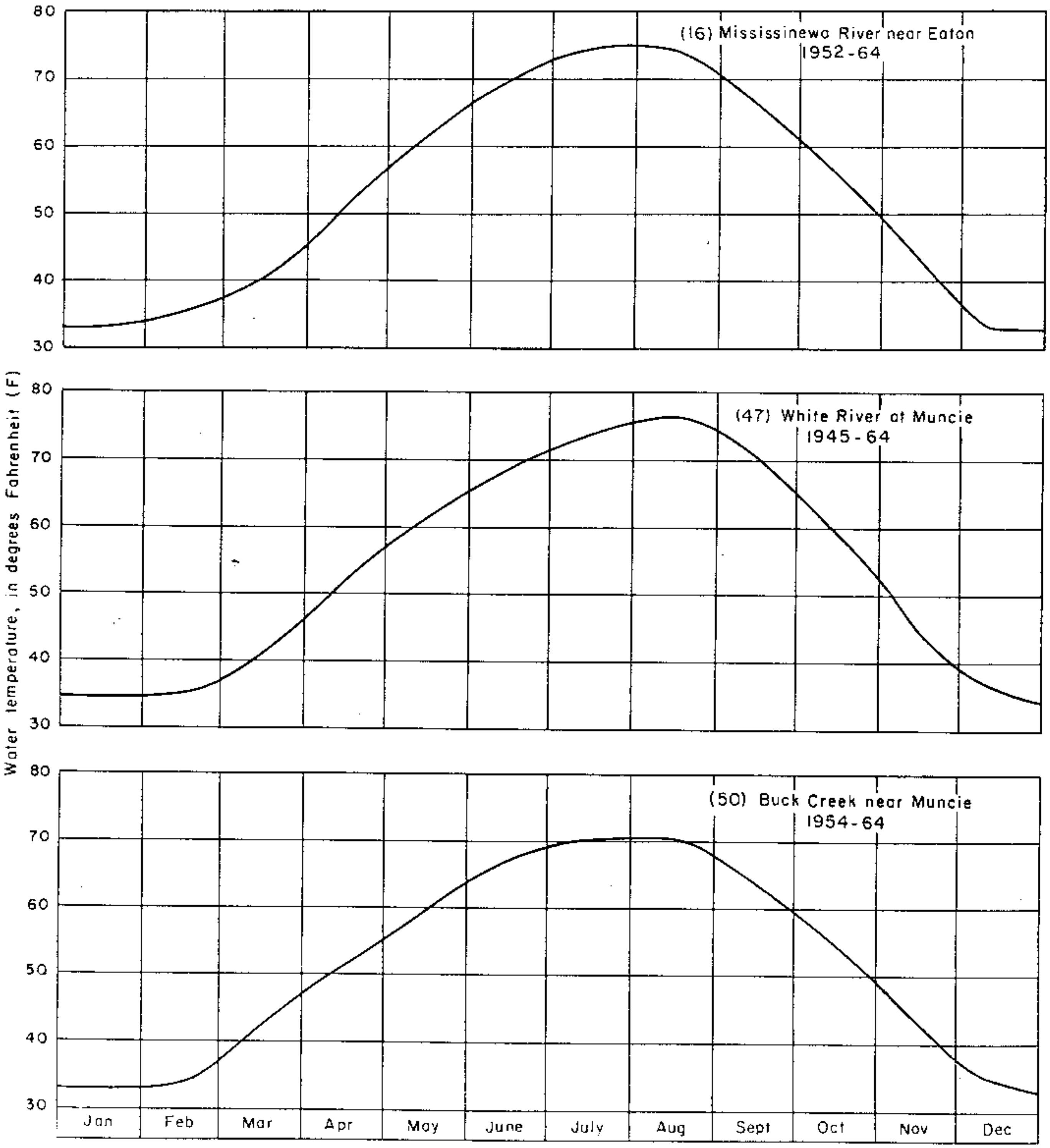


Figure 20.--Variation in approximate average water temperature during year for the Mississinewa River near Eaton, White River at Muncie, and Buck Creek near Muncie.

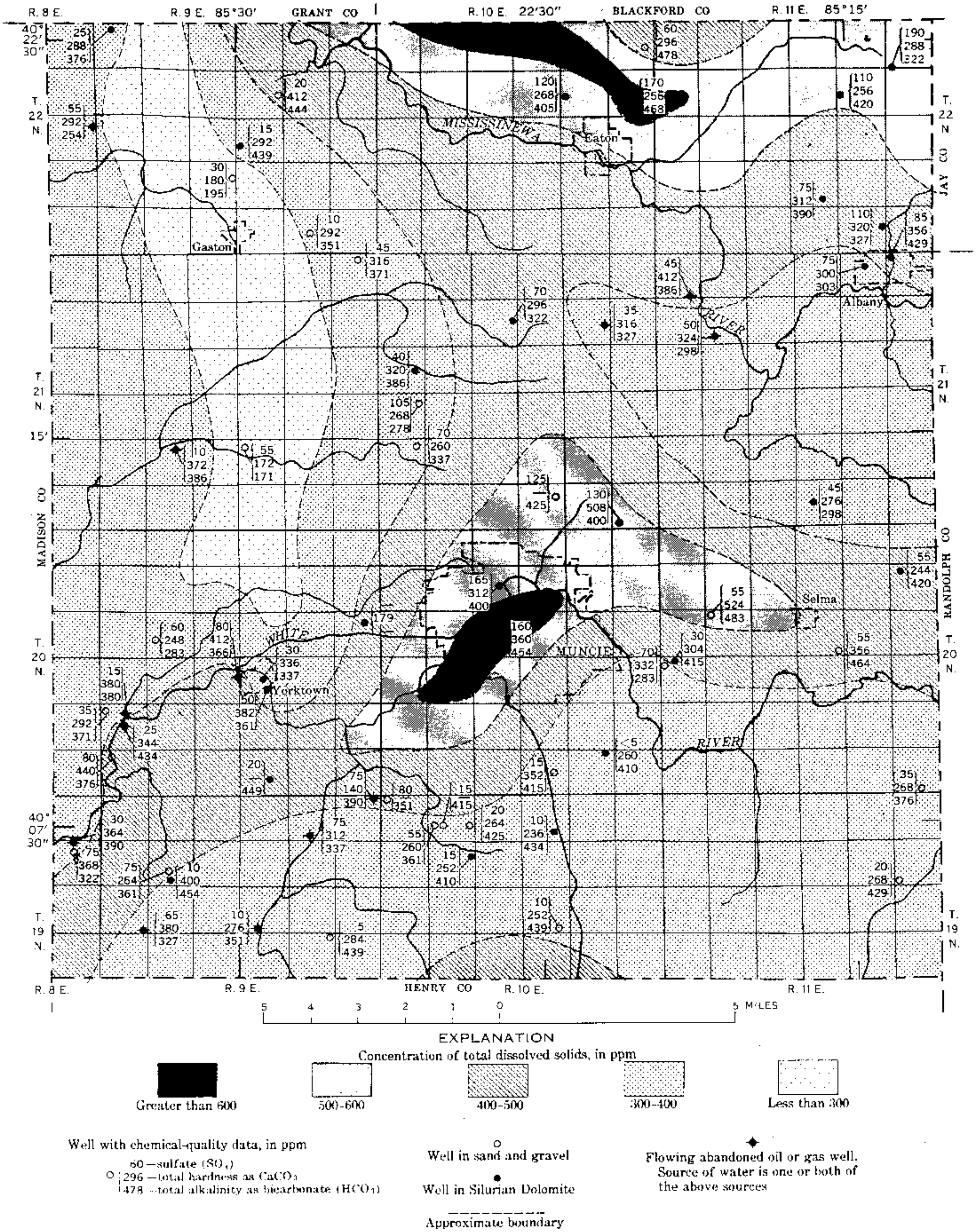


Figure 21.—Quality of ground water in Delaware County is similar in all important aquifers.

Table 8. Summary of water quality in Delaware County. Concentrations in ppm.

	Number of samples		Iron (Fe)	Total Alkalinity As Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total Dissolved Solids [b]	Hardness As $CaCO_3$
Streams [a]	29	range	---	200-435	22-455	5-162	298-922	258-716
		mode	---	367	74	9	386	362
Principal Pleistocene Aquifer	27	range	0.1-5.0	171-483	5-195	<4-48	205-724	172-524
		mode	0.9	388	66	4	379	288
Silurian Dolomite	28	range	0.1-7.5	303-468	<5-190	<4-32	302-653	179-508
		mode	1.6	425	17	3	407	288
Flowing Wells	14	range	0.8-2.5	254-434	5-80	4-28	302-449	276-440
		mode	2.1	370	30	9	350	333

[a] Sampled at approximately 90 percent flow duration (Week of Nov. 11, 1963).

[b] Total dissolved solids for ground-water samples estimated (Collins, 1927).

surface sources on hardness and alkalinity of the water and its chloride content is shown on figure 19. This figure is based on data collected by the State of Indiana at 3 gaging stations in the area.

As an example of the use of figure 19, let as assume that the industry investigating a location at Eaton in the hypothetical case desires water for a manufacturing process that will not exceed a hardness concentration of 250 ppm. From the curve for the Mississinewa River at Marion it is estimated that the hardness may be less than 250 ppm about 15 percent of the time, or 85 percent of the time the water would not meet the standards of the industry unless softened. Therefore, during the periods of objectionable quality, it would be necessary to set up a treatment process, or seek out a ground-water supply that would meet the criteria in quality. If a ground-water supply is considered there is a good possibility that the hardness of the water will be greater than 250 ppm (fig. 21, p.47), and treatment will be necessary.

An important physical characteristic of any surface water is its temperature. The use to which a water of sufficient quantity and acceptable quality may be put can be limited by too high a temperature. Figure 20 illustrates the approximate average variation of water temperature at the 3 stream-gaging stations in Delaware County. These curves are based on determinations of the temperature, usually once a month, for the period of record shown on the graphs. The variation at these 3 stations is similar. The White River at Muncie reached a high of approximately 77° F. during August whereas the Mississinewa River near Eaton and Buck Creek near Muncie reached a high of approximately 75° and 70° F., respectively. The lower average temperature on Buck Creek is due to the larger yield from ground water. None of the curves indicate heavy thermal loading by man immediately above the stream-gaging stations.

If a more even temperature is needed throughout the year (e. g. cooling, etc.), a prospective user should consider a ground-water source.

Chemical Quality of the Ground Water

The principal dissolved constituents are bicarbonate, calcium, and magnesium. In some areas, sulfate is a major constituent. Areal distribution of total dissolved solids, and sulfate, hardness, and alkalinity at selected wells is shown on figure 21. The range of concentration and mode (most common value) is shown on table 8.

Concentration of the chemical constituents are similar in range and distribution in all important aquifers. This similarity is a result of the recharge characteristics of the area. Most of the recharge to all aquifers must percolate through the surface till (fig. 6). Only a minor amount of water enters the county by underground flow. After percolating through the surface till, the water has dissolved soluble minerals and consequently has lost much of its ability to dissolve additional minerals. The water-soluble minerals in the till are principally dolomite and limestone.

Although the water in the dolomite is similar in quality to the water in the principal Pleistocene aquifer, the range in concentration of each constituent except iron is slightly smaller in the dolomite. This apparently greater uniformity of chemical character of the water in the dolomite indicates that some mixing of recharge water of differing chemical composition has taken place.

The chemical quality of the water in the streams, during the week of November 11, 1963, in a period of approximately 90% flow duration is similar to the quality of water shown on table 8 for ground-water aquifers. This is to be expected as much of the runoff during periods of low flow is derived from ground-water discharge. The extremes found in the dissolved chemical constituents at both high and low flows are not natural and may be attributed to the works of man.

Effects of Man's Activities on Water Quality

The effect of man's activity on water quality in Delaware County is generally not so adverse as to render the chemical quality of surface and ground waters undesirable.

His effect on surface water quality with respect to chloride, sulfate, and total dissolved solids may partially be seen in figures 16, 17, and 18. The larger concentrations and abrupt changes in concentration may be attributed to the works of man. These figures represent perhaps the worst conditions because of the low flow in the streams during the sampling period.

A further look at the surface water quality is shown by figures 22 and 23 in which concentrations of alkyl benzene sulfonate (ABS) and dissolved oxygen are shown by color lines along the sampled streams at 90 percent flow duration. The largest amounts of the synthetic detergents and the smallest amounts of dissolved oxygen were downstream from the larger towns. The White River below Muncie is the most adversely affected; however, the quality improves considerably before leaving the county, owing to the dilution effect of the waters from Buck and York Prairie Creeks.

The temperature of the water in White River downstream from Muncie is increased for a few river miles by the addition of sewage effluent. During the week of November 11, 1963, heat loss had taken place over the distance between Muncie and the county line and the water temperature was nearly the same at the county line as in other streams in the area. This cooling was due not only to the distance traveled but also to the addition of discharge from Buck and York Prairie Creeks.

Contamination of the surface waters by waste from oil wells has happened in the past. This is not a major problem at the present owing to the small activity in this field.

Man's effects on the surface water are not always adverse. The quality may be improved by impounding during high runoff periods and releasing during low runoff or base-flow periods. This is evidenced in Prairie Creek where hardness has been decreased by the release of impounded reservoir water.

The chemical quality of ground water has not been measurably affected by man. The relatively impermeable surficial confining layer prevents direct contamination of aquifers throughout most of the county. Contamination of fresh-water aquifers by upward movement of saline water from deep aquifers is a remote possibility if the hydraulic head in the Silurian dolomite is drastically lowered for a long period of time.

PLANNING WATER DEVELOPMENT

The planning of a water development entails a large amount of engineering and management know-how. Before the first shovel of dirt is moved for a new reservoir or a driller sets up his rig to drill a well for a large water supply, someone has had to make decisions as to the quantity and quality of the water needed and possibilities of getting this water through the new development.

Problems to Consider

Many problems must be considered by those concerned with the development and use of water when seeking a new supply. The first problem is that of deciding between a surface-water or ground-water supply.

If a surface-water supply is being considered some of the problems are: (1) Is there a dependable flow in the stream sufficient to meet future demands without reservoir construction? (2) If not, is there enough natural flow available in the stream to make the construction of a reservoir feasible? (3) Does the topography lend itself to a reservoir site? (4) What will be the losses in the reservoir, if constructed, owing to leakage and evaporation? (5) Will the losses be of sufficient magnitude to nullify the advantage of storage? (6) What is the quality of the water and treatment necessary? (7) If municipal and industrial wastes are emptied into the stream, will streamflow be adequate to dilute present and future volumes of waste effluent?

If a ground-water supply is being considered some of the problems are: (1) Can enough water be obtained to supply anticipated needs? (2) If so, will treatment be necessary to overcome water quality problems? (3) What will heavy pumping in the new area do to existing water levels?

Interrelated and similar problems will occur when either of the above sources are considered. The most significant of these problems are: (1) How will the proposed reservoir or pumped well affect downstream or nearby users of water? (2) Which source of supply of possibly several alternates will produce the desired quantity and quality for the least expenditure of funds? (3) Will well supplies located near stream courses be affected by

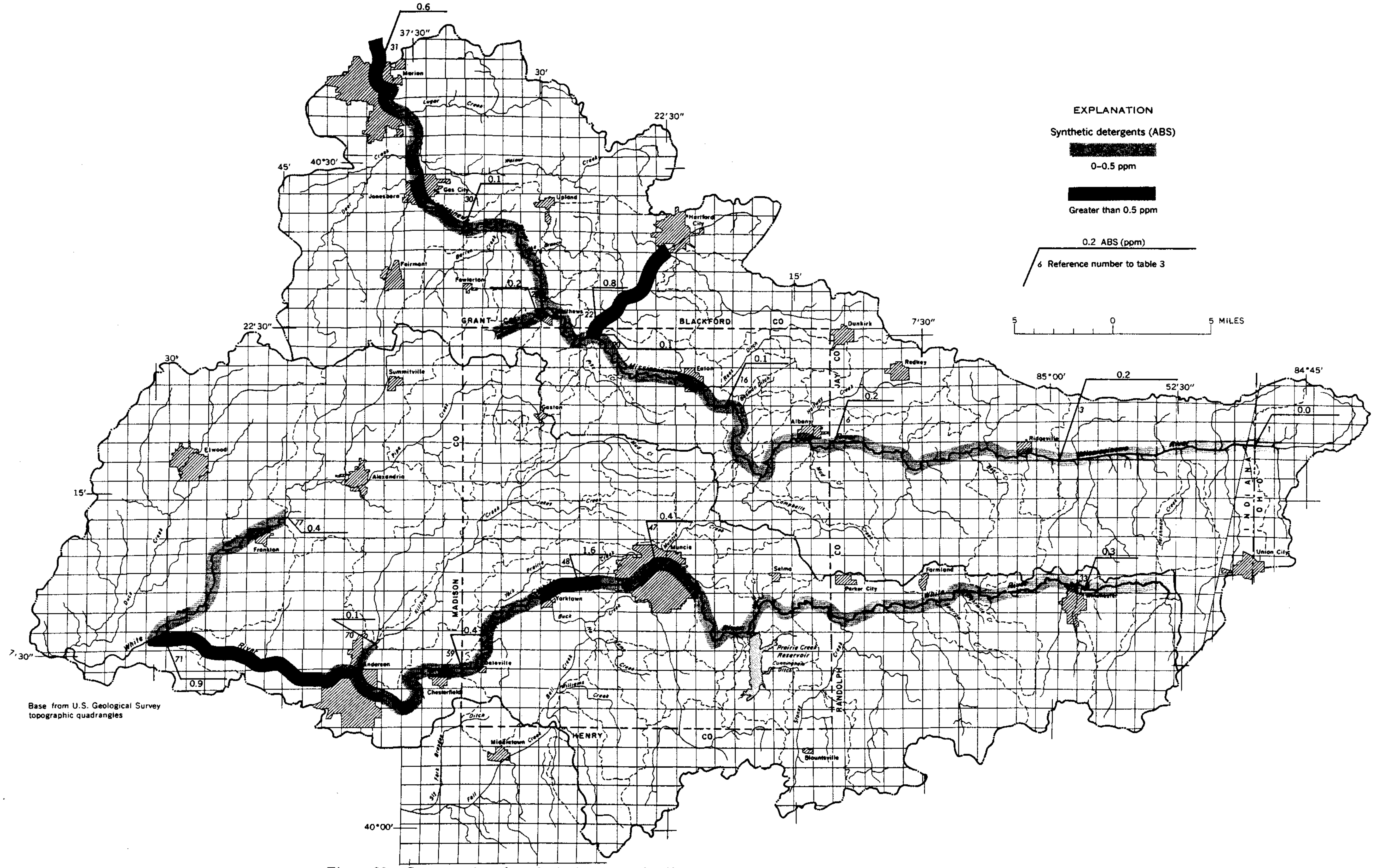


Figure 22.—Concentration of synthetic detergents (ABS) in the Mississinewa and White Rivers in Delaware County at about 90 percent flow duration (week of Nov. 11, 1963) was less than about 0.1 ppm for the Mississinewa River and 0.4 ppm for the White River excepting on the White River below Muncie.

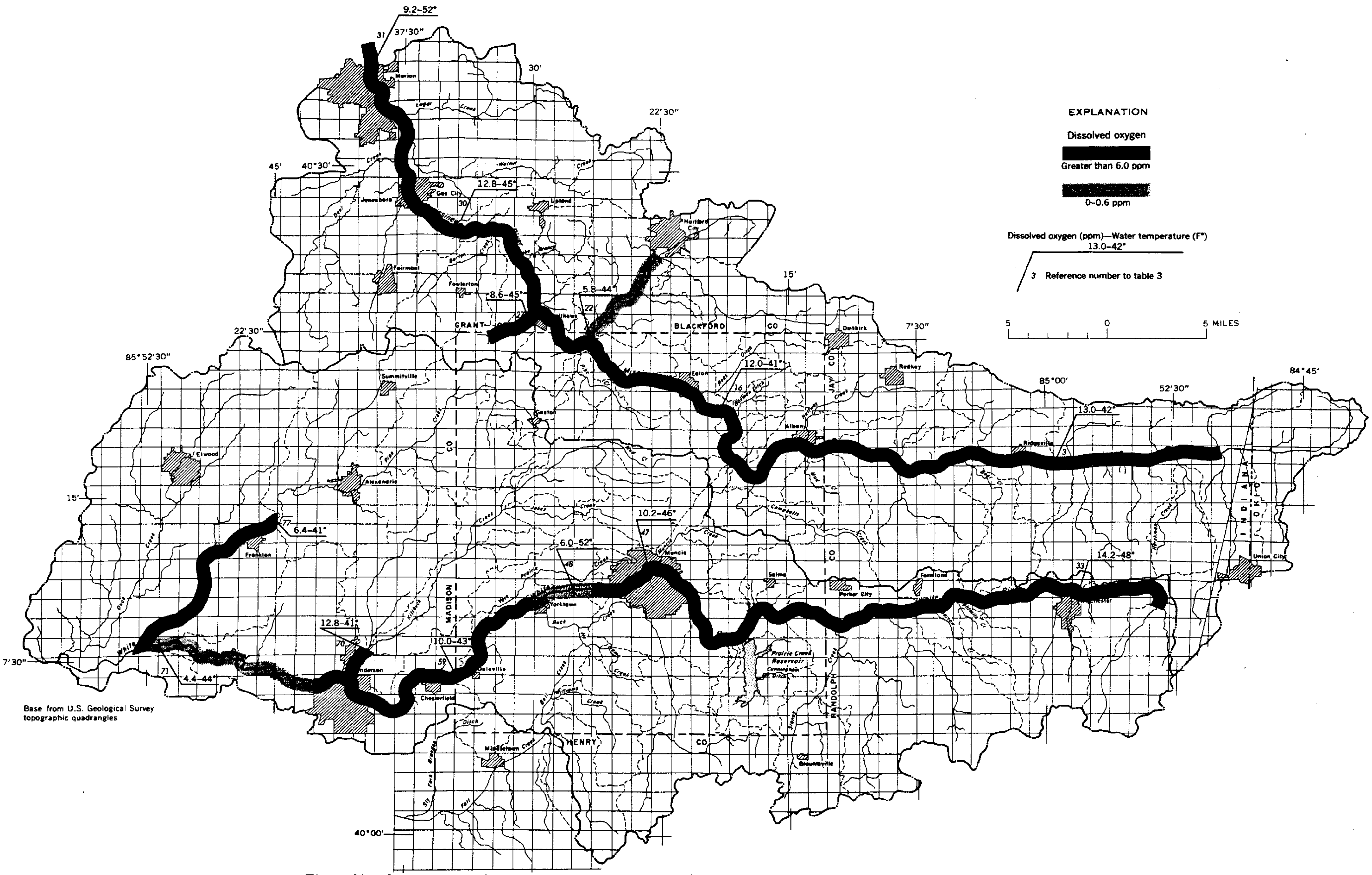


Figure 23.—Concentration of dissolved oxygen in the Mississinewa and White Rivers in Delaware County at about 90 percent flow duration (week of Nov. 11, 1963) was generally greater than 10 ppm excepting in the White River below Muncie.

chemical or bacterial pollutants from surface sources? (4) Will heavy pumping of wells in the vicinities of streams during low flows affect the ground-water discharge sifnificantly, thus decreasing the amount of base flow available to streams to dilute waste effluents?

A problem is presented in Delaware County by gas wells which were drilled during the period of the old "Trenton Field Boom". These wells, many of which are improperly plugged or abandoned, constitute a potential problem to water supplies. They serve as points of weakness for conveying water to or from deeper horizons where mineralized water exists.

There is no end to the problems that the decision makers must confront, and their decisions will affect the economy, the environment, and thus the lives of future generations.

CONCLUSIONS

The availability of water in the streams, glacial deposits, and upper bedrock formations in Delaware County is generally adequate for most foreseeable development and use. The chemical and physical quality of water in the streams and in the aquifers is acceptable for most uses.

Conclusions reached by this study are:

1. Most streams in the northern half of the county having less than 10 square miles of drainage area, including the headwaters of larger streams, go dry frequently.

2. Most streams in the southern half of the county, regardless of size, yield more than 9 gpm (0.013 mgd) per square mile 90 percent of the time.

3. A large user of water in the county requiring 25 mgd or more, more than 90 percent of the time, will have to depend on surface-water impoundment.

4. The limit of surface-water potential in cfs on any streams in the county is approximately the product of the drainage area, in square miles, times 1 cfsm. This would necessitate an impoundment and the ability to release at a uniform rate the total water that flows from the area above the reservoir.

5. The principal sources of ground water occur within 400 feet of the surface. The rocks below this depth are potential sources of uncertain but probably small quantities of saline water.

6. The ground-water reservoir has a recharge rate of about 80 mgd, of which 6.8 mgd is currently being pumped.

7. The best sources of ground and surface water are located in the southern and southeastern parts of the county. Wells in this area could yield as much as 1,000 gpm by using all of the aquifers. The upper part of Buck Creek yields as much as 120 gpm per square mile 90 percent of the time.

8. There is adequate ground water available throughout the county for rural domestic and livestock use.

9. Occasionally the hardness may be more than 500 ppm in the ground water and 700 ppm in the surface water. The total dissolved solids may be more than 700 ppm in the ground water and 900 ppm in the surface water.

10. Iron content in the ground is generally greater than 1.0 ppm.

11. The available surface and ground water sources with proper development should be adequate to supply the needs of the county in the foreseeable future.

DEFINITIONS

Base flow (ground-water runoff). That part of runoff which has passed into the ground, has become ground water, and has been discharged into a stream channel as spring or seepage water.

cfs. Abbreviation of cubic feet per second. One cfs equals 448.83 gpm or 0.646317 mgd.

Coefficient of permeability. Measure of a material's capacity to transmit water; expressed as rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under hydraulic gradient of 1 foot per foot at prevailing temperature. (After Ferris and others, 1962).

Flow-duration curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

gpm. Abbreviation of gallons per minute. One hundred gpm equals 0.22280 cfs or 0.144 mgd.

Low-flow frequency curve. A graph showing the magnitude and frequency of minimum flows for a period of a given length. Frequency is usually expressed as the average interval, in years, between recurrences of an annual minimum flow equal to or less than that shown by the magnitude scale.

mgd. Abbreviation of million gallons per day. One mgd equals 1.5472 cfs or 694.44 gpm.

Mode. The value which occurs most frequently.

Porosity. Volume of pore space expressed as a percentage of the total volume of the rock.

Recurrence interval. The average interval of time within which the given low flow will be less than or equaled once. A recurrence interval of two years is equivalent to a 50 percent chance of the event occurring in any one year and a recurrence interval of 20 years is equivalent to a 5 percent chance of the event occurring in any one year.

Specific capacity. Yield of well in gallons per minute per foot of drawdown. Usually stated for a definite period of pumping.

Storage-required frequency curve. A graph showing the frequency with which storage equal to or greater than selected amounts will be required to maintain selected rates of regulated flow.

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PLATE 1

Plate 1.—Map of upper Mississinewa and White River basins embracing Delaware County showing stream runoff for the week of November 11, 1963, at about 90 percent flow duration.