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WATER RESOURCES OF THE MILWAUKEE AREA WISCONSIN

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WATER RESOURCES OF THE MILWAUKEE AREA, WISCONSIN

By William J. Drescher, Frederick C. Dreher, and Paul N. Brown

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WATER RESOURCES OF THE MILWAUKEE AREA, WISCONSIN

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INTRODUCTION

Lake Michigan-Huron affords Milwaukee an almost unlimited supply of good quality, cold, fresh water. The Milwaukee River in the vicinity of Port Washington Road Bridge is capable of supplying 25 or more mgd for 95 percent of the time. It is estimated that the sandstone aquifer underlying the area is capable of supplying about 60 mgd if wells are properly located and spaced. The Niagara dolomite and the Pleistocene deposits in many parts of the area are capable of supplying larger quantities of water than have been developed.

A satisfactory water supply is one of the factors that affects the economic growth of a region. Cities and towns must have adequate amounts of pure water for domestic use. Industries also must have sufficient quantities of suitable water. In order to assure success and economy, the development of water resources should be based on adequate knowledge of the quantity and the quality of the water, the amount of its present use, and the possibility of future development. As a nation, we cannot afford to run the risk of dissipating our resources, especially in times of national emergency, by building projects that are not founded on sound engineering and adequate water-resources information.

Lake Michigan is a source of large quantities of water of good quality; therefore, one might think that the search for water for Milwaukee need not go beyond the lake. However, other sources may be more economical for some uses. Lake intakes are expensive and difficult to construct. Unless the water is to be used at the edge of the lake, an expensive pipe line is required to transport the water to the point of use. Streams, the ground, or the public supplies may be the most economical source if the quantity is small or the point of use is some distance from the lake. Water temperature and quality are other factors that must be considered when the most economical source is selected.

Purpose

The purpose of this report is to summarize and interpret all available water-resources information for the Milwaukee area. The report will be useful for initial guidance in the location or expansion of water facilities for defense and nondefense industries and the municipalities upon which they are dependent. No attempt has been made to present a complete record of the hydrology of the area.

Acknowledgments

This report is one of a series concerning water resources of selected areas of strategic importance, prepared under the technical supervision of the Water Utilization Section of the Technical Coordination Branch. This report was prepared under the direct supervision of F. C. Christopherson, district engineer (Surface Water), W. J. Drescher, district engineer (Ground Water), and W. L. Lamar, district chemist (Quality of Water).

Most of the data summarized in this report have been collected over a period of many years by the U. S. Geological Survey in cooperation with agencies of the State of Wisconsin, the University of Wisconsin, and the Corps of Engineers.

Additional data were obtained from industries, State and local government officials, and individuals. The pollution data were taken from reports published by the U. S. Public Health Service and the Milwaukee County Survey of Social Welfare and Health Services, Inc. One analysis was made by the Wisconsin State Laboratory of Hygiene. Data on the Milwaukee public-water supply were obtained from the Milwaukee Department of Public Works, through the generous cooperation of Edward F. Tanghe, superintendent of filtration, and Norton A. Thomas, assistant superintendent of filtration and chief chemist. Much of the data on Lake Michigan-Huron were obtained from the Great Lakes Division, Corps of Engineers, U. S. Army. Some of the flood data for the Milwaukee River were obtained from a bulletin on flood conditions of the Milwaukee River by the Wisconsin State Planning Board. The sections of this report dealing with ground water are abstracted from a more comprehensive report, Ground-water conditions in the Milwaukee-Waukesha area, Wisconsin.

Definition of Terms

Throughout this report chemical concentrations are expressed in either of two units, parts per million or equivalents per million. Parts per million (ppm) is the number of unit weights of the constituent in one million unit weights of the solution. For example, 20 ppm of chloride means that there are 20 milligrams of chloride in 1,000,000 milligrams of the solution.

Equivalents per million (epm), an expression of concentration in terms of reacting capacity, is the number of unit equivalent weights of an ion contained in one million unit weights of the water. An equivalent weight of a substance is defined as the weight that is exactly equal in reacting capacity to one atomic weight (1.0080 grams) of hydrogen. The equivalents per million for each constituent is calculated by dividing its concentration in parts per million by its equivalent weight. For example, 100.16 ppm of calcium divided by its equivalent weight (20.04) amounts to 5 epm of calcium. Equivalents per million are useful in expressing chemical combinations as well as in expressing analyses graphically, since one equivalent of a cation, such as calcium, will combine exactly with one equivalent of an anion, such as chloride, to form one equivalent of a compound, such as calcium chloride.

Most Probable Number (MPN) of coliform organisms is that density of such organisms, which if it had been actually present in the sample, would, more frequently than any other, have given the observed analytical results. The density of organisms is usually given as the most probable number per 100 milliliters.

Water-year is that period of time between October 1 and September 30. An acre-foot (ac-ft) is the quantity of water required to cover an acre to the depth of 1 foot and is equivalent to 43,560 cubic feet. A cubic feet per second (cfs) is the rate of discharge of a stream whose channel is 1 square foot in cross-sectional area and whose average velocity is 1 foot per second. Mgd is the abbreviation for million gallons per day. 1 cfs = 0.646 mgd.

The transmissibility of an aquifer or water-yielding formation is a measure of its ability to transmit water. The coefficient of transmissibility is defined as the number of gallons that will move in 1 day through a section of the aquifer 1 mile wide and having a height equal to the saturated thickness of the aquifer under a hydraulic gradient of 1 foot per mile (gpd per ft).

The coefficient of storage of an aquifer is the amount of water in cubic feet that is released from a vertical column of the aquifer having a height equal to the saturated thickness of the aquifer and a base of 1 square foot when the head on the aquifer is lowered 1 foot. The coefficient of storage generally is expressed as a dimensionless fraction.

The specific capacity of a well is the rate of pumping per foot of drawdown (gpm/ft) and is a qualitative rather than an absolute term. Specific capacity depends not only upon the hydraulic characteristics of the aquifer but also upon the size and construction of the well, amount and kind of well development, amount of penetration of the aquifer, rate of pumping, and length of time of pumping.

Description of Area

The Milwaukee area in this report consists of all of Milwaukee County and the east half of Waukesha County (fig. 1). In 1950 the population of Milwaukee County was 863,937 of which 632,651 were in the city of Milwaukee. The population of that part of Waukesha County included in this report was about 61,000 in 1950 of which 21,186 were in the city of Waukesha.

The U. S. Geological Survey has made 15-minute quadrangle topographic maps of the Milwaukee Area. The following quadrangles with dates of survey cover the Milwaukee area and adjacent areas: Milwaukee (1899), Waukesha (1890), Oconomowoc (1907), Bayview (1890), Muskego (1899), Eagle (1903). All the maps are old and are considered obsolete according to present standards. However, they are useful for showing the general topography.

The dominant topographic feature of the area is the shore of Lake Michigan. Along the lakeshore, except near the mouth of the Milwaukee River in the Milwaukee Harbor area, there is a bluff that rises 60 to 120 feet above the lake. The surface of Lake Michigan is about 580 feet above sea level. From the crest of the lakeshore bluff the surface rises gradually toward the west as an undulating plain. Superposed on the plain is a series of generally north-south trending ridges successively higher westward from Lake Michigan. In the northwestern part of the area the ridges become more irregular, and (in T. 6 N., R. 19 E., and T. 7 N., Rs. 19 and 20 E.) local groups of drumlins occur as rounded elongated hills whose axes trend generally a little north of east. They are well developed in the area immediately west of the city of Waukesha.

The western part of the area is higher in the north than in the south. The greatest altitude is about 1,150 feet above sea level in sec. 29, T. 8 N., R. 19 E. (See fig. 13.) The maximum relief in the area is about 570 feet but local relief is not usually more than 100 feet.

The north-south ridge pattern of the topography effectively controls the drainage pattern. All the major streams flow south roughly parallel to the shore of Lake Michigan for many miles. Milwaukee River approximately parallels the shore for 28 miles from Fredonia in Ozaukee County before entering Lake Michigan at Milwaukee. Root River flows southward nearly its whole length in Milwaukee County before turning eastward for about 5 miles near the Racine County line. Fox River rises in northeastern Waukesha County and flows generally southwestward to the southwest corner of the Milwaukee area where it turns sharply eastward for about 6 miles to Big Bend. It then turns southward again. No stream in the area is very large, for the drainage area is limited on the west by the kettle moraine hills and the Niagara escarpment. The kettle moraine lies only 3 miles west of the northwest corner of the Milwaukee area and extends a little west of south from that point. The eastern end of Lake Pewaukee is in the area, the easternmost of the group of lakes associated with the kettle moraine area.

The elongated valleys between the north-south ridges are, on the whole, poorly drained and large marsh areas result. Many of the marshes have been drained and are under cultivation.

The climate of the area is temperate with an average annual temperature of 45.5 F. Both summer and winter extremes of temperature are modified by Lake Michigan, especially when winds blow from the lake. The average annual precipitation at Milwaukee is 31.0 inches. Figures 2 and 3 show the maximum, minimum, and average temperature and precipitation for the 78-year period 1871 to 1948.

The Milwaukee area is primarily an industrial center although the rural part of the area is agricultural. Milwaukee is a principal Great Lakes port and is served

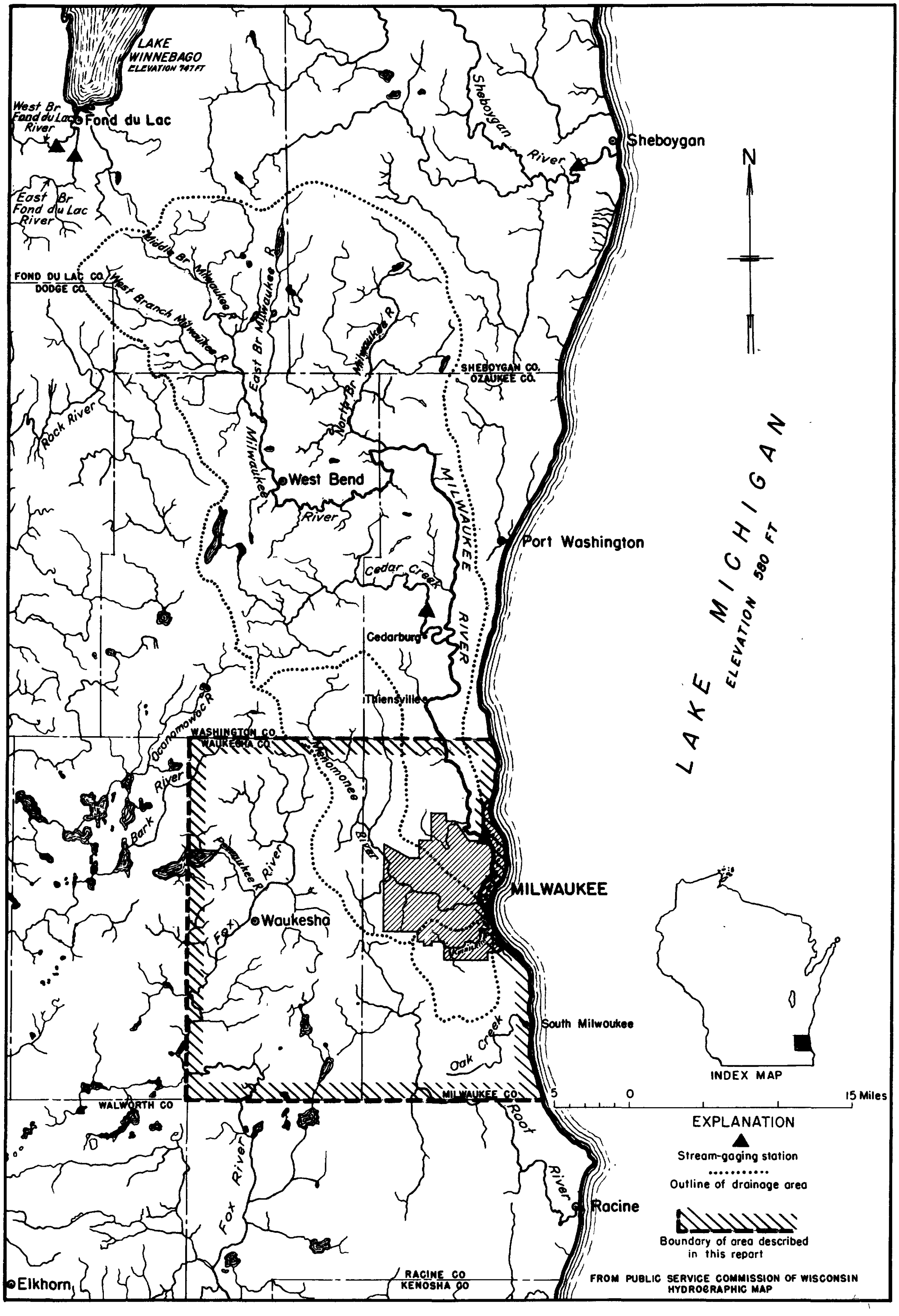

Figure 1.—Map of Milwaukee area showing gaging stations.

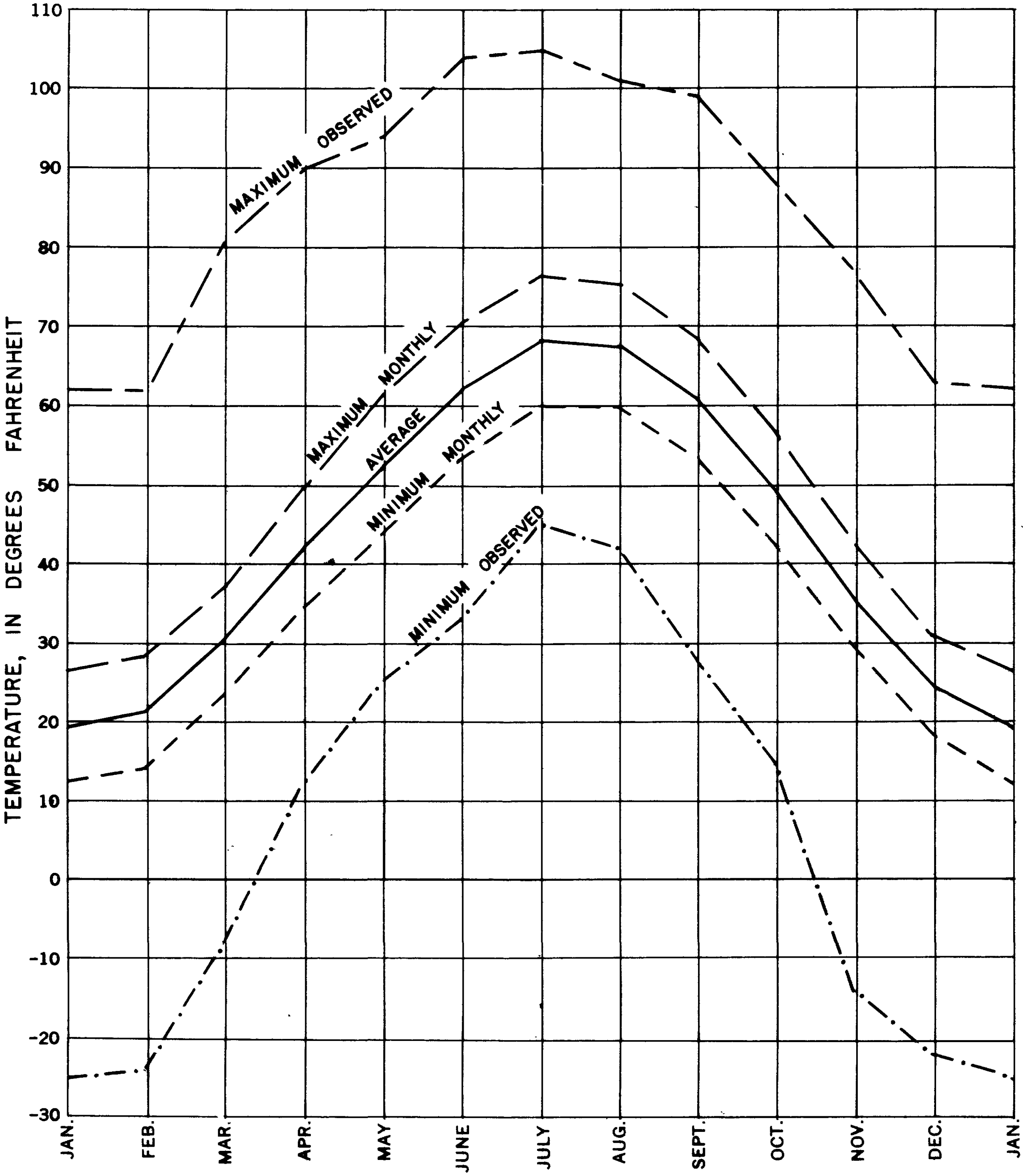

Figure 2.—Air temperatures at Milwaukee, 1871-1948.

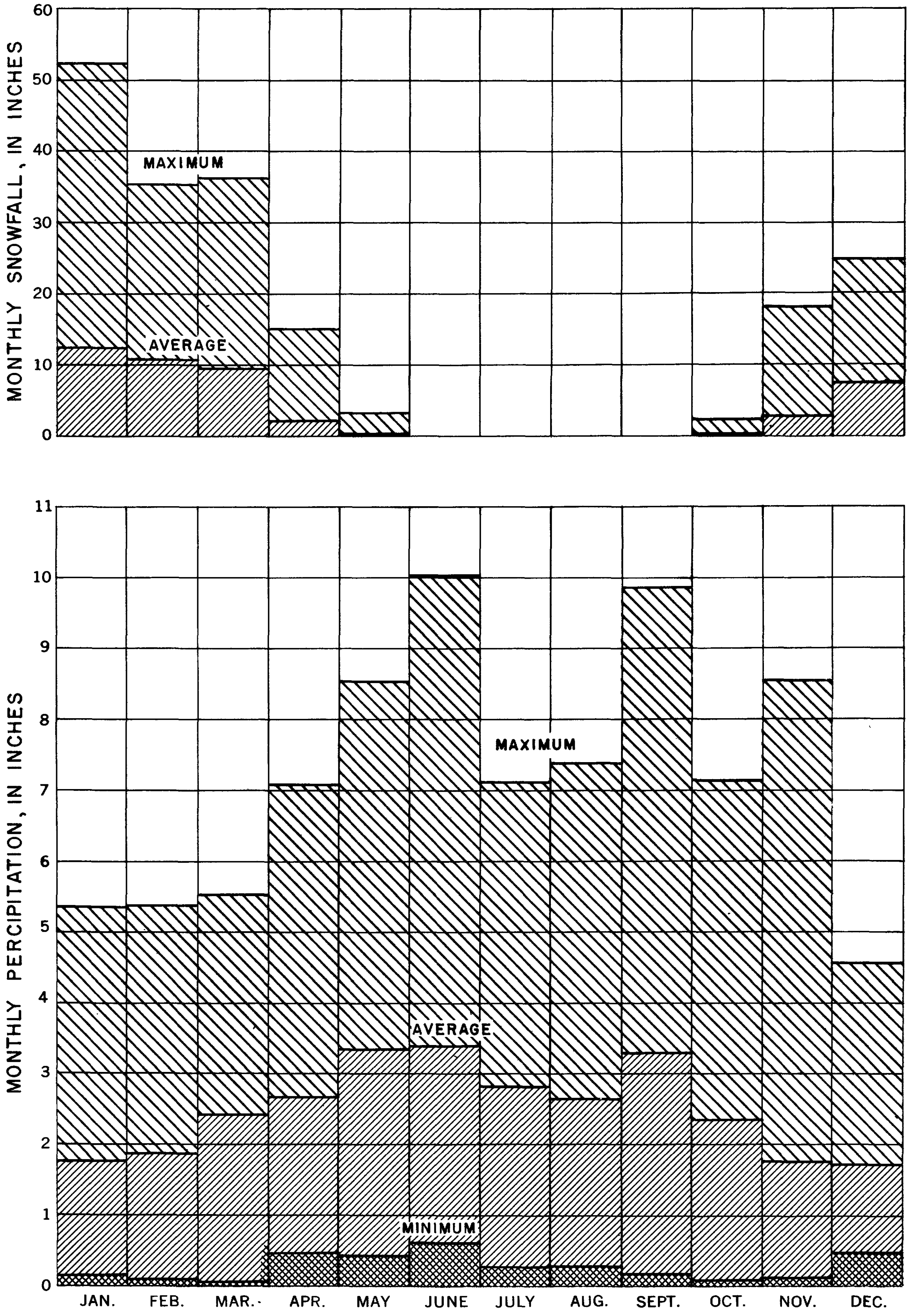

Figure 3.—Precipitation at Milwaukee, 1871-1948.

by several railroads, highways, and airlines. In 1950 the total traffic through the port was 8.9 million tons of which 65 percent was coal and much of the remainder was automobile-ferry traffic. At the present time (1952) there is a downward trend in coal shipment and an upward trend in the shipment of petroleum products through the port. Milwaukee serves as a receiving center and transshipment point for coal, petroleum products, construction material, grain, food stuffs, and other commodities. The principal industries are engaged in the manufacture or processing of auto frames and bodies, gas engines, cement machinery, heavy machinery, chemicals, food products, candy, beer, malting, and meat packing.

SOURCES OF WATER

The supply of fresh water available is dependent upon precipitation. Water in the lakes, streams, and beneath the land surface is moving through a phase of the hydrologic cycle—the path of water from the atmosphere to land and water bodies and back to the atmosphere through evaporation.

The weathered zone of the earth's surface constitutes a vast regulating reservoir for the water that falls on the land. At times the rate of precipitation exceeds the rate at which water can enter the soil, and part of the precipitation flows over the ground into the streams. The water that percolates into the ground replenishes the shallow zone of soil water that supports vegetation, and the water not held in this zone continues to move by gravity to the zone of saturation, the upper surface of which is the water table. The ground water reservoir is not static, but inflow and outflow constantly seek to reach equilibrium—adding more flow to the streams when storage is high, and less flow after periods of little or no infiltration from precipitation.

The water resources available in the Milwaukee area consist of Lake Michigan, several small streams, and ground water. Because of the great volume of water stored in Lake Michigan, local precipitation is of less importance in the water supply of the area than in many other localities.

SURFACE WATER

The great volume of good quality, cold, fresh water of Lake Michigan-Huron is available to the Milwaukee area in an almost unlimited quantity. This very favorable condition has led to the exploitation of the lake water to satisfy most of the water demand. The lake could easily supply many times the amount of water now used by this industrial highly populated area. Only the enlargement of the systems for obtaining, treating, and distributing the water would be required to greatly expand utilization. Several rivers and streams form a secondary source of surface water supply. The Milwaukee, Monomonee, and Kinnickinnic Rivers have been developed near their mouths as harbors or navigation terminals for Great Lakes commercial traffic. In their upper reaches parkways and residential areas utilize the recreational and scenic aspects of the rivers.

Lake Michigan-Huron

Lake Michigan, 22,400 square miles in extent, lies in a basin 69,040 square miles in area. The lake has a maximum depth of 923 feet, is 307 miles long, and is about 85 miles wide near Milwaukee. The Straits of Mackinac, the connection between Lake Michigan and Lake Huron, is so broad and deep that there is no perceptible flow between the lakes; their surfaces stand at the same elevation, making them in effect one lake, referred to as Lake Michigan-Huron. Lake Huron, with a surface area of 23,010 square miles, lies in a basin of 72,420 square miles. The navigation season between Lakes Michigan and Huron, which is governed by ice conditions in the Straits of Mackinac, has averaged April 12 to December 15.

Navigation.—Milwaukee Harbor, at the mouth of the Milwaukee, Monomonee, and Kinnickinnic Rivers is 85 miles north of Chicago Harbor. It is made up of an outer harbor which is well protected by a breakwater more than 3 miles long, a river entrance channel which is protected by parallel piers, and an inner commercial harbor which is maintained by the city. Outer harbor channels and the lower navigable reaches of the rivers require periodic dredging for depth and width maintenance. Depths in the outer harbor, aside from the dredged channels, vary from 6 to 10 feet near shore to 28 to 35 feet near the outer breakwater. Depths of 22 to 32 feet are reached a quarter of a mile offshore in the area south of the river mouth; depths more than 21 feet are reached half a mile offshore north of the river. The protected outer harbor has an area of 1,200 acres, of which 850 acres has depths from 18 to 30 feet. Dredging to a depth of 26 feet would be necessary to accommodate oceangoing ships that might be expected with the construction of the proposed St. Lawrence Seaway. Terminal facilities of the harbor include slips, four car-ferry slips, many wharves, and warehouses. Future development is expected along the outer harbor, two municipal piers having already been completed.

Lake levels.—The level of Lake Michigan is subject to considerable natural fluctuation, seasonal and annual depending on the runoff, and lesser pulsations due to wind storms or sharp differences in barometric pressures. Since 1860 the U. S. Lake Survey, Corps of Engineers, has made systematic and continuous measurements of lake levels. Since 1900 the average elevation of the lake surface has been 579.81 feet above mean tide at New York. During the same period the mean surface of Lake Michigan was 22.48 feet below the surface of Lake Superior. During the period of record, 1860-1951, the highest monthly average was 583.68 feet in June, 1886; the lowest 577.35 feet in February 1926. Short period fluctuations of several feet lasting as much as several hours are quite common during storms. When short-period fluctuations are superimposed on general levels excessive highs or lows may result. The seasonal and annual fluctuations are caused by variations in precipitation and evaporation, and long term changes may be caused by crustal movement of the earth in the Great Lakes area affecting the Lake Michigan-Huron outlet. High seasonal stages occur in summer or early fall, usually July; lows occur in winter, mostly in February. The

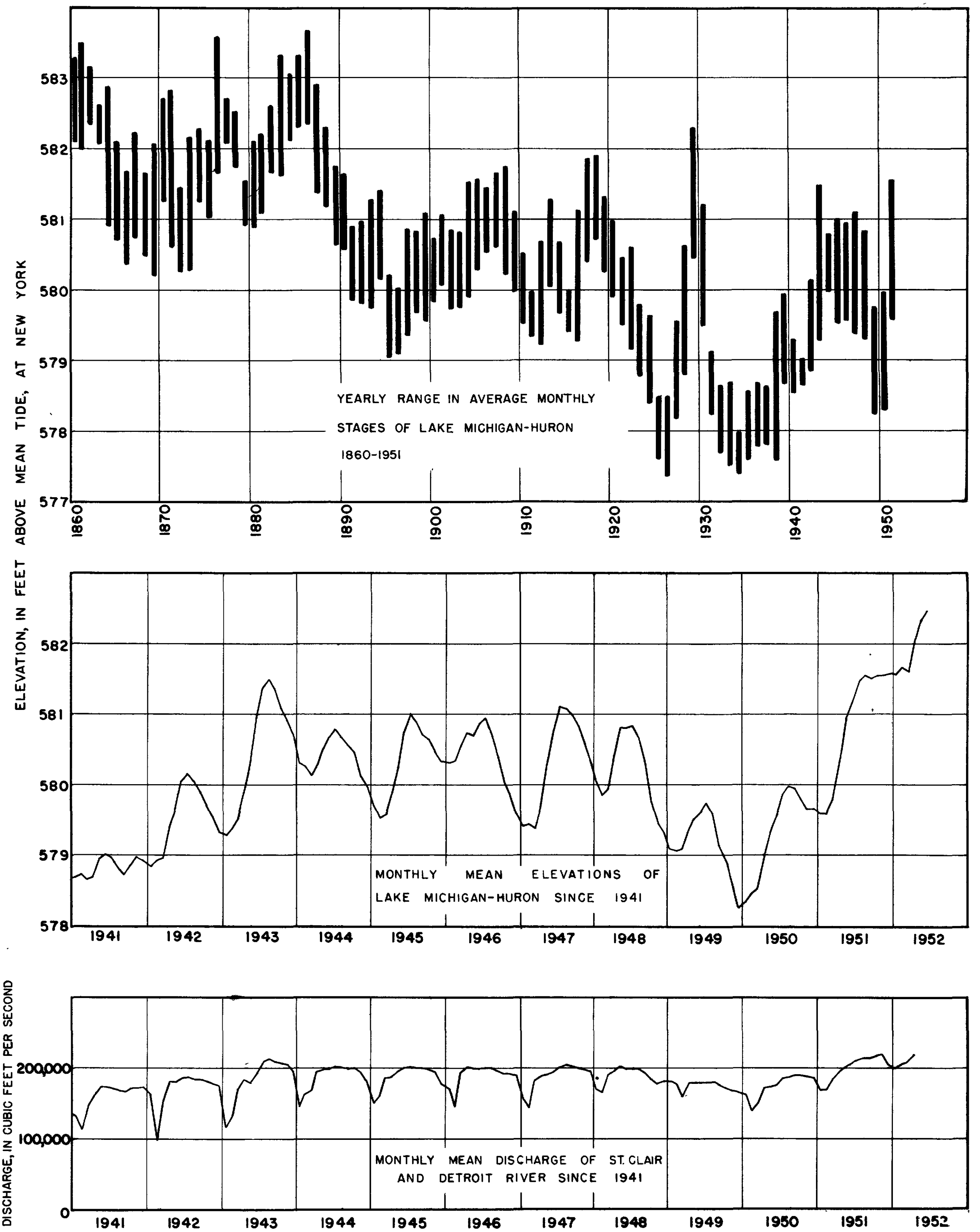

Figure 4.—Water levels of Lake Michigan-Huron and discharge of St. Clair and Detroit Rivers. (From U. S. Lake Survey records.)

average seasonal range is 1.1 feet. The studies of the U. S. Lake Survey have failed to support theories of cycles in lake levels over various periods of years. Diversions and control structures have a net total effect on lake level of only a few inches, extremely small when compared to long period fluctuations as much as 6 feet, or short period local fluctuations which are even greater. Figure 4 shows the yearly range of high and low months from 1860 to 1951 and monthly elevations since 1941. The average inflow, since 1900, to Lake Michigan-Huron from Lake Superior has been 73,200 cfs. During the same period the outflow from Lake Michigan-Huron has been 181,400 cfs—175,100 cfs through the St. Clair River and an average diversion of 6,300 cfs through the Chicago Sanitary Canal. Diversion through the Chicago Sanitary Canal, exclusive of pumpage for domestic use, has been reduced to 1,500 cfs in compliance with an order of the Supreme Court of the United States. There is no definite control section in St. Clair River. The entire system is the control. A hydrograph of the St. Clair and Detroit Rivers is shown in figure 4.

Beach erosion.—The Lake Michigan shoreline in the Milwaukee area is characterized by narrow beaches backed by glacial bluffs except in the harbor area. Here the river valleys form a flat lake shore. Beach and shore erosion is considerable outside the breakwaters, especially during periods of high lake level. The general wind effect upon the lake is such as to cause a drift along the western shoreline in a southerly direction making it difficult to maintain sand beaches. The city and county have cooperated in the riprapping of shorelines, construction of breakwaters, jetties, seawalls, and cribs in an effort to control erosion. This work is most effective where a long stretch of shoreline has been protected according to an integrated plan. Ice damage is very small.

Quality.—Lake Michigan provides a source of water of good chemical quality which does not vary greatly from season to season or from year to year. The water from this lake may be used with very little or no treatment by some industries, and extensive treatment is not required by many others. The water contains a moderate amount of dissolved solids and is low in suspended solids, as shown in table 1. The alkalinity (as $CaCO_3$) of the lake water ranged from a minimum of 107 to a maximum of 118 ppm for the 5-year period, 1946-50. The average alkalinity during 1950 was 111 ppm. The water is moderately hard, averaging 133 ppm during 1950. This total average hardness consisted of 111 ppm of carbonate hardness and 22 ppm of noncarbonate hardness.

The maximum raw water temperatures at the Milwaukee public supply intake in Lake Michigan for the years 1946-50 were 67.5, 73.9, 68.0, 71.2, and 65.0 F. The frequency with which a given raw water temperature was equaled or exceeded during this period is shown graphically in figure 5. For example, the water temperature equaled or exceeded 60 F 6 percent of the time, or on the average the temperature was 60 F or greater on 22 days per year. The temperature of the raw water at the Milwaukee intake depends to some extent upon the wind direction, since offshore winds bring in water of lower temperature.

Table 1.—Chemical analyses of the Milwaukee public water supply, Lake Michigan, treated and untreated water, 1950

(From Annual Summary of Laboratory Results, 1950, Milwaukee Water Works)

[Parts per million]

	U. S. Public Health Service Standards [a]	Untreated Water			Treated Water		
		March	May	November	March	May	November
Temperature (F)		32.5	41.7	45.2	32.7	42.2	46.1
Silica (SiO_2)		8.1	5.2	4.1	3.6	3.5	3.4
Total Iron (Fe)	b 0.3	.05	.06	.01	.00	.02	.00
Calcium (Ca)		35.5	34.2	34.2	35.8	33.9	33.9
Magnesium (Mg)	125	11.6	11.4	11.0	11.1	10.9	10.8
Sodium and Potassium (as Na)		5.5	5.5	4.6	6.1	5.3	4.5
Sulfate (SO_4)	250	20.3	17.1	16.2	24.5	22.6	21.6
Chloride (Cl)	250	4.5	4.5	5.5	5.5	5.5	6.5
Nitrate (NO_3)		.71	.66	.53	.71	.71	.53
Total solids	c 500	157	146	160	151	147	157
Dissolved solids		151	145	155	-	-	-
Hardness as $CaCO_3$							
Total		136	132	131	135	130	129
Noncarbonate		24	21	22	30	27	27
Alkalinity as $CaCO_3$		112	111	109	105	103	102
pH		7.95	8.00	8.22	7.29	7.30	7.52
Turbidity		4.0	1.1	.3	.0	.0	.0

a Drinking water standards, 1946.
b Iron and manganese together.
c If such water is not available, a total solids content of 1,000 ppm may be permitted.

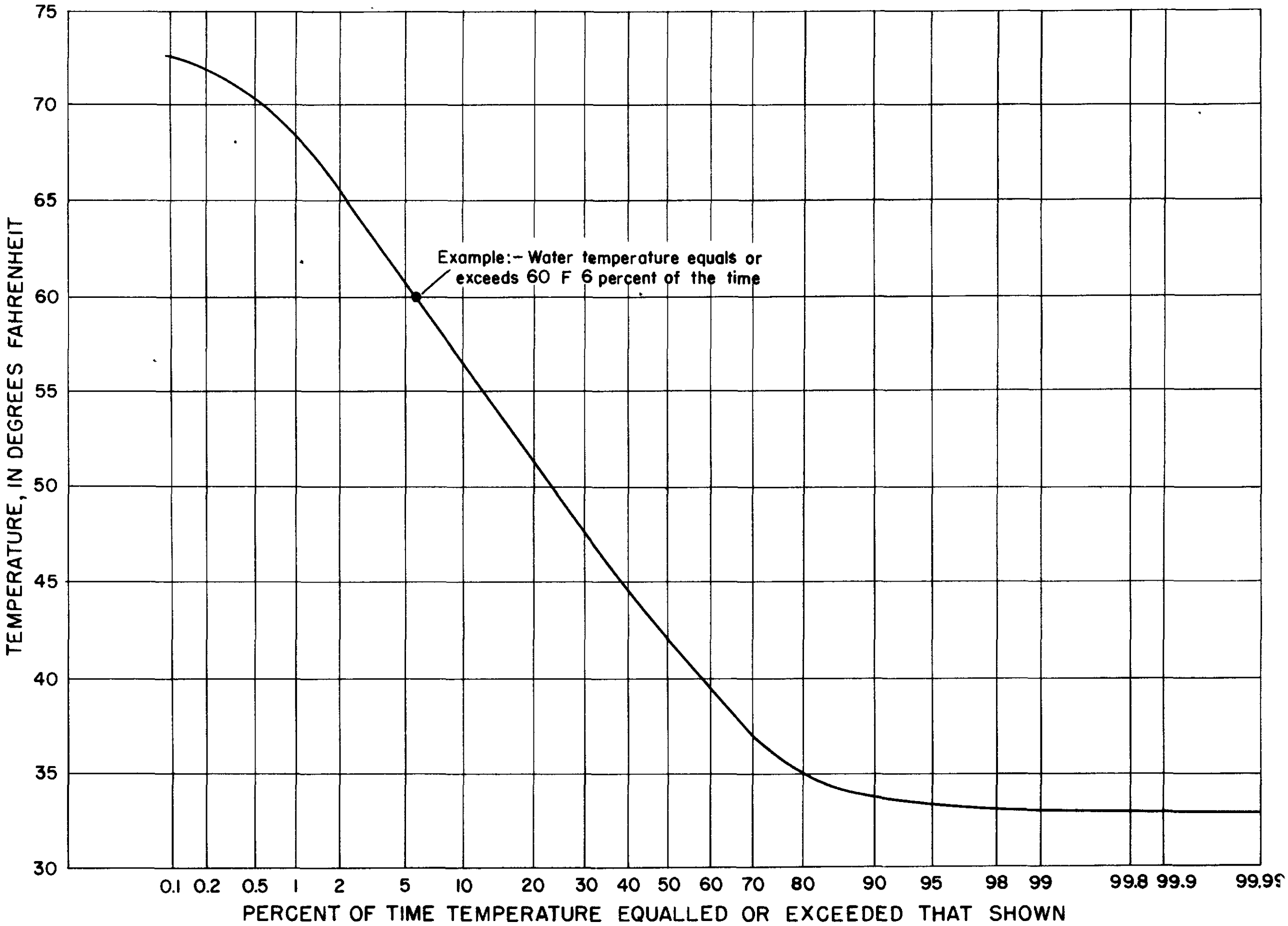

Figure 5.—Cumulative frequency distribution of daily temperatures of untreated water of Milwaukee water works, 1946-50.

Table 2.—Densities of coliform organisms, Lake Michigan, Milwaukee County, June, July, and August 1948

(From Tri-State survey of Lake Michigan waters, by U. S. Public Health Service)

[Most probable number per 100 milliliters]

Sample point	Location	Maximum	Minimum	Median	Log average
1	Fox Point, near Doctors Park	2,400	a 3	43	54
2	Klode Beach	1,400	a 3	43	64
3	Shorewood, Atwater Beach	1,100	a 3	93	113
4	Bradford Beach	24,000	3	460	344
5	Opening in north harbor breakwater	46,000	93	2,400	1,550
6	West opening in south harbor breakwater	110,000	91	2,400	2,130
7	South Shore Park Beach	11,000	43	930	1,080
8	Grant Park Beach	4,600	3.6	930	655

a Most probable number indeterminate but less than value given.

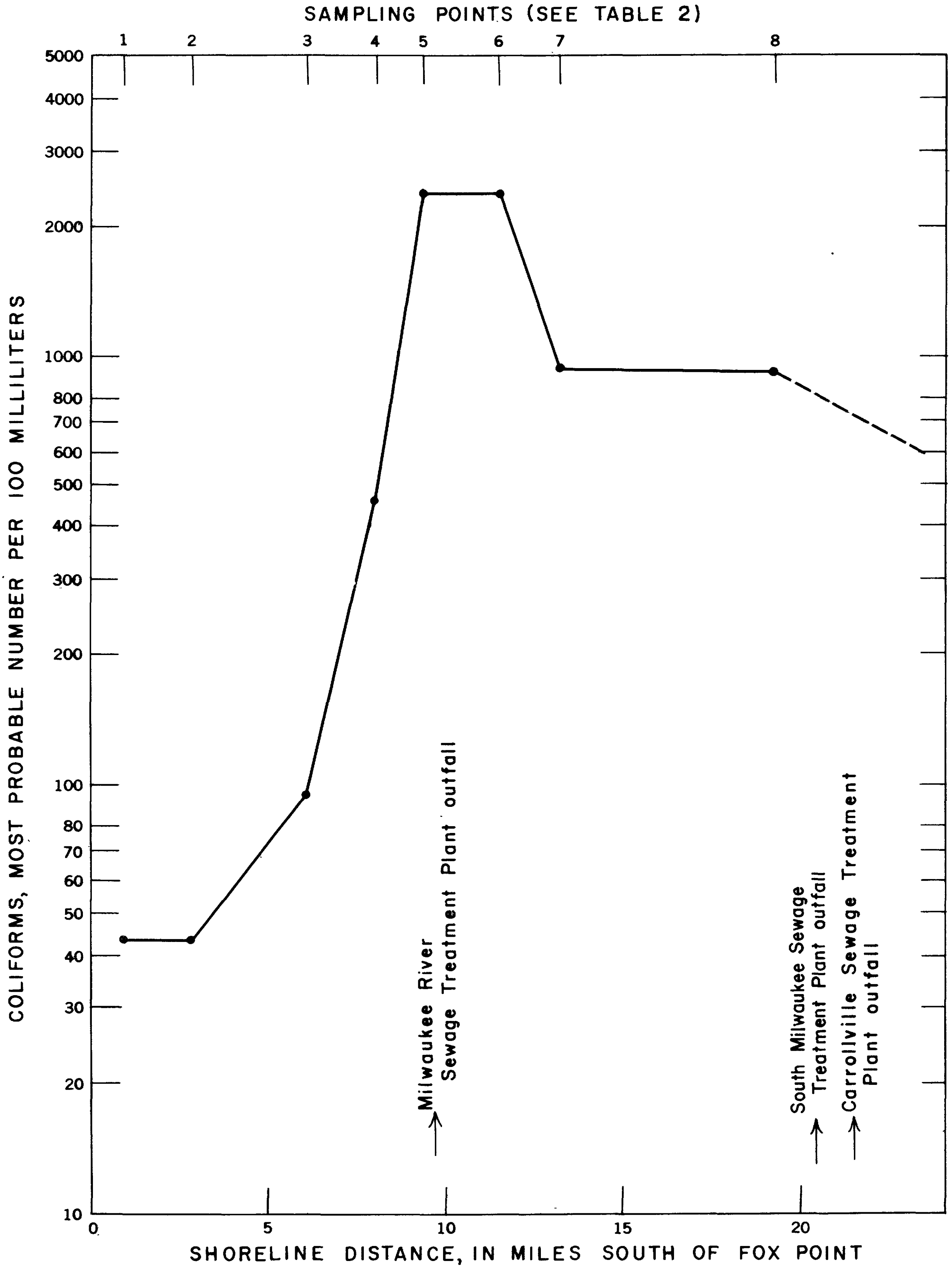

Figure 6.—Medians of MPN values of coliforms, Lake Michigan in Milwaukee County, June, July, and August 1943.

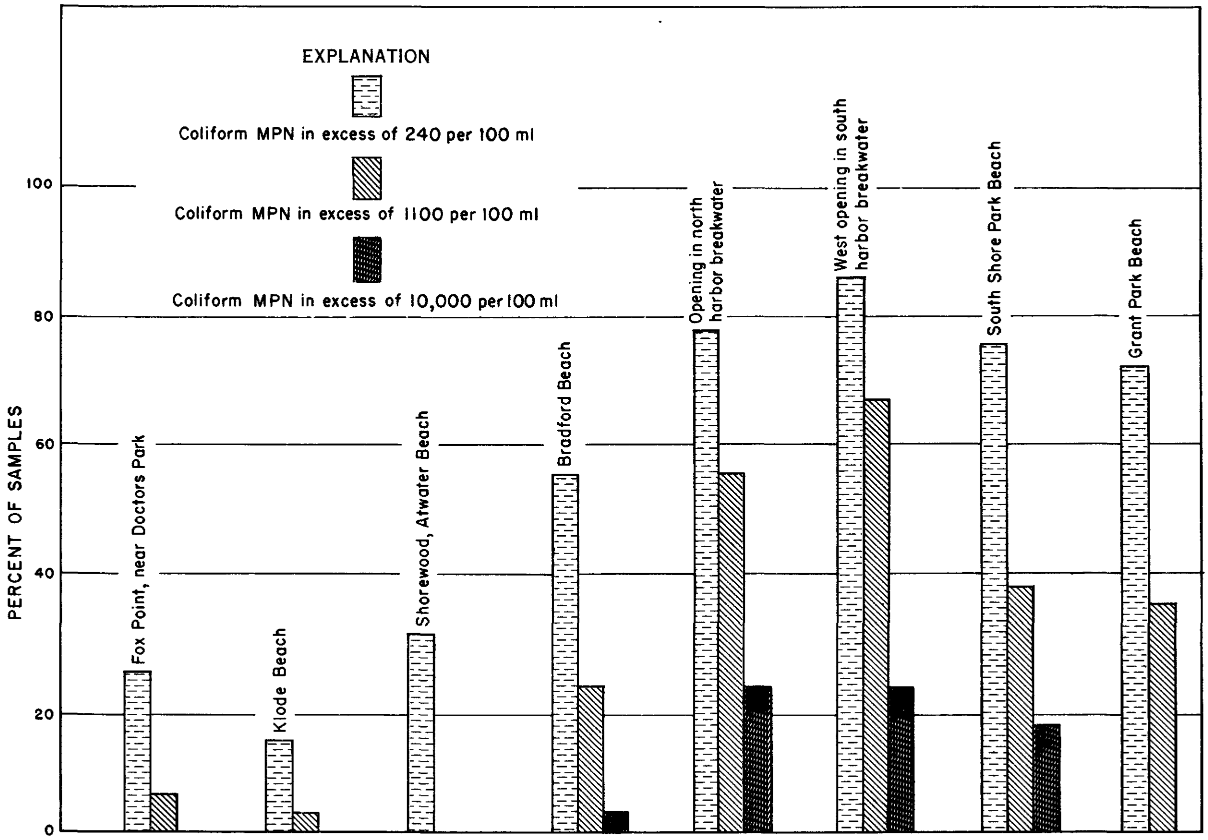

Figure 7.—Density of coliform organisms, Lake Michigan in Milwaukee County, June, July, and August 1948. (From Tri-State survey of Lake Michigan waters, U. S. Public Health Service, 1948.)

Table 3.—Results of bacteriologic and microscopic examinations of untreated water, Lake Michigan, and treated water, Milwaukee public supply, 1950

(From Annual Summary of Laboratory Results, 1950, Milwaukee Water Works)

	Agar plate count 37 C. - 24 hours (Number per ml)				Coliform organisms (MPN per 100 ml)				Nonpathogenic organisms[a] (Number per ml)			
	No. of samples	Max.	Min.	Avg.	No. of samples	Max.	Min.	Avg.	No. of samples	Max.	Min.	Avg.
Raw water	1,094	1,100	0	28	1,094	b 16,000	0	142.4	253	2,960	71	693
Finished water	1,094	17	0	1	2,182	0	0	0	....	....	....	....
Water in distribution system	1,593	42	0	1	2,973	2	0	0	....	....	....	....
Reservoir outlet pipe	....	....	....	....	....	....	....	....	52	2	0	1
Reservoir surface	....	....	....	....	....	....	....	....	42	2	0	1

a Diatomaceae, chlorophyceae, cyanophyceae, protozoa.

b Maximum occurred in March; minimum for the month, 0 MPN per 100 ml; average for the month, 569.7 MPN per 100 ml.

The Milwaukee, Menomonee, and Kinnickinnic Rivers discharge raw sewage into Lake Michigan through Milwaukee Harbor during times of heavy rainfall. Occasional overload at the Jones Island sewage disposal plant of the Metropolitan Sewerage District results in bypass of raw sewage to the lake. At times other municipalities divert raw sewage to the lake. Industrial wastes, generally treated but some untreated, are discharged to the lake directly or through tributaries. Principal pollution is in Milwaukee Harbor. Varying amounts of pollution have been present in the lake at the Milwaukee intake, 5 miles north of the harbor entrance, but the coliform count has not exceeded the limits of established standards for such a raw supply. Wind and weather conditions cause a variation in intensity and direction of the movement of pollution out of Milwaukee Harbor. The normal lake current is to the south, and the shore waters north of the harbor are generally better in sanitary quality than the waters south of the harbor.

Nonpathogenic organisms that might interfere with the use of the water by some industries are not present in the lake water in amounts great enough to present a serious problem in its use. The results of bacteriologic examination of shore waters in this area are listed in table 2 and are depicted graphically in figures 6 and 7. The results of bacteriologic and microscopic examination of the Lake Michigan water at the Milwaukee public supply intake are listed in table 3. Maximum, minimum, and average sanitary chemical quality of untreated and treated water from the Milwaukee public water supply for 1950 are shown in table 4.

Table 4.—Maximum, minimum, and average sanitary chemical quality of untreated and treated waters, Milwaukee public water supply, 1950

(From Annual Summary of Laboratory Results, Milwaukee Water Works)

[Parts per million]

	Untreated water Lake Michigan			Treated water Milwaukee public supply		
	Max.	Min.	Avg.	Max.	Min.	Avg.
Temperature (F)	51.0	32.4	37.3	52.5	32.5	37.6
Total iron (Fe)	.14	.00	.043	.01	.00	.005
Chloride (Cl)	5.0	4.0	4.4	6.5	5.0	5.6
Total solids	170	140	152	165	142	151
Ignition loss	23	3	12	25	6	13
Total hardness as $CaCO_3$	132	124	129	130	125	128
Alkalinity as $CaCO_3$	112	109	111	105	101	104
pH	8.20	7.90	8.06	7.75	7.20	7.43
Turbidity	5.0	.4	1.4	.0	.0	.0
Dissolved oxygen	13.9	10.7	13.0	14.1	10.9	13.2
Free carbon dioxide	.0	.0	.0	1.8	1.0	1.3
Free ammonia	.038	.000	.004	.104	.020	.058
Albuminoid ammonia	.074	.034	.047	.050	.020	.033
Nitrite (as N)	.005	.000	.001	.000	.000	.000
Nitrate (as N)	.25	.12	.15	.19	.09	.15

Milwaukee River

The Milwaukee River, the largest river in the area, empties into Lake Michigan at Milwaukee. The headwaters are in the gravelly hills of the kettle moraine about 8 miles from the south end of Lake Winnebago (fig. 1). The river parallels Lake Michigan's shoreline at a distance of less than 4 miles for the last 35 miles. The river drains an area of slightly more than 661 square miles (exclusive of the Menomonee River) of which about one-tenth lies within Milwaukee County. A little of the hilly headwater country is timberland. The remainder of the watershed is undulating and gently sloping fertile agricultural land. Falling in a relatively uniform and steep grade, the river descends 437 feet in the last 82 miles. The stream bed is on solid rock, chiefly dolomite, over a part of its course. Artificial storage on the river is now negligible. Power development facilities at a number of small feed mills and electrical and industrial plants have been mostly abandoned and the dams left to deteriorate. The larger of two detention reservoir sites in the upper reaches of the basin could provide 116,000 acre-feet of storage capacity. The river has been dredged to 21 feet for almost 3 miles above the mouth. Above the dredged section of the river, park areas and boulevards have been developed under the control of the Milwaukee County Regional Planning Department and County Park Commission.

Discharge.—The U. S. Geological Survey operates 2 gaging stations in the Milwaukee River basin, 1 on the Milwaukee River 6 miles above the mouth and the other on Cedar Creek near Cedarburg. Discharge of the Milwaukee River at Milwaukee averaged 386 cfs during the 37-year period, 1915-51. The hydrograph for the Milwaukee River for the water year 1949-50, a fairly typical year, is shown in figure 8. As a result of regulation there was no flow on September 8, 1943. Table 5 lists minimum instantaneous and minimum daily discharges for the water years 1944-51.

There are several graphic methods of showing the flow characteristics of a stream. The flow-duration curve (fig. 9) shows the percentage of time during which a specified daily flow is equaled or exceeded. It may be used as a probability curve to estimate the probable recurrence of a specified discharge. A second method of showing the low-flow characteristics of a stream is by use of curves showing the longest period of time during which the discharge was less than a specified amount (fig. 10). A third method of showing the low-flow characteristics of a stream is by use of drought-frequency curves (fig. 11).

In addition to giving graphically the general flow characteristics of the streams, these curves are valuable for use in solving problems of plant location and operation. For example, assume that it is desirable to locate a manufacturing plant on Milwaukee River at Milwaukee. Construction of a storage dam is not contemplated. A flow of 27 cfs is required to operate the plant. It is necessary to know the average number of days each year when there will be a shortage of water. Using the flow duration curve (fig. 9), it is seen that a flow equal to or exceeding 27 cfs will prevail during 98 percent of the time. On the average there would be sufficient water 98 percent of the year and a shortage for only 7 days per year.

It may be possible to operate the plant for short periods on less than 27 cfs. However, it is necessary to know the maximum number of consecutive days, even in unusual years, when the flow will be less than 27 cfs. Figure 10 shows that the flow of Milwaukee River may be expected to be less than 27 cfs for not more than 36 consecutive days.

It may be desirable to know how frequently the flow will be less than 27 cfs. The drought-frequency curve (fig. 11) shows that daily flow will fall below 27 cfs at average intervals of 2 years and that the average flow for 7 consecutive days will fall below 27 cfs at average intervals of about 5 years.

Table 5.—Minimum discharge Milwaukee River at Milwaukee, 1944-51

Water year	Minimum instantaneous discharge (cfs)	Date	Minimum daily discharge (cfs)	Date
1943-44	2.0	May 31, 1944	14	June 1, 1944
1944-45	4.7	Nov. 16, 1944	6.2	Sept. 10, 1945
1945-46	9.0	Mar. 29, 1946	21	Aug. 5, 1946
1946-47	4.0	Nov. 15, 1946	30	Oct. 7, 1946
1947-48	8.0	Apr. 10, 1948	26	Sept. 7, 1948
1948-49	0.8	Nov. 18, 1948	16	Sept. 5, 1949
1949-50	4.5	June 23, 24, 1950	6.0	June 24, 1950
1950-51	1.3	Mar. 30, 1951	15	Nov. 14, 1950

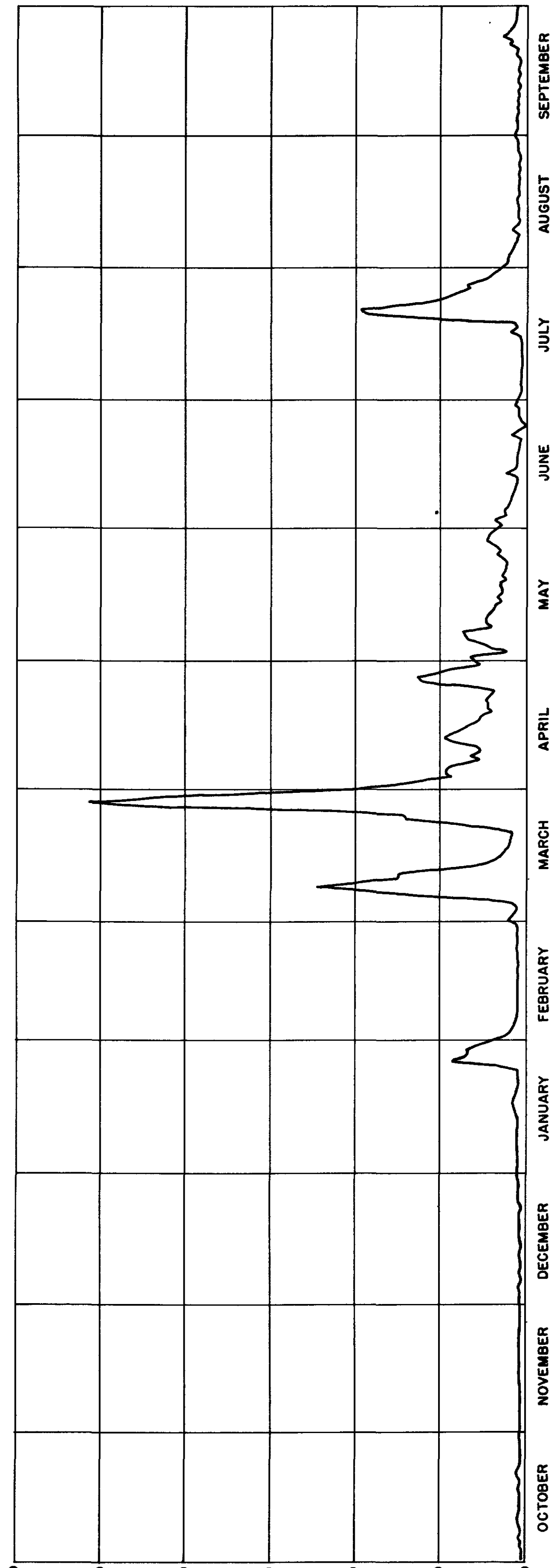

Figure 8.—Hydrograph of Milwaukee River at Milwaukee, 1949-50.

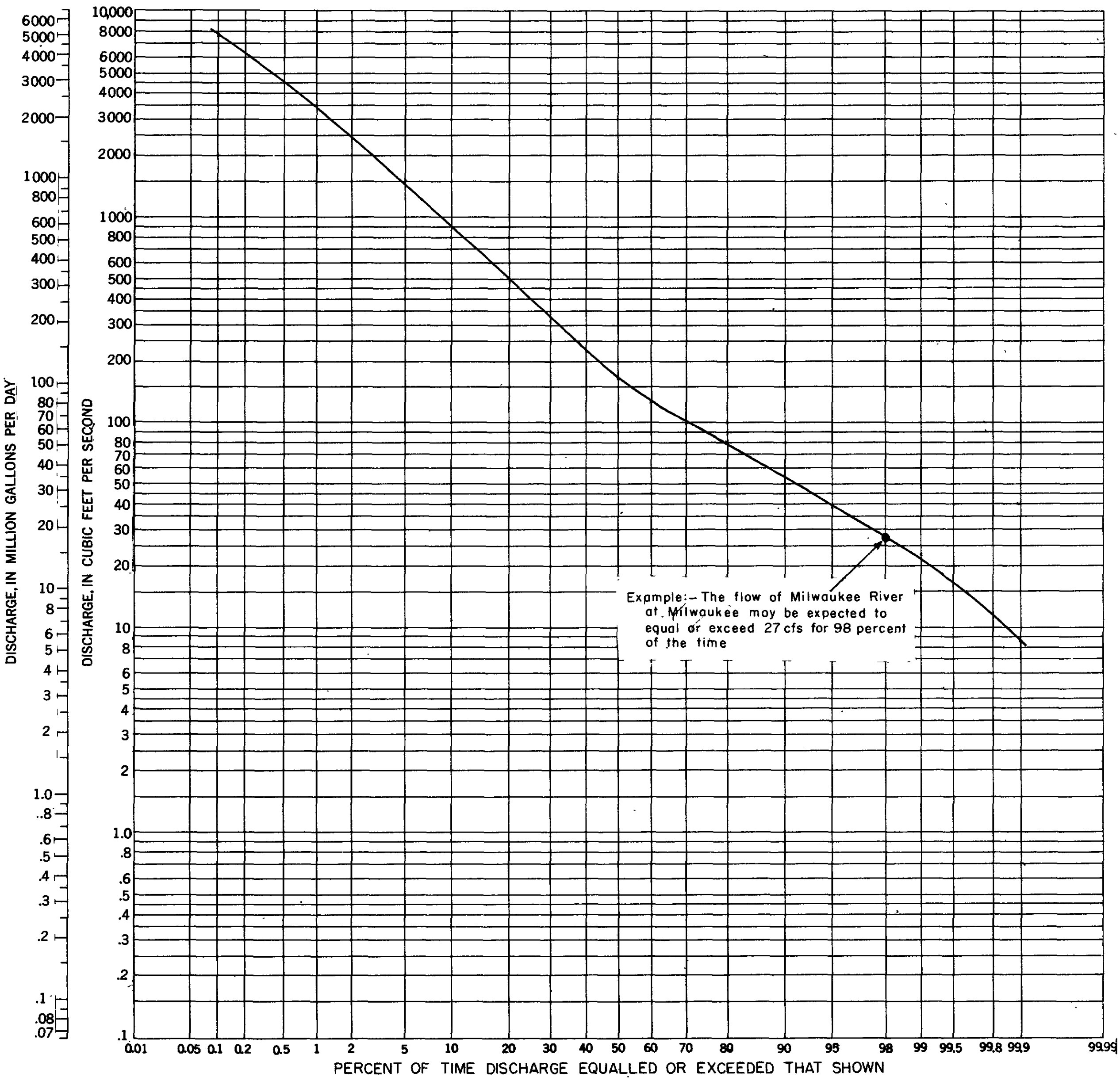

Figure 9.–Flow-duration curve for Milwaukee River at Milwaukee, 1915-51.

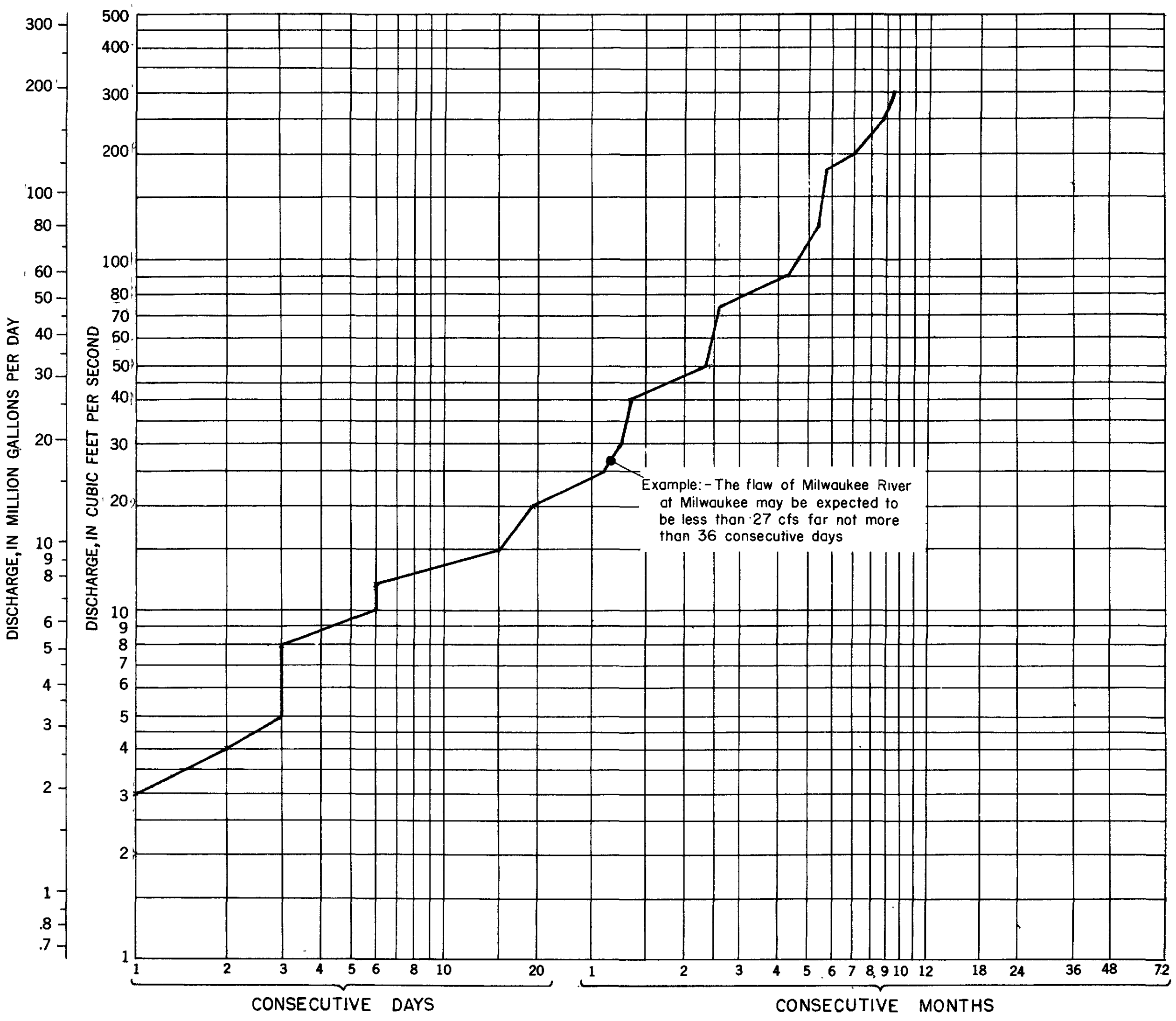

Figure 10.—Maximum period of deficient discharge of Milwaukee River at Milwaukee, 1915-51.

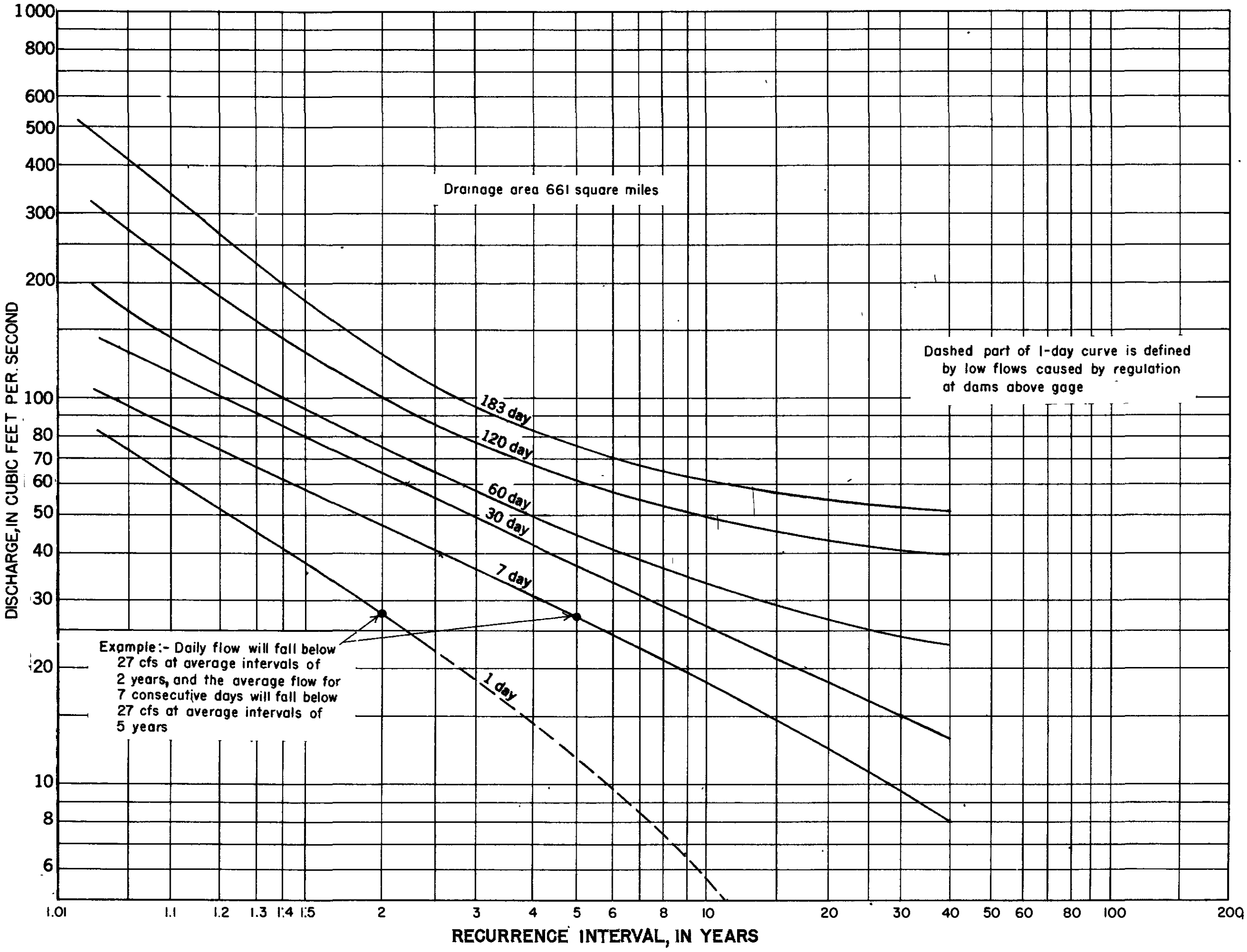

Figure 11.—Drought-frequency graphs for Milwaukee River at Milwaukee, 1915-52.

Floods.—The greatest flood during the period of record was that of March 1918, which reached a peak of 15,100 cfs. In January and February the equivalent of 5.43 inches of water fell on the basin in the form of snow. On the 13th and 14th of March, 0.83 inches of rain fell, which combined with rapidly rising temperatures on the 16th and accelerated runoff when the ground was still frozen. On March 16 the river was discharging about 3,000 cfs. On March 20 it reached a peak of 15,100 cfs, and by March 26 the discharge had decreased to 2,000 cfs. Major floods on the Milwaukee River are listed in table 6.

Table 6.—Major floods on Milwaukee River at Milwaukee, 1915-51

Date	Discharge (cfs)
Mar. 20, 1918	15,100
Aug. 6, 1924	14,800
Mar. 15, 1929	10,800
Mar. 19, 1948	8,080
Feb. 12, 1938	7,360
Apr. 7, 1923	6,820
Feb. 21, 1937	6,640
June 24, 1940	6,570
June 17, 1920	6,470
Mar. 15, 1946	6,330

The flood frequency curve (fig. 12) may be used to predict the probability of the recurrence of floods of a given magnitude. However, it must be remembered that the data have been obtained over a very short period of time, 37 years. Until long-period records are available, flood frequency prediction on the basis of these curves must be done carefully, keeping in mind the short period of time that data have been collected. The Wisconsin State Planning Board, in a study made in June 1940 of floods in the Milwaukee River basin, estimated the size of an annual spring flood likely to be equalled or exceeded once in a 100-year period as 16,000 cfs. A study is being made of the possibilities for construction of a diversion channel or tunnel near Thiensville which might control a flood of 21,000 cfs. Two detention reservoirs have been proposed, the larger of which, it is planned, could control a flood of the size of that of 1918.

Present demand for control of floods on the Milwaukee River comes from those occupying lands within that portion of the flood plain in Milwaukee County lying north of Lincoln Park and along Lincoln Creek, a total distance of about 2 miles. Damage to park property is not extensive. Channel improvement and city-zoning regulations have reduced flood damage considerably. Most of the lower part of the river in the commercial and industrial section of the city is in backwater from the lake, and floods on the river have little effect on the stage.

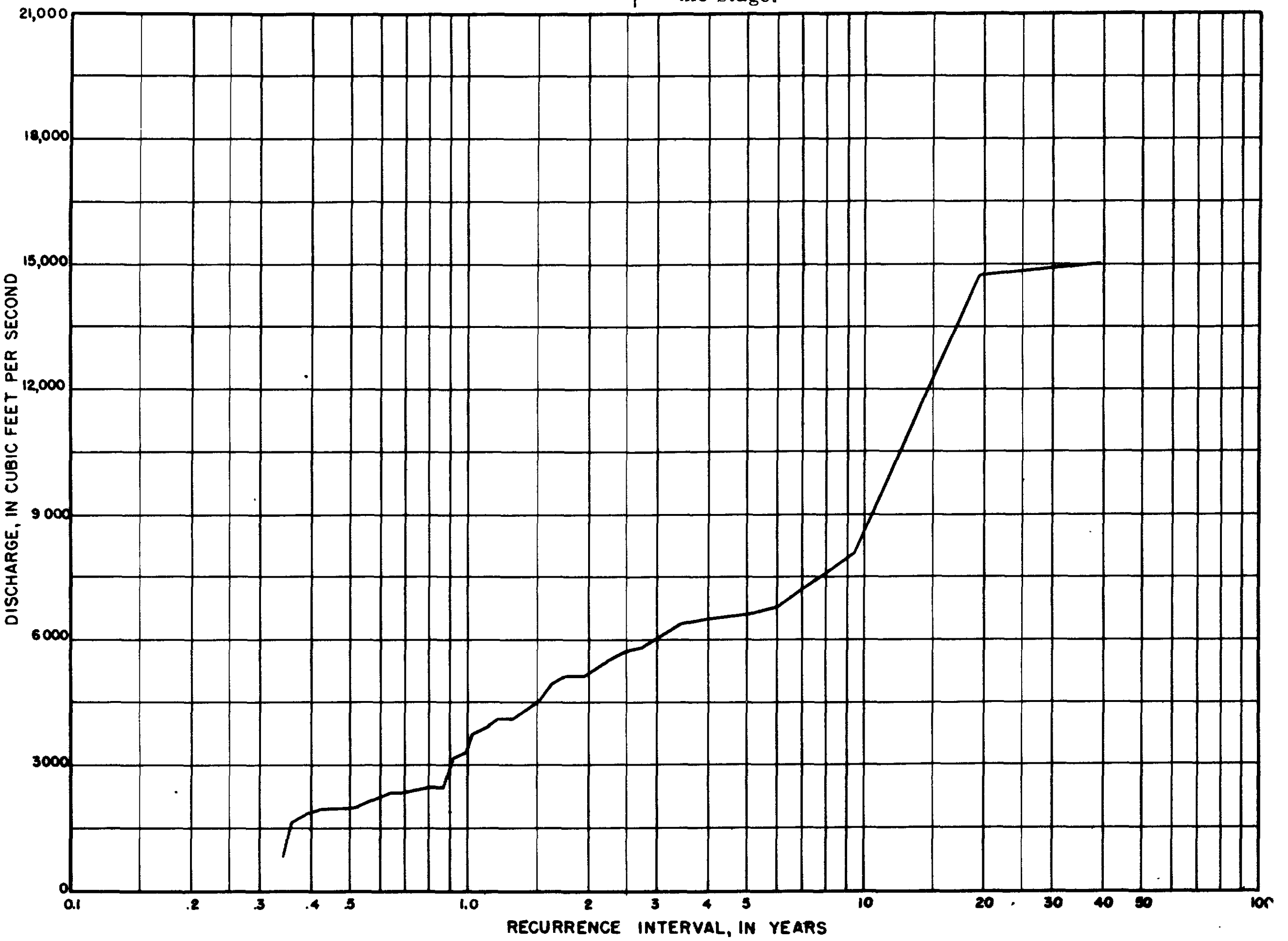

Figure 12.—Flood frequency on the Milwaukee River at Milwaukee, 1914-51.

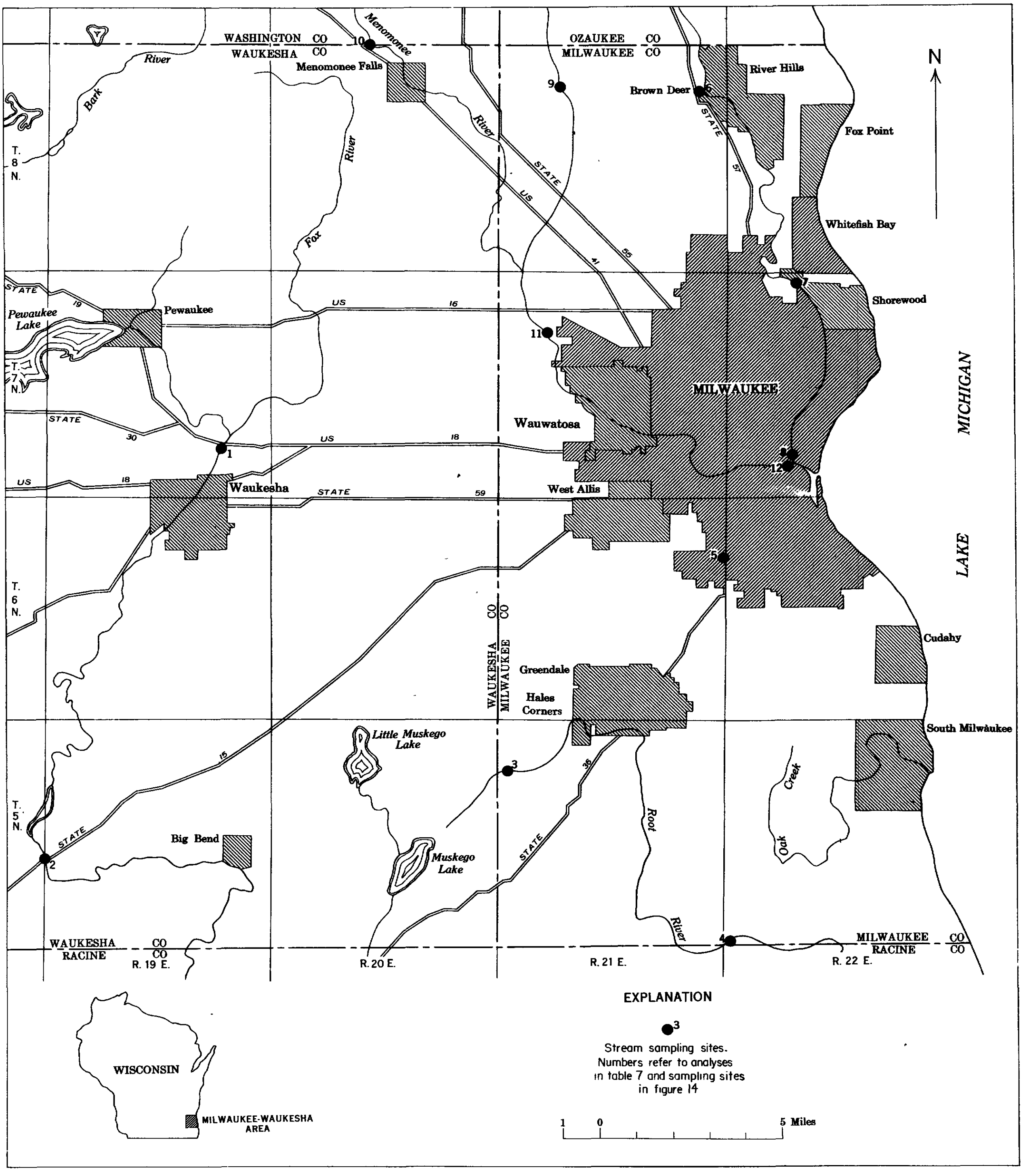

Figure 13.—Map of Milwaukee area showing sampling sites for quality of surface waters.

Table 7. –Chemical quality of water from selected streams in the Milwaukee area

[Analyses, in parts per million, by U. S. Geological Survey]

	Fox River near Waukesha	Fox River near Mukwonago	Root River near Hales Corners	Root River near South Milwaukee	Kinnickinnic River at Milwaukee	Milwaukee River at Brown Deer	Milwaukee River at Estabrook Park Milwaukee	Milwaukee River at Wisconsin Avenue Milwaukee	Little Menomonee River at Granville	Menomonee River near Menomonee Falls	Menomonee River at Wauwatosa	Menomonee River at Milwaukee
Analysis no. a	1	2	3	4	5	6	7	8	9	10	11	12
Date of collection	Oct. 2, 1951	Oct. 2, 1951	Oct. 2, 1951	Oct. 2, 1951	Oct. 2, 1951	Oct. 3, 1951	Oct. 3, 1951	Oct. 3, 1951	Oct. 3, 1951	Oct. 3, 1951	Oct. 4, 1951	Oct. 4, 1951
Discharge (cfs) b	15.2	59.7	.11	5.50	4.76	184	225	c 226	.87	4.37	7.17	d 20.2
Silica (SiO_2)	8.1	9.8	14	6.7	8.4	5.4	5.2	2.9	11	13	4.6	3.4
Iron (Fe) e	.02	.03	.03	.04	.05	.02	.02	.02	.07	.05	.03	.04
Calcium (Ca)	55	68	96	93	105	66	58	48	106	82	70	53
Magnesium (Mg)	37	35	44	44	22	27	30	22	47	37	31	26
Sodium (Na)	6.3	10	10	36	22	6.8	6.8	10	8.2	13	17	11
Potassium (K)	2.9	2.9	5.3	6.2	3.5	3.7	3.7	2.8	4.0	4.7	5.2	3.0
Bicarbonate (HCO_3)	284	314	376	330	212	277	275	226	285	363	249	242
Carbonate (CO_3)	0	0	0	0	0	10	8	0	9	0	0	0
Sulfate (SO_4)	53	54	116	168	194	32	31	33	202	62	102	41
Chloride (Cl)	10	12	13	36	18	9.8	9.8	12	9.8	16	23	13
Fluoride (F)	.1	.1	.1	.4	.4	.1	.1	0	.1	0	.1	.1
Nitrate (NO_3)	3.0	6.1	1.2	3.9	.6	.5	.5	.6	1.7	3.4	1.2	.4
Dissolved solids	334	370	514	581	f 504	314	305	249	568	415	399	281
Hardness as $CaCO_3$												
Total	290	316	420	412	352	276	270	212	459	356	304	238
Noncarbonate	57	56	112	143	179	32	29	25	209	59	98	41
Specific conductance at 25C (micromhos)	519	574	732	829	684	490	484	419	766	650	613	465
pH	7.9	8.0	7.9	7.9	7.8	8.4	8.3	7.8	8.2	7.9	7.9	7.7

a Numbers refer to sampling site in figure 13 and analysis in figure 14.
b Measured at place and time of sample collection unless otherwise noted.
c Point of collection is in Lake Michigan backwater. Discharge was measured at gaging station in Estabrook Park. Stage at Wisconsin Avenue bridge was 0.32 feet.
d Point of collection is in Lake Michigan backwater. Discharge was measured at 34th Street, just above lake backwater.
e Iron in solution when analyzed.
f Hexavalent chromium (Cr), 0.06 ppm.

Quality.—The Milwaukee River provides a calcium-magnesium bicarbonate water of moderate mineral content. Samples collected the same day in 1951 at Brown Deer and at the river mouth showed an increasing ratio of magnesium to calcium in the river, although the concentration of dissolved solids and the total hardness remained about the same throughout that section of the stream. (See table 7 and figs. 13 and 14.) The sulfate and chloride content of this stream was relatively low. The water may be classed as hard; however, the noncarbonate hardness is low. Both treated and untreated domestic and industrial wastes have been discharged into the Milwaukee River north of Milwaukee, but this pollution was dissipated before it reached Milwaukee County. Surveys made in 1948 indicated satisfactory conditions in the river to a point about half a mile below North Avenue, in Milwaukee, while unsatisfactory conditions prevailed downstream from that point. The latter condition was ascribed to the discharge from about 47 combined sewer relief outlets and to backwater from Milwaukee Harbor.

The lower Milwaukee River has been periodically flushed with water from Lake Michigan in an attempt to provide a fair sanitary condition through the maintenance of about 2 ppm of dissolved oxygen in the water.

The city flushes the river daily from May 1 to December 1 with lake water, pumping over 21,823 million gallons in 1951.

Menomonee River

The Menomonee River is tributary to the Milwaukee River just before the Milwaukee River enters Lake Michigan. It drains an area of 129 square miles to the west and northwest of the city. The greater part of the drainage basin is in Milwaukee County. The average fall of the river is 10 feet to the mile, with falls of 60 and 24 feet at Wauwatosa and Menomonee Falls, respectively. The Geological Survey does not operate a gaging station on the Menomonee River. The low water flow is very small. The flow on October 4, 1951, just above lake backwater, was 20.2 cfs. The channel has been dredged for harbor traffic to depths greater than 19 feet for about 2 miles above the mouth. Much of the channel above this point is concrete or rock-lined where it passes through the commercial and industrial section of the city. In its upper reaches, including the small creek tributaries, the river flows through parks, boulevards, and new residential areas.

Quality.—Samples of Menomonee River water were collected at three places in October, 1951. Analyses showed the water to be very hard with a moderate concentration of dissolved solids (see table 7 and fig. 14). The water was a calcium-magnesium bicarbonate type with the ratio of magnesium to calcium increasing downstream. The sulfate content of the Monomonee River water was found to be appreciably higher than that of the Milwaukee River. A sample collected near

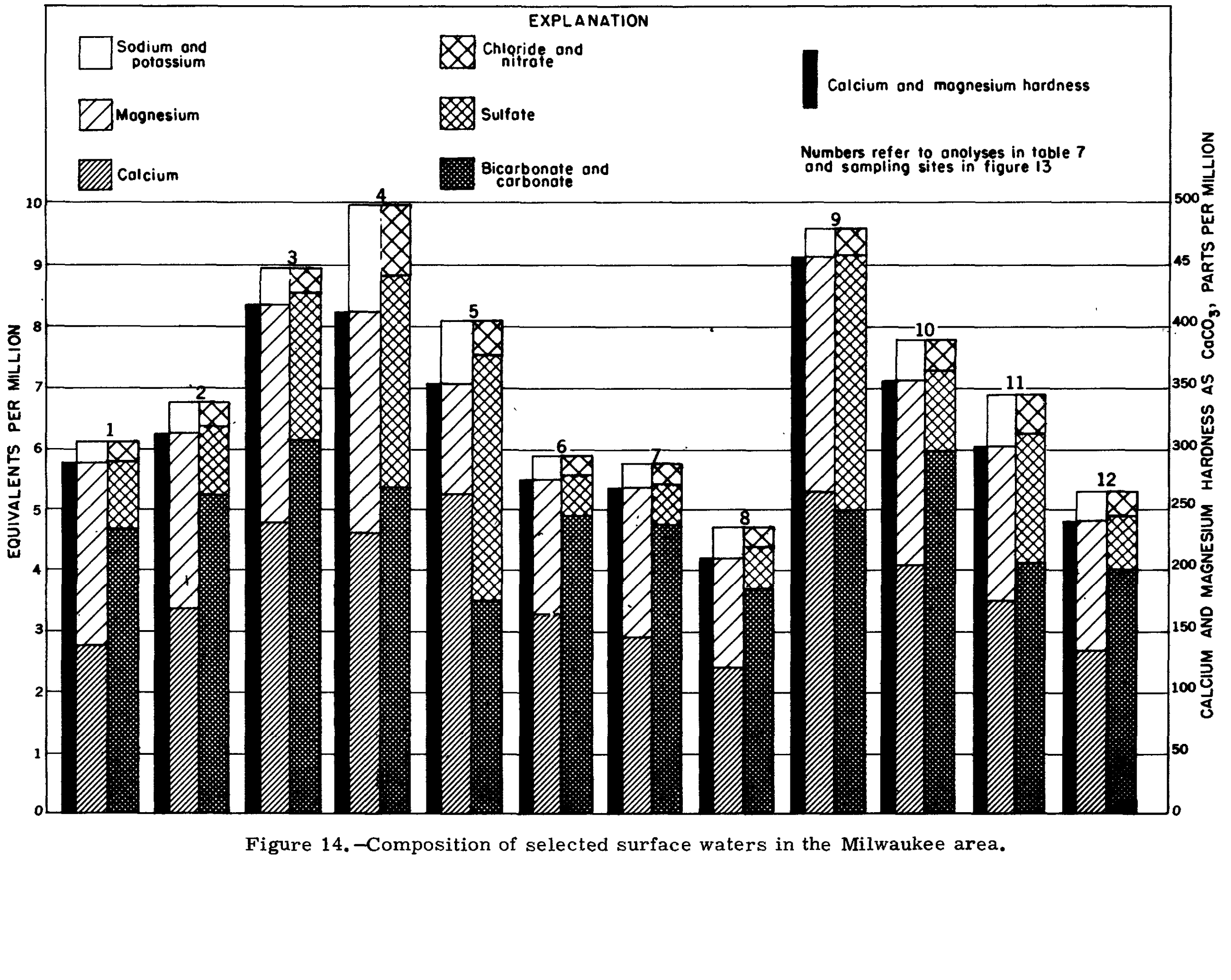

Figure 14.—Composition of selected surface waters in the Milwaukee area.

Menomonee Falls had a sulfate content of 62 ppm, and a sample collected at Wauwatosa below the mouth of the tributary Little Menomonee River had a sulfate content of 102 ppm.

Surveys made in 1948 showed that domestic sewage from private outlets and milk plant wastes were being discharged into the Menomonee River before it entered Waukesha County, and that the effluent from a municipal sewage disposal plant was discharged into the stream in Waukesha County. These surveys also indicated that discharge of raw sewage into the Menomonee River from combined sewer relief outlets during heavy rainfall caused the sanitary condition of the stream to become increasingly poor towards its mouth.

Little Menomonee River

In 1951, an analysis of water from the Little Menomonee River showed this water to be very hard with a high concentration of dissolved solids (table 7 and figs. 13 and 14). The water was a calcium-magnesium bicarbonate-sulfate type, with the sulfate content almost equal to the bicarbonate in equivalents per million. The hardness of the water at the time of analysis in 1951 was 459 ppm as calcium carbonate, and the concentration of dissolved solids was 568 ppm. A survey made in 1948 showed that the Little Menomonee River carried treated industrial wastes from wood-preservative and food-processing plants, but that the processes of natural purification tended to correct any objectionable conditions before the stream entered Milwaukee County.

Kinnickinnic River

The Kinnickinnic River drains an area of 33 square miles. It flows northeastward from the southwestern part of the city and empties into the Milwaukee River just above its mouth. Some of the normal runoff is intercepted by city storm sewers. The lower Kinnickinnic carries almost half of the harbor water traffic tonnage, which includes all of the year-round car-ferry traffic. Kinnickinnic Basin, a large manmade bay adjoining the river about a mile south of the entrance channel, is used primarily for winter moorage of large vessels. The river channel depth is maintained greater than 19 feet for about 2 miles above the mouth. Many parks border the river in its upper reaches. The city flushes the navigable portion of the stream daily from May 1 to December 1 with lake water, displacing a total volume of about 13,490 million gallons in 1951.

Quality.—One sample of Kinnickinnic River water, collected in 1951, was very hard with a moderately high mineral content. (See table 7 and figs. 13 and 14.) The water was of the calcium sulfate type. The sulfate exceeded the bicarbonate in equivalents per million. A concentration of 0.06 ppm of hexavalent chromium was found in this sample. Industrial wastes were discharged into this stream, and during times of heavy rainfall raw sewage was discharged into the river from storm relief outlets. Surveys conducted in 1948, based on dissolved oxygen content and most probable numbers of coliforms, showed sanitary conditions in the stream to be satisfactory upstream from Chase Avenue in Milwaukee. They also showed excessively high most probable numbers of coliforms downstream from Chase Avenue. At that time, flushing operations in the lower Kinnickinnic River had not entirely eliminated the pollution problem.

Fox River

The Fox River and its tributary, the Pewaukee River, drain most of the western part of the Milwaukee area. The Fox River flows south and west toward the Mississippi River. The drainage area of the Fox River above the Pewaukee is 88 square miles and the Pewaukee drains an area of 32 square miles. The largest concentration of fall is found at Waukesha. The river has an average fall of only 1.4 feet per mile below Waukesha.

Quality.—Two samples from the Fox River were analyzed in 1951. (See table 7 and figs. 13 and 14.) The sample collected near Waukesha showed the magnesium concentration to be higher than calcium in equivalents per million, whereas the sample collected farther downstream below Lake Mukwonago showed the calcium concentration in equivalents per million to be somewhat higher than the magnesium. The Fox River water was a hard calcium-magnesium bicarbonate water with a moderately high concentration of dissolved solids. The sulfate and chloride concentrations were moderately low in comparison with other streams in this area, although not as low as in the Milwaukee River.

Root River

The Root River drains part of southern Milwaukee County and flows into Lake Michigan at Racine. The drainage area is 184 square miles.

Quality.—Two samples of Root River water were analyzed in 1951. (See table 7 and figs. 13 and 14.) The analyses showed a very hard water with a fairly high mineral content. The water was of the calcium-magnesium bicarbonate type with a relatively high concentration of sulfate and moderately low chloride. A definite increase in noncarbonate hardness towards the mouth of the river was indicated, although the total hardness remained about the same. At the same time there was a noticeable increase in dissolved solids towards the mouth. Negligible pollution enters the Root River within the Milwaukee area.

GROUND WATER

Occurrence

Ground water is water that occurs below the surface of the earth where all open spaces in the earth material are filled with water, that is, where the earth material is saturated. Open spaces in the earth material are of great variety in number, size, and shape. They range in size from extremely minute spaces between clay particles in clay and shale, through larger openings between grains or pebbles in sand, gravel, and sandstone, to open channels formed by fractures and solution channels in limestones and dolomites. The larger the opening the more readily does water move through it and the rock material is therefore more permeable, provided the openings are interconnected. A formation, part of a formation, or group of formations, in which connected openings are large enough to allow water to flow to a well or spring is called an aquifer.

Where ground water is not confined by overlying impermeable strata, the upper boundary of the zone of saturation is called the water table, and the water level in wells coincides with the water table. When the water table is lowered, some of the material is dewatered; similarly, a rise in the water table means that some earth material previously unsaturated has become saturated. Ground water that is thus unconfined is said to occur under water-table conditions.

Where a water-bearing, or better a well-yielding, formation, or aquifer, is confined between relatively impermeable beds and where water is supplied to it from a higher elevation, the water is confined under hydraulic pressure much as water in a pipe is under pressure when it is connected to a reservoir at a higher elevation. When such an aquifer is punctured by a well, water will rise in the well to a height equal to the hydraulic head on the aquifer. If the pressure, or piezometric surface happens to be above the land surface at the well, the well will flow. Ground water that is thus confined under pressure is said to be under artesian conditions, and wells are artesian whether they flow or not. When artesian pressures, and hence the ground-water levels, are lowered by pumping or free flow of wells, the aquifer is not dewatered but is still completely full, unless the water level is lowered below the top of the aquifer.

The term "water table" should be applied to the upper boundary of the zone of saturation where ground water is unconfined. The surface to which water will rise under confined or artesian conditions is not the water table but is a pressure surface or piezometric surface.

Both water-table and artesian conditions occur in the Milwaukee area. Water-table conditions are found only in the shallow aquifers. In many places where no permeable sand or gravel occurs in the glacial drift or where they are deeply buried, all wells are artesian. It is difficult to tell whether or not artesian conditions prevail in some wells. An aquifer-performance test will determine the hydraulic characteristics of an aquifer and generally will indicate whether artesian or water-table conditions exist.

Ground water in the deeply buried St. Peter, Eau Claire, and Mount Simon sandstones is all under artesian pressure. These three sandstone formations together form the sandstone aquifer as used in this report. The Galena dolomite and Platteville limestone may contribute some water but are not considered a major part of the aquifer. The sandstone aquifer is effectively separated from the shallower drift and Niagara dolomite aquifers by the Maquoketa shale.

Principal Aquifers

The principal aquifers in the Milwaukee area are the Pleistocene sands and gravels, Niagara dolomite, and the sandstones. Their water-bearing characteristics are given in table 8. Figure 15 is a geologic cross section from Sun Prairie, Wis., to Milwaukee. The letter prefix of the well number designates the county, i. e., Wk, Waukesha, and Ml, Milwaukee.

Pleistocene aquifers.—Permeable sand and gravel deposits in or at the base of the glacial drift in the area provide water to some shallow wells in quantities adequate for domestic or farm supply. In the northern part of the area the drift consists mostly of relatively impermeable till, and no continuity of permeable material is discernible. One prominent buried valley with several tributaries occurs in the bedrock in the southwest. Some of the buried valleys have been partly filled, especially the lower parts of the fills, with sand and gravel deposits that are potential aquifers as yet largely undeveloped.

Apparently the general custom in the area has been to develop ground water for domestic and farm use by wells that penetrate the Niagara dolomite, and in some cases deposits of sand and gravel have been cased off. It is probable that such sand and gravel deposits would yield adequate quantities of water if properly screened and developed, especially in the buried valleys. Figure 16 is a contour map of the bedrock in the area and shows the locations of preglacial valleys.

The Pleistocene glacial drift receives water from precipitation that falls within the area. Recharge takes place most readily where sand and gravel in the glacial drift occur at the surface. Ground water moves down gradient from the areas of recharge to areas of discharge. The most prominent discharge area is Lake Michigan, but many stream valleys are areas of discharge. Water levels in wells in the recharge areas averaged about 5 feet higher in May 1951 than in September 1950. The maximum rise was 10.39 feet.

Recharge of the aquifers does not occur from Lake Michigan except possibly a small quantity in downtown Milwaukee where water levels have been lowered below lake level. Recharge from Lake Michigan, if any, is undoubtedly very slow, for the lake silt and the glacial drift are relatively impermeable.

Niagara dolomite aquifer.—Niagara dolomite, commonly called limestone, underlies the whole Milwaukee area except in the deepest buried valleys in the south and southwestern part of the area.

The Niagara dolomite is an aquifer though not a consistent one. Water occurs in joints and along bedding planes and where these have been enlarged by solution, the dolomite yields water readily. The rock itself is dense and impermeable and if a well does not intersect many or only very small joints or openings along bedding planes, it will yield only small amounts of water. It frequently happens that two wells drilled into the Niagara dolomite only a few hundred feet or even a few feet apart have entirely different capacities. Wells in the Niagara dolomite in the Milwaukee area have produced up to 600 gpm while others have produced only enough for domestic use.

The water-producing openings in the Niagara dolomite are normally more abundant and larger in the upper part of the formation just below the glacial drift or in areas of outcrop. Solution has had more opportunity to enlarge them close to the preglacial land surface than at greater depths. To develop the whole

Table 8.–Stratigraphy of the Milwaukee-Waukesha area and the water-bearing characteristics of the principal formations

System	Series or group	Formation	Thickness (feet)	Character	Water-bearing characteristics
Quaternary	Recent.	Alluvium.	0-	Alluvium, beach sand, peat, muck, marl.	Insignificant; in places will yield water from sand.
	Pleistocene.	Glacial deposits.	0-450	Boulder clay, sand, gravel.	Yields water from sand and gravel. Buried valleys important.
Carboniferous	Mississippian.		55	Black carbonaceous shale.	Not water yielding.
Devonian		Milwaukee formation.	110	Gray shale, dolomite, some limestone.	Yields some water from crevices to domestic wells.
		Thiensville formation.	50	Light- to dark-brown dolomite. Some beds bituminous.	Yields some water from crevices to domestic wells.
Silurian	Cayuga.	Waubakee dolomite.	477	White to gray dolomite. Some coral reefs. Mostly massive. Crevices and solution channels abundant but inconsistent.	Important aquifer but variable. Yields water from crevices and solution channels. Yields 5 to 600 gpm.
		Niagara dolomite.			
Ordovician	Richmond	Maquoketa shale.	90-225	Blue-gray dolomitic shale with dolomite beds.	Not water yielding. Usually cased off in wells.
		Galena dolomite and Platteville limestone.	215-305	Light-gray to blue-gray dolomite, massive. Sandy at base.	Some water is yielded from crevices. Not important.
		St. Peter sandstone.	80-357	Sandstone, fine to medium, white to light-gray, dolomitic in some places. Lower part may represent Dresbach sandstone (Cambrian).	Water yielding. Capacity as aquifer varies with permeability.
		Unconformity			
Cambrian		Eau Claire sandstone.	105-390	Sandstone, fine to medium, light-gray to light-pink, dolomitic; some shale beds.	Water yielding but permeability low. Never developed as sole aquifer.
		Mount Simon sandstone.	145+	Sandstone, white to light-gray, fine to coarse, mostly medium; some beds dolomitic.	Water yielding. Generally best of deep aquifers.
Pre-Cambrian				Crystalline basement rocks.	Not water yielding.

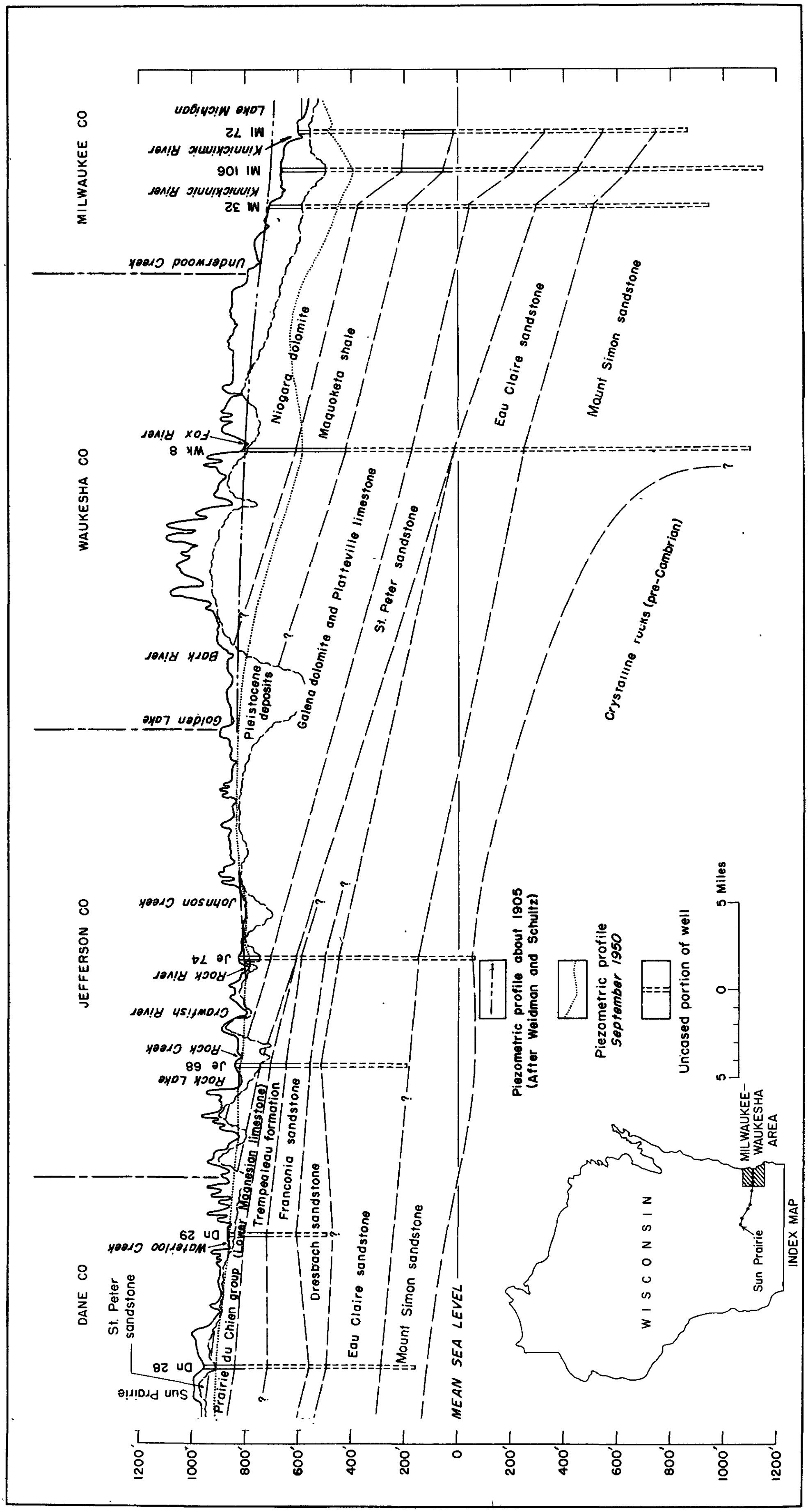

Figure 15.—Geologic cross section and profile of piezometric surface from Sun Prairie to Milwaukee.

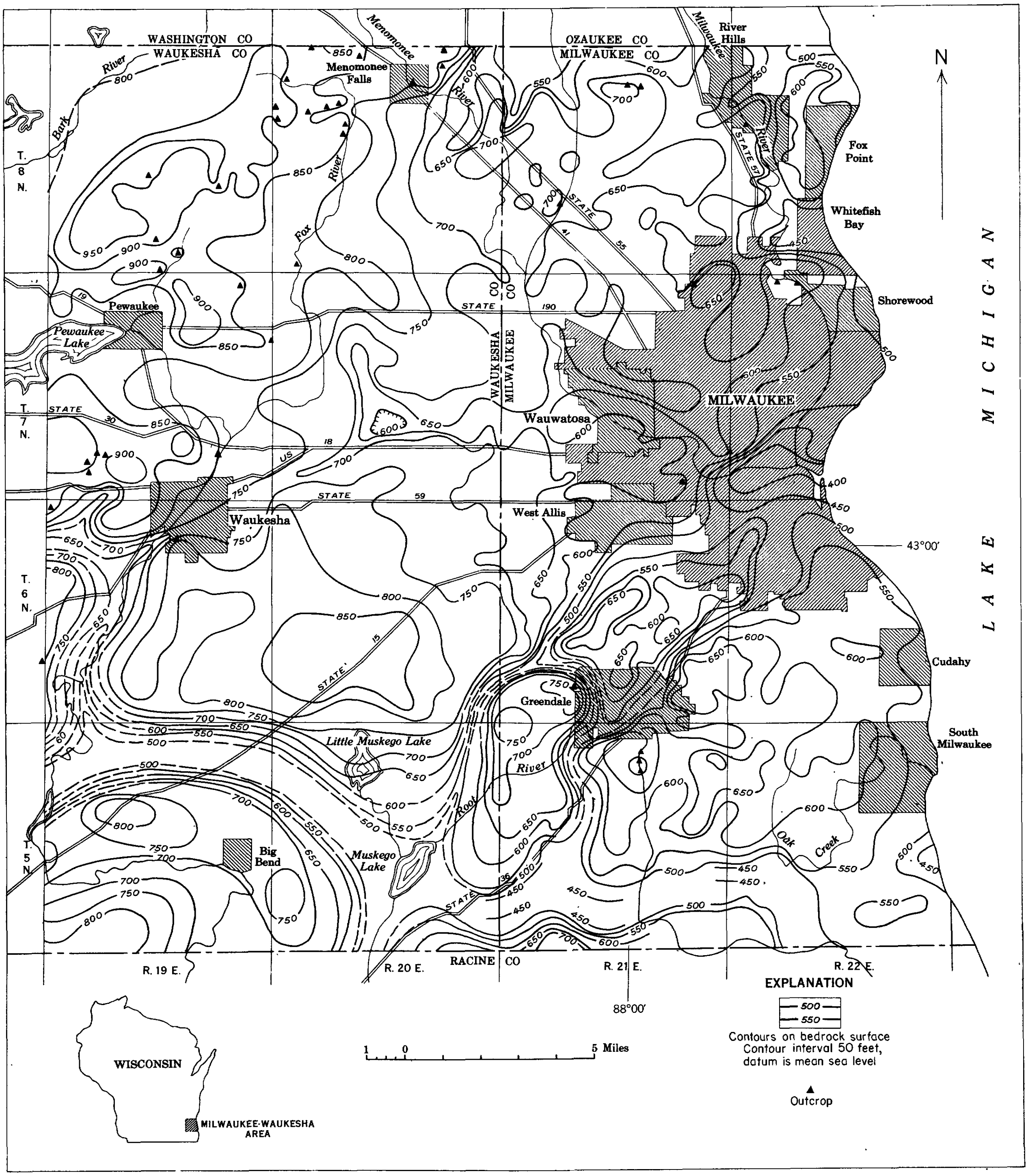

Figure 16.—Bedrock contour map of the Milwaukee Area.

capacity of the Niagara dolomite, however, wells should be drilled to the base of the formation. The Niagara dolomite, like the Pleistocene, receives water from precipitation that falls in the area. Recharge takes place most readily where the bedrock occurs near the surface.

Many of the wells drilled into the sandstone aquifer are left uncased in Niagara dolomite. Such wells generally have higher yields than wells drawing from only one aquifer.

Sandstone aquifer.—The shallow aquifers consisting of the glacial drift of Pleistocene age and the Niagara dolomite of Silurian age are separated from the deeply buried sandstone aquifer of Ordovician and Cambrian age by 90 to 225 feet of Maquoketa shale, which is essentially not water yielding. The Maquoketa shale forms a relatively impermeable seal above the deeply buried sandstone aquifer and maintains artesian pressure. Very few wells in the area are known to obtain water from the Maquoketa or Galena dolomite and Platteville limestone. It is probable that the Galena and Platteville yield small amounts of water in the area. The Maquoketa shale is almost invariably cased off in deep wells because it caves badly.

The sandstone aquifer consists of the St. Peter sandstone, the Eau Claire sandstone, the Mount Simon sandstone, and the Galena and Platteville. The Galena and Platteville may supply small quantities of water and are therefore included as parts of the aquifer. The St. Peter and the Mount Simon are the most productive formations with the Eau Claire probably supplying small quantities of water. Many of the deep wells that penetrate the sandstone aquifer are open also in the Niagara dolomite and produce water from both aquifers.

Recharge to the sandstone aquifer in the Milwaukee area can take place in three ways. Recharge may be directly downward from the Niagara dolomite and glacial drift through wells that are open in both the Niagara dolomite and the sandstone aquifer. Thus, local precipitation on the Milwaukee area indirectly recharges the sandstone aquifer. There is also a small amount of recharge through the Maquoketa shale. Recharge to the sandstone aquifer in the Milwaukee area also takes place by movement of water from the principal recharge area which is about 25 miles west of Milwaukee. The greater hydraulic gradient in 1950 as compared to the gradient in 1905 has caused an increase in the rate of movement of water toward the areas of withdrawal (fig. 15).

Aquifer performance tests were made at four places in the Milwaukee area to determine the hydraulic characteristics of the sandstone aquifer. The average coefficient of transmissibility from 48 tests was about 24,000 gpd per ft. The average coefficient of storage from 26 tests was about 0.0004. The specific capacity of wells penetrating the sandstone aquifer ranges from about 3 to about 19 gpm per ft of drawdown and averages about 11 gpm per ft of drawdown.

Water Levels

Pleistocene and Niagara dolomite aquifers.—In many parts of the area static ground-water levels in the glacial drift and in the Niagara dolomite are different, but in others, water levels in both are essentially the same. Very few wells finished in the glacial drift were available for measurement. The glacial drift and Niagara dolomite behave as one aquifer in many places, especially where sand and gravel of the drift lie directly on the bedrock. In the central and western part of T. 6 N., R. 22 E., and the eastern part of T. 6 N., R. 21 E., beds of sand in the drift have essentially the same water levels as the Niagara dolomite. In some places the permeable beds of the drift are separated from the Niagara dolomite by a bed of relatively impermeable till, but undoubtedly these permeable beds are connected laterally with other permeable beds that do lie directly on the Niagara dolomite. Water levels common to both the drift and the Niagara dolomite occur also in the buried valleys in the southwestern part of the area.

The water table in the Niagara dolomite contains a cone of depression at downtown Milwaukee, just west of the Milwaukee River and at the mouth of the Menomonee River in the southwestern part of T. 7 N., R. 22 E. The depression, which extends under most of Milwaukee, has been caused by heavy pumpage from wells in the Niagara dolomite and from wells open in both the Niagara dolomite and the sandstone aquifer and by the lack of recharge through the clay muck, and marl overlying the Niagara dolomite in the area. Originally water levels in the Niagara dolomite and in the overlying glacial drift and alluvium of the low river valley area were the same. The permeability of glacial material, especially the clay silt and a large part of the alluvium, is much less than that of the Niagara dolomite. Lowering of the water level in the Niagara dolomite has caused the ground water in the overlying material to move downward very gradually in an attempt to adjust the level in the overlying material to the new lower water level of the Niagara dolomite.

Figure 17 shows hydrographs of 2 wells in the Pleistocene glacial drift and 3 wells in the Niagara dolomite for the years, 1946-50. The fluctuations in water levels are less in the Pleistocene drift wells than in the Niagara dolomite wells. The hydrograph which shows the greatest fluctuation in the Niagara dolomite is that of Ml 120, which is the observation well closest to the cone of depression in downtown Milwaukee.

Sandstone aquifer.—In 1885 water levels in wells penetrating the sandstone aquifer at Wauwatosa had a piezometric head about 170 feet above Lake Michigan. The early wells were allowed to flow or were pumped, and the water levels declined. The profile of the piezometric surface of about 1905 (Weidman and Schultz, 1915) is shown in figure 15. Water levels declined gradually until about 1935 when they were about 30 feet above the level of Lake Michigan. Increasing use from 1935 to the present time (1952) has caused further declines so that at the end of 1951 water levels at Wauwatosa were about 130 feet below lake level. Hydrographs of three wells in the sandstone aquifer are shown in figure 18.

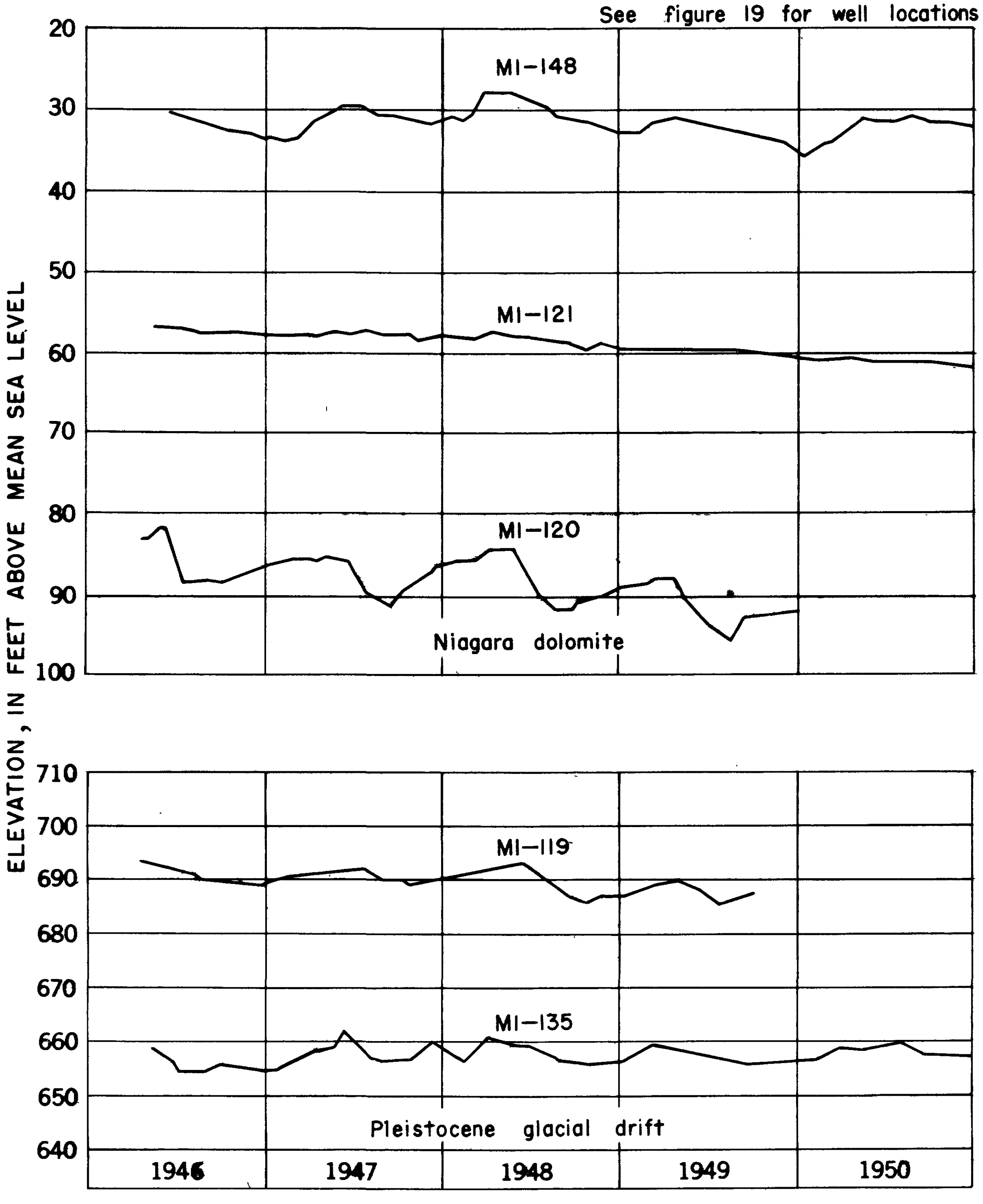

Figure 17.—Water levels in wells in Niagara dolomite and Pleistocene glacial drift, 1946-50.

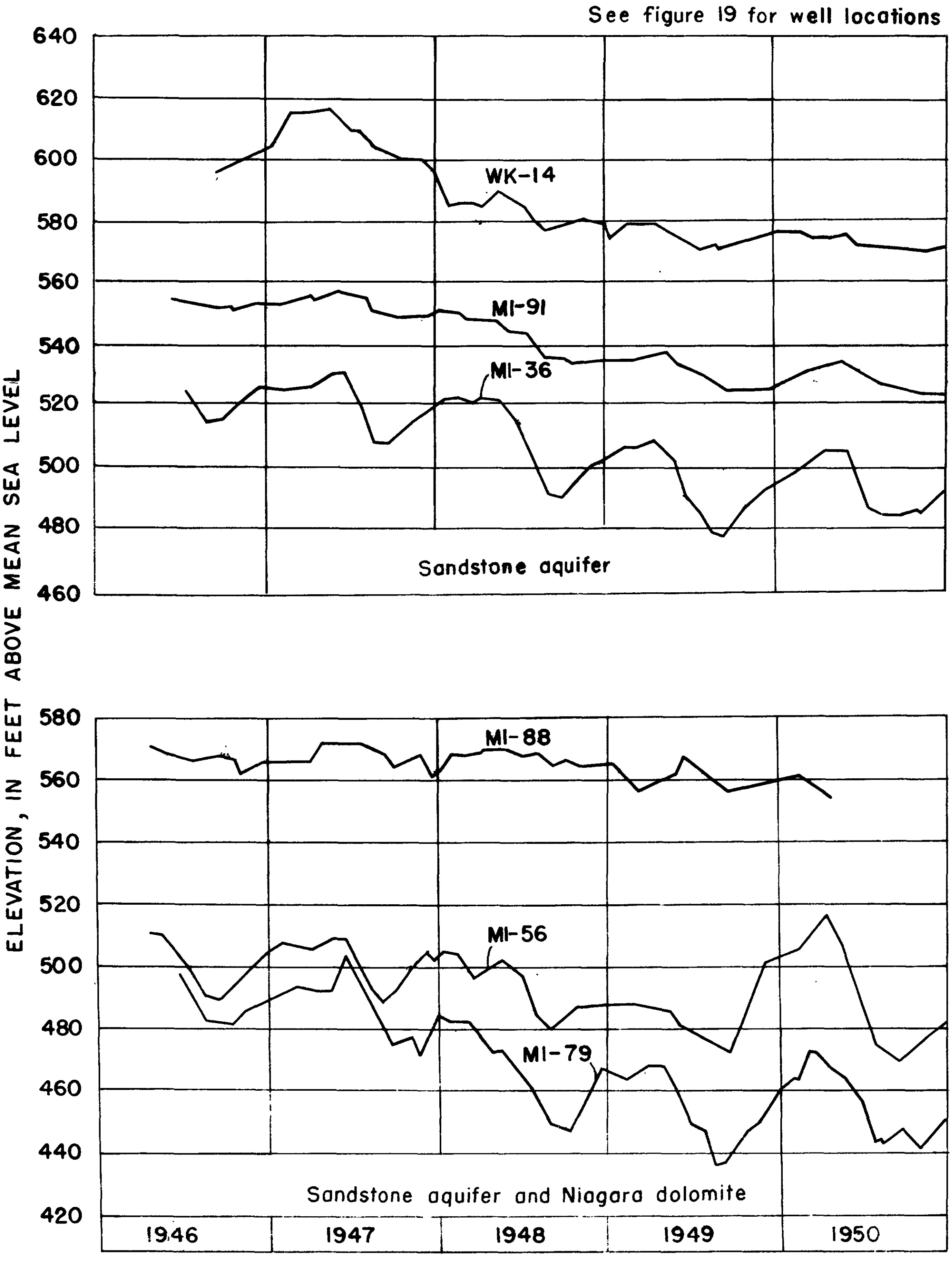

Figure 18.–Water levels in wells in the sandstone aquifer and in wells tapping both the sandstone aquifer and the Niagara dolomite, 1946-50.

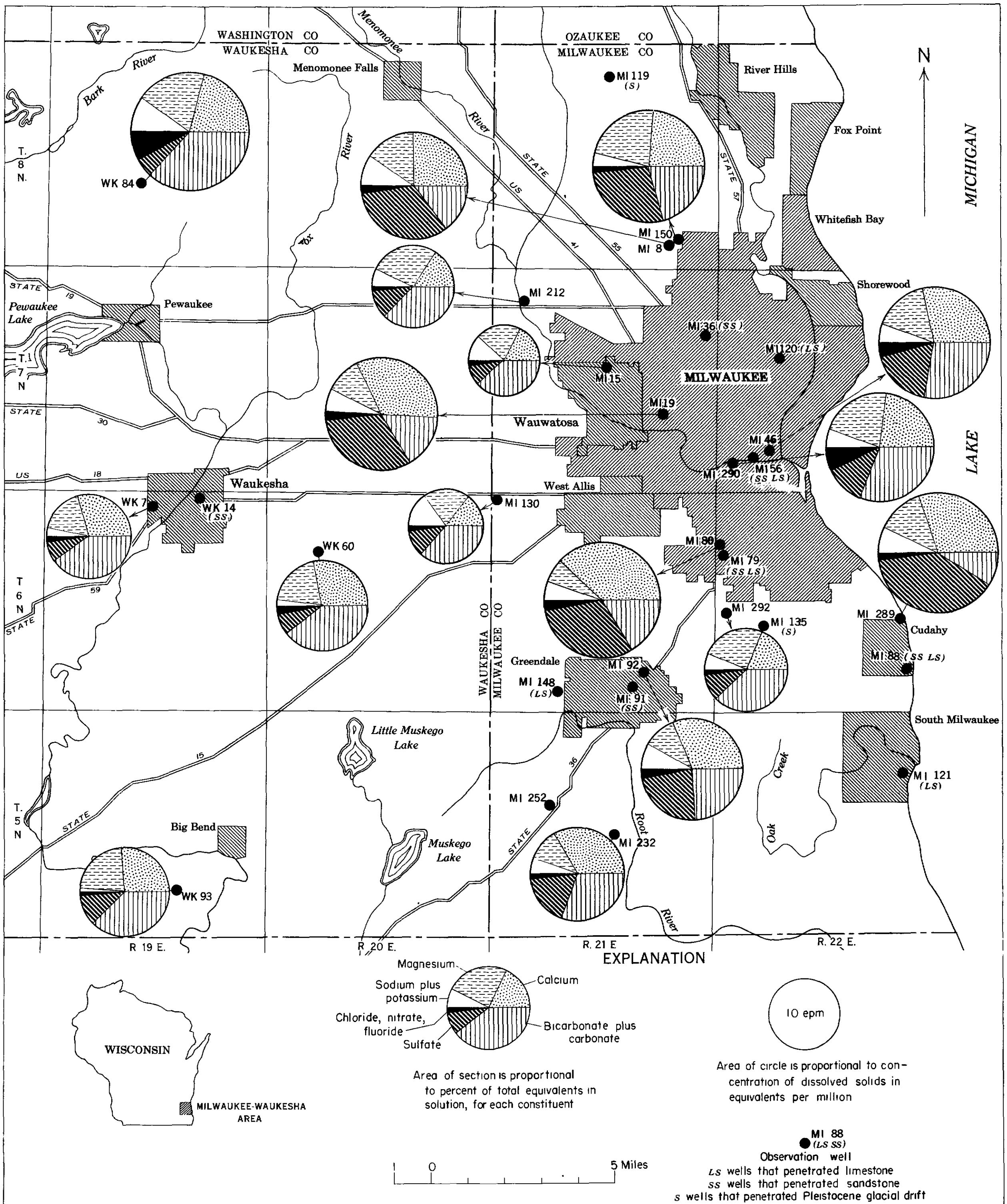

Figure 19.—Composition of selected ground waters in the Milwaukee area.

Wells in Niagara dolomite and sandstone aquifer.— In the wells which are uncased in the Niagara dolomite and in the sandstone aquifer, water levels are higher than in wells tapping only the sandstone aquifer. There was loss of water from the sandstone aquifer into the Niagara dolomite through such wells until about 1925 owing to the higher head in the sandstone aquifer. Since about 1925 the head has been lower in the sandstone aquifer than in the Niagara dolomite, and consequently water from the Niagara dolomite moves downward into the sandstone. Hydrographs of three wells tapping both the sandstone aquifer and the Niagara dolomite are shown in figure 18.

Quality

The amounts of dissolved solids in ground water of the Milwaukee area range from moderate to excessive, and the waters generally may be classed as hard or very hard. There is a general tendency towards increase in mineral content with increase in depth of the aquifer, although there are exceptions to this trend. The deep-seated waters are likely to contain relatively large amounts of sulfate and low concentrations of chloride. Waters adjacent to the shale may contain large amounts of sulfate. Calcium is commonly the predominant cation in the ground waters of the Milwaukee area, although magnesium is the more important contributor to hardness in some of the waters. Sodium and potassium are sometimes present in more significant amounts than magnesium. The ground waters of the area are, in general, either of the bicarbonate or sulfate type. Chloride waters rarely occur in this area. Bicarbonate waters are of somewhat more frequent occurrence than waters with sulfate as the predominant anion. Graphic representations of some waters from the various aquifers, together with the well locations, are given in figure 19. Compositions of selected ground waters from the Milwaukee area are presented in tables 9, 10, and 11.

Highly mineralized ground waters may be encountered in this area, especially along the shores of Lake Michigan where the aquifers obtain their greatest depth. These waters of high mineral content may contain more than 1,000 ppm of dissolved solids. Such waters occur from the surface deposits to the deepest aquifers, although they are usually found in the deeper aquifers. The types of highly mineralized waters found in this area, in the order of the frequency of their occurrence, are sulfate, chloride, and bicarbonate waters. The probability of calcium and magnesium or sodium and potassium being the predominant cations seem to be about equal. Only rarely are nitrates a significant constituent of these waters. Weidman and Schultz (1915), reported wells in the sandstone aquifers yielding water of as high as 1,419 ppm of dissolved solids, and a well in the Niagara dolomite providing water containing 1,476 ppm of dissolved solids. A recent analysis of water from well Ml-289 (table 9), located near Cudahy, showed a dissolved solids content of 894 ppm and a total hardness of 570 ppm. The water from this well is of the calcium sulfate type and contains only minor quantities of chloride. The ground waters of the Milwaukee area cannot be definitely characterized according to the aquifer from which they are drawn. Weidman and Schultz inferred from their investigations that "the controlling factor in the mineralization of the water in the several districts is the depth of the sea of underground water in the district." It is likely that, for a given location, the deeper wells will supply water of higher mineral content than will those wells in the shallower aquifers. The composition of water of high and low content of dissolved solids for each of the aquifers is depicted graphically in figure 20.

PUBLIC WATER SUPPLIES

Milwaukee Public Water Supply System

The Milwaukee water works obtains its entire water supply from Lake Michigan. Two huge intakes have been constructed, one of which has been in use since 1918. North Point intake with a capacity of 95 mgd is not now in service but could be utilized again with some repair work (fig. 21). The Linwood Avenue intake has a capacity of 366 mgd at a velocity of 5 feet per second. The intake is 55 feet below normal lake level and 6,565 feet out in Lake Michigan in a northeasterly direction from the purification plant. The water is normally 67 feet deep at this point. The intake is in a submerged crib 80 feet in diameter and 12 feet high. The city has experienced no trouble with needle ice in intake or shafts chiefly because of this depth of water. The filtration plant is the rapid sand mechanical type with a rated daily capacity of 275 million gallons. The water is treated with liquid chlorine (disinfectant), aluminum sulfate and lime (coagulant), and activated carbon (taste and odor control). Two pumping stations have a rated capacity of 345 mgd. A booster station and storage or demand-equalizing facilities are used in summer months over peak demands. The general arrangement of the distribution network is the gridiron system. At the end of 1950, the system included 1,082 miles of distribution pipe within the city and is growing at the rate of 50 to 60 miles of mains per year. Equipment for fluoridation has been installed. The system supplied a population of about 716,000 people in 1950, including the city of West Allis and the villages of Whitefish Bay, Shorewood, West Milwaukee, and Fox Point, and numerous county institutions.

Chemical quality.—The treated water supplied by the Milwaukee water works is of consistently good quality. It is a water of moderate hardness and alkalinity. Treatment of the raw supply is carefully controlled, and the resulting water supplied to consumers is satisfactory both chemically and bacteriologically. (See tables 1, 3, and 4.)

Other Public Water Supply Systems

Carrollville, Cudahy, and South Milwaukee with a combined population of about 25,000 have their individual water supply systems, using Lake Michigan water at a combined rate of about 5 mgd. Waukesha and Wauwatosa, total population about 55,000, obtain their water from ground-water supplies.

PRESENT WATER USE

In 1950 the Milwaukee area used water at an average rate of 482 mgd, of which 39 mgd was from wells and 443 mgd from surface water.

Table 9.—Chemical quality of water from the Niagara dolomite aquifer

[Analyses, in parts per million, by U. S. Geological Survey]

	MI-130	MI-150	MI-212	MI-289	MI-290	WK-60	WK-84	WK-93
Date of collection	Feb. 11, 1947	Mar. 11, 1947	Jan. 16, 1952	Jan. 17, 1952	Jan. 17, 1952	Jan. 16, 1952	Jan. 16, 1952	Jan. 31, 1952
Silica (SiO_2)	18	16	19	10	31	18	12	13
Iron (Fe)[a]	.21	1.5	.23	.44	.90	.55	1.2	3.3
Calcium (Ca)	29	137	40	160	100	90	112	80
Magnesium (Mg)	28	48	42	41	53	37	63	43
Sodium (Na)	33	17	20	47	32	2.5	47	2.7
Potassium (K)	5.3	2.7	.7	2.1	.6	1.5	21	.2
Bicarbonate (HCO_3)	235	298	287	147	386	382	590	357
Carbonate (CO_3)	0	0	0	0	7	0	0	0
Sulfate (SO_4)	66	310	73	508	134	64	65	80
Chloride (Cl)	2.0	8.0	4.8	3.5	46	2.8	66	7.2
Fluoride (F)	.9	.8	1.1	1.3	1.1	.8	.1	.2
Nitrate (NO_3)	.8	.2	.8	3.0	.6	.4	14	.1
Dissolved solids	299	726	335	894	592	416	689	390
Hardness as $CaCO_3$								
Total	188	539	272	570	470	378	540	376
Noncarbonate	0	295	37	447	139	64	55	84
Specific conductance at 25 C. (micromhos)	483	985	561	1,110	917	648	1,150	646
pH	7.6	7.5	8.0	7.8	8.1	7.8	7.5	7.7

a Iron in sediment and solution (sample turbid when collected).

Table 10.—Chemical quality of water from the sandstone aquifer

[Analyses, in parts per million, by U. S. Geological Survey]

	MI-1 [a]	MI-92	MI-19	MI-8	MI-232	WK-7
Date of collection	May 2, 1950	Feb. 11, 1947	Feb. 13, 1947	Jan. 30, 1952	Jan. 17, 1952	Jan. 16, 1952
Silica (SiO_2)	--	7.2	7.2	22	8.9	8.5
Iron (Fe)	.1	.38	.39	b1.9	3.0	4.7
Calcium (Ca)	74	118	158	100	111	75
Magnesium (Mg)	37	25	29	47	23	28
Sodium (Na)	--	32	30	31	15	6.3
Potassium (K)	--	9.0	8.0	1.9	4.9	3.4
Bicarbonate (HCO_3)	273	280	235	214	313	313
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	125	223	361	317	140	56
Chloride (Cl)	7.0	11	13	5.8	8.1	4.0
Fluoride (F)	1.6	.3	.2	1.1	.7	.6
Nitrate (NO_3)	--	.5	.2	1.0	.2	.4
Dissolved solids	400	597	770	661	492	342
Hardness as $CaCO_3$						
Total	320	397	513	443	373	303
Noncarbonate	--	168	321	267	115	46
Specific conductance at 25 C. (micromhos)	--	691	938	884	723	557
pH	7.55	7.5	7.6	7.6	7.8	7.9

a Analysis by Wisconsin State Laboratory of Hygiene.
b Iron in sediment and solution (sample turbid when collected).

Table 11.—Chemical quality of water from glacial drift in a buried valley and of mixed waters from Niagara dolomite and sandstone aquifers

[Analyses, in parts per million, by U. S. Geological Survey]

	Glacial drift	Niagara dolomite and sandstone			
	MI-292	MI-8	MI-80	MI-46	MI-15
Date of collection	Jan. 17, 1952	Mar. 11, 1947	Mar. 11, 1947	May 15, 1947	Jan. 1952
Silica (SiO_2)	32	14	5.5	20	16
Iron (Fe)	.71	.75	.83	2.4	.38
Calcium (Ca)	45	117	183	136	34
Magnesium (Mg)	40	44	25	43	25
Sodium (Na)	19	43	25	26	23
Potassium (K)	.7	3.0	4.5	2.0	1.1
Bicarbonate (HCO_3)	298	215	240	389	230
Carbonate (CO_3)	0	0	0	0	0
Sulfate (SO_4)	65	368	397	196	41
Chloride (Cl)	3.2	5.5	5.8	36	2.4
Fluoride (F)	1.4	1.0	.6	.9	1.4
Nitrate (NO_3)	.1	.2	.2	.2	.8
Dissolved solids	362	735	826	725	248
Hardness as $CaCO_3$					
Total	276	473	559	516	186
Noncarbonate	33	297	363	197	0
Specific conductance at 25 C. (micromhos)	559	980	1,070	1,020	427
pH	7.9	7.4	7.3	7.3	7.9

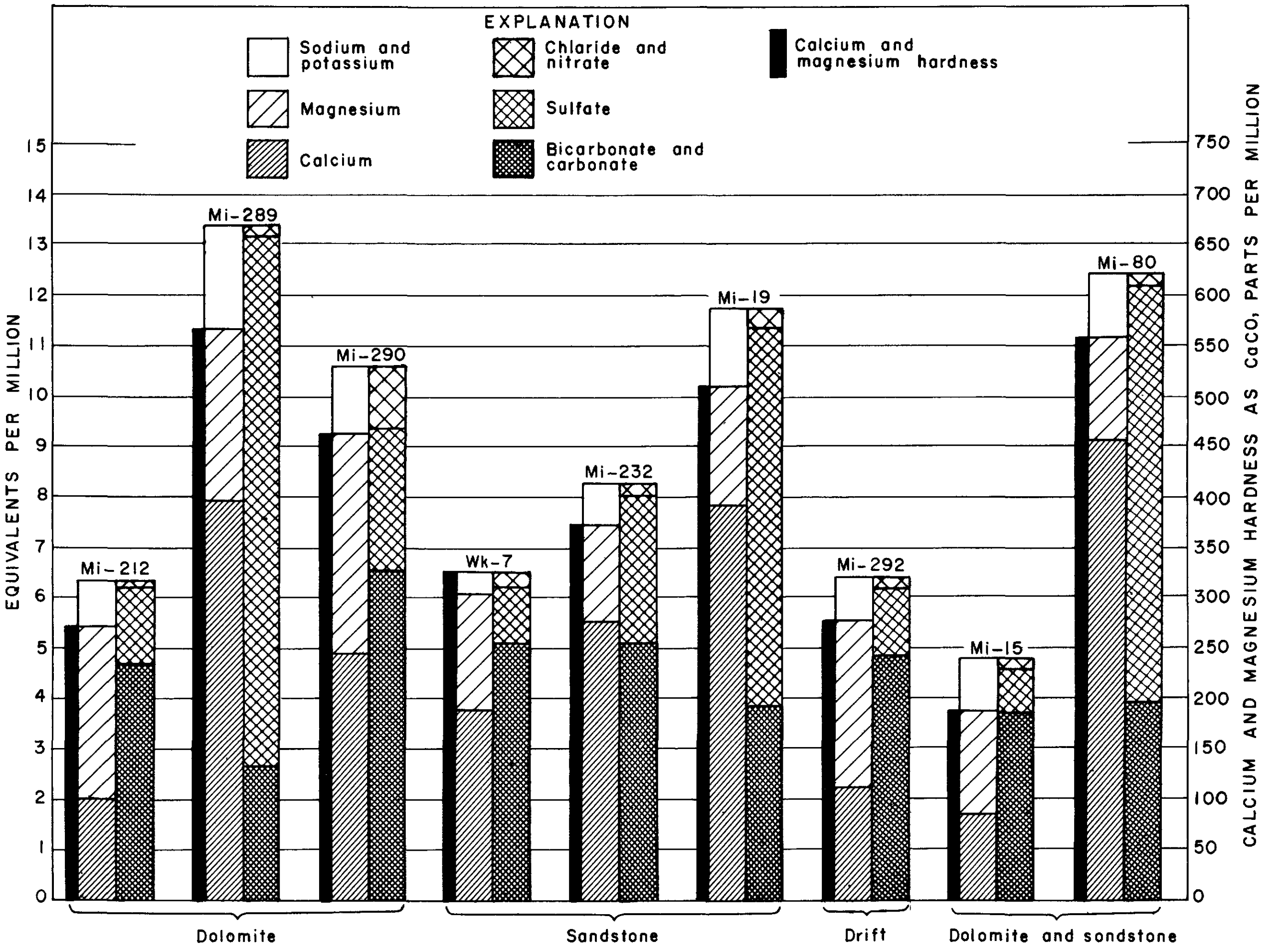

Figure 20.—Composition of selected ground water from various aquifers in the Milwaukee area.

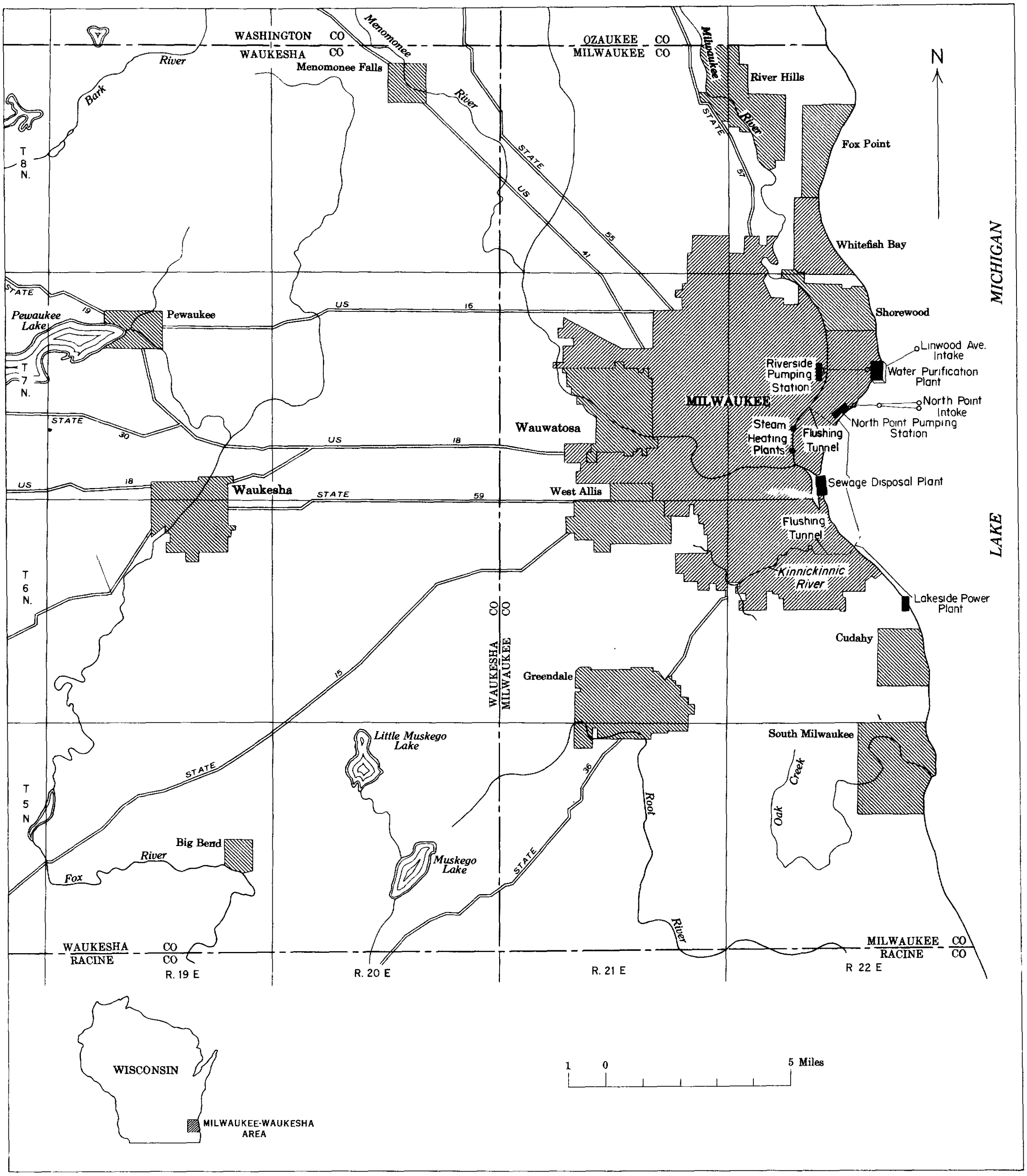

Figure 21.—Map showing Milwaukee public water supply system and other major uses.

Surface Water Use

The largest use of surface water in the area was for cooling in steam-electric power generation (table 12). Most of the water so used was obtained from Lake Michigan. A very small amount of river water was used for cooling, and most of it was returned to the river immediately.

Table 12.—Use of surface water in the Milwaukee area, 1950

	Quantity (mgd)
Steam electric power	220
Flushing Milwaukee and Kinnickinnic Rivers	97
Public supplies	125
Total	442

Public supplies.—Of the 125 mgd used for public supplies in 1950, 120 mgd were used by Milwaukee and about 5 mgd were used by Wauwatosa.

The average daily pumpage of 120 mgd by Milwaukee water works was about 167 gallons per capita per day. Figure 22 shows the population served and water pumped by the Milwaukee water works since 1912. The quantities of water used from the Milwaukee public water supply are shown in figure 23 for each year from 1900 to 1950. Beginning with 1921, the total use is divided according to type of use, public and operational, industrial, and residential and commercial. Industries used 50 mgd from the Milwaukee public supply in 1950. The largest uses of water from the Milwaukee public supply are the breweries. The city flushed the Milwaukee and Kinnickinnic Rivers with lake water from May 1 to December 1, 1951, at an average rate of 165 mgd.

The Milwaukee Sewage Disposal Plant treated an average of 140.7 mgd in 1951. The plant uses the activated sludge treatment method. Effluent is discharged directly into Lake Michigan near the mouth of the Milwaukee River. Because much of the sewage is of industrial origin, the combined raw wastes have an oxygen demand comparable to that of raw sewage from a population of 2,300,000 people.

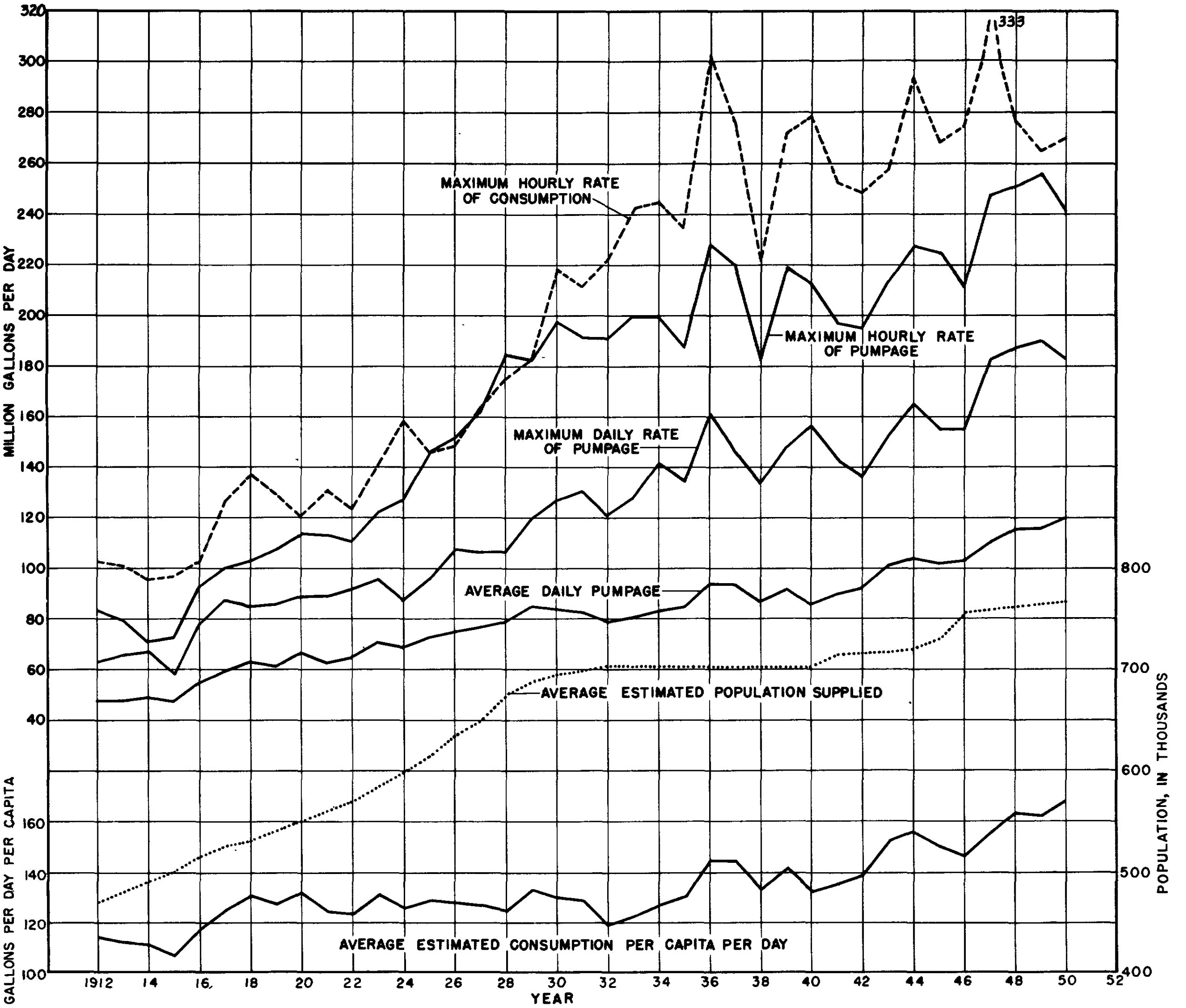

Figure 22.—Water pumped and population supplied by Milwaukee water works. (From Milwaukee water works data, 1950.)

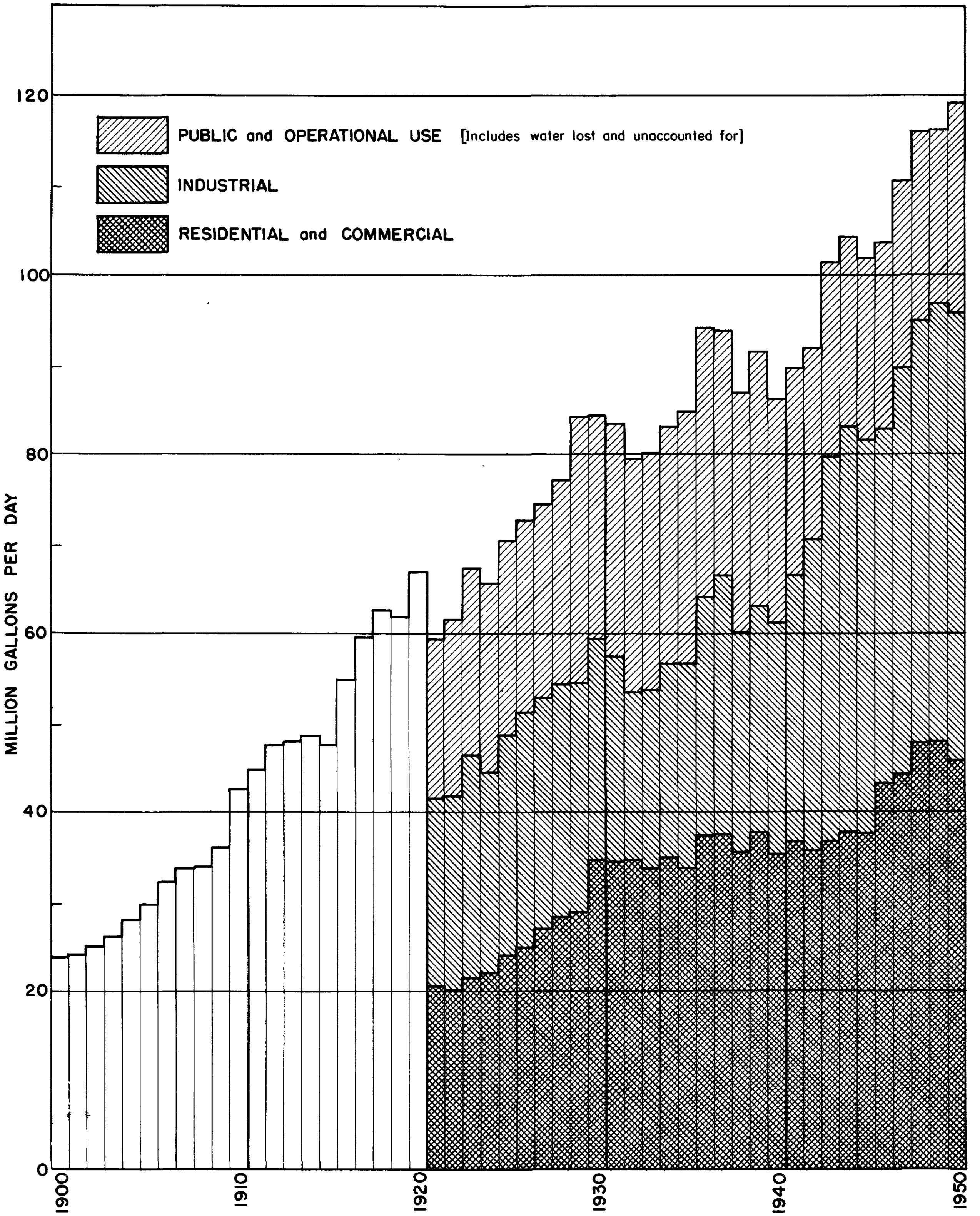

Figure 23.—Use of water pumped by Milwaukee water works. (From Milwaukee water works data, 1950.)

Private industrial supplies.—There are very few private industrial systems for obtaining lake water. A few steam power plants in the area use lake water for condensing purposes. The Port Washington Plant, situated 20 miles north of Milwaukee, and the Lakeside Plant, situated just south of the city limits, are 2 of the 25 largest in the United States. A smaller plant is under construction in the town of Oak Creek. In 1950 the Lakeside Plant used about 220 mgd, in 1951 about 210 mgd. This water is returned directly to the lake.

Two steam-heating plants use Milwaukee River water during the heating season. A few other industrial concerns draw small amounts of river water for cooling.

Irrigation and rural supplies.—The Milwaukee water works lists no pumpage for irrigation. There may be a very small amount of private pumping from the rivers for small scale irrigation of farm lands and some from the lake for irrigation of golf courses.

Ground Water Use

About 39 mgd of ground water are used in the Milwaukee area: about 25 mgd by industrial and commercial concerns, about 7.5 mgd by municipalities and county institutions, and about 6 mgd for private domestic supply (table 13).

Table 13.—Use of ground water in the Milwaukee area 1949

Type of use	Source	Quantity (mgd)
Public water supplies.	Sandstone	7.61
Industrial and commercial.	....do	17.44
Do	Niagara dolomite	7.5
Domestic	....do	5.5
Do	Pleistocene deposits	.5
Total		38.55

The source of ground water was as follows: about 25 mgd from the sandstone aquifer of which 6 mgd was recharged from the Niagara dolomite, 13 mgd from the Niagara dolomite, and about 0.5 mgd from Pleistocene deposits.

Public water supplies in the Milwaukee area use about 30 percent of the water pumped from deep wells, and commerce and industry use about 70 percent in addition to the water taken from public supplies (tables 14 and 15). Deep wells are those penetrating the sandstone aquifer. About 90 deep wells in Milwaukee County supplied about 96 percent of the ground water pumped for commerce and industry exclusive of that taken from public supplies. The greatest use of ground water by commerce and industry involves various cooling processes.

Table 14.—Average daily use of ground water for public supplies from deep wells, 1949

Public Supply	Quantity (mgd)
City of Wauwatosa	2.87
City of Waukesha	2.82
Town of Lake	.73
Village of Greendale	.24
Village of Pewaukee	.20
Village of Menomonee Falls	.13
Milwaukee County Parks	.55
Waukesha County Farm	.07
Total public supply	7.61

Table 15.—Average daily use of ground water pumped from deep wells by commerce and industry, 1949[1]

Type of Industry	Quantity (mgd)
Malting	5.17
Metal working and fabrication	4.22
Brewing	3.33
Air conditioning (stores, theaters, hotels, offices, etc)	1.11
Meat packing	.91
Dairy products processing	.68
Tannery processes	.68
Food processing	.57
Cold storage and ice manufacture	.39
Railroads	.13
Miscellaneous commercial (cemeteries, golf courses, etc.)	.23
Miscellaneous industrial	.02
Total	17.44

[1] Excludes water from municipal supplies of Wauwatosa, Waukesha, Town of Lake, Greendale, Pewaukee, Menomonee Falls.

Figure 24 shows the average daily pumpage from deep wells in the Milwaukee area by months for 1949. Maximum daily pumpage occurs during the months of June, July, and August, depending primarily upon maximum daily temperatures.

It is estimated that about 120,000 people are supplied by private domestic wells in the Milwaukee area. Assuming a per capita consumption of 50 gallons a day, about 6 mgd are pumped from domestic wells in the area. About 90 percent of the domestic wells are developed in the Niagara dolomite; therefore, about 5.5 mgd are taken from the Niagara dolomite for domestic use and 0.5 mgd from Pleistocene deposits.

About 70 wells developed in the Niagara dolomite are used by commerce and industry. A detailed survey of pumpage from these 70 wells has not been made, but it

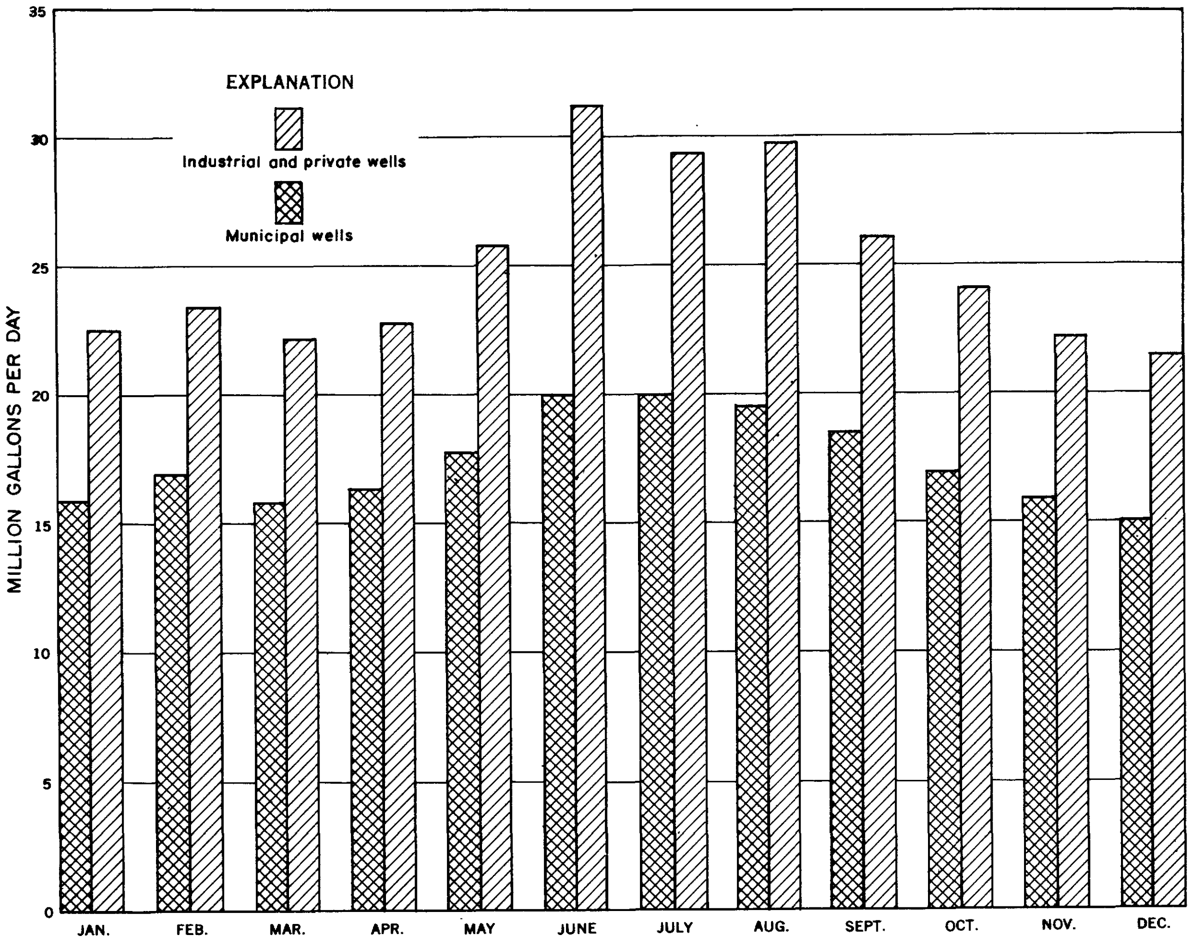

Figure 24.—Average daily pumpage from deep wells in the Milwaukee area, 1949.

is estimated to be between 5 and 10 mgd or about 7.5 mgd. The withdrawal from the Niagara dolomite is as follows: 5.5 mgd for domestic use, 7.5 mgd for industrial and commercial use, and 6.0 mgd is withdrawn from the sandstone after recharge from the dolomite; total 19 mgd.

About 0.5 mgd are pumped from farm and domestic wells developed in various deposits of the Pleistocene. Most of the wells developed in these deposits are located in the southern parts of Milwaukee and Waukesha Counties where a thick cover of drift exists over the Niagara dolomite. Many small wells have been developed in Pleistocene drift deposits in the Muskego Lake area and in several villages in the southern part of the area.

Fluctuation in Water Use

Summer demands on water supplies exceed the demand during colder seasons. Variation in monthly pumpage at the Milwaukee water works in 1950 is shown in figure 25 and variation in pumpage from deep wells in the Milwaukee area is shown in figure 24. During the summer large quantities of water are used for lawn sprinkling, cooling, and refrigeration. The maximum daily pumpage at the Milwaukee water works is usually somewhat more than 50 percent higher than the average daily pumpage for the year, and the minimum is about 60 percent less than the daily average.

The maximum volume of water pumped in one day at the Milwaukee water works during 1950 was 183.64 million gallons on August 15. The minimum volume pumped in one day in 1950 was 71.12 million gallons on January 1. The all-time maximum daily pumpage of 189.9 million gallons occurred in 1949. An all-time peak consumption rate of 333 mgd was attained in 1947. This was a short period rate, however, occurring only during a peak period of a peak day and before lawn sprinkling restriction were imposed. In 1951 the maximum rate of consumption was 274 mgd.

The economic condition of the area is a factor in the fluctuation of water demand over a longer period of time. For example, the rate of water use decreased in the years 1930-33 (figs. 22 and 23). Milwaukee, a

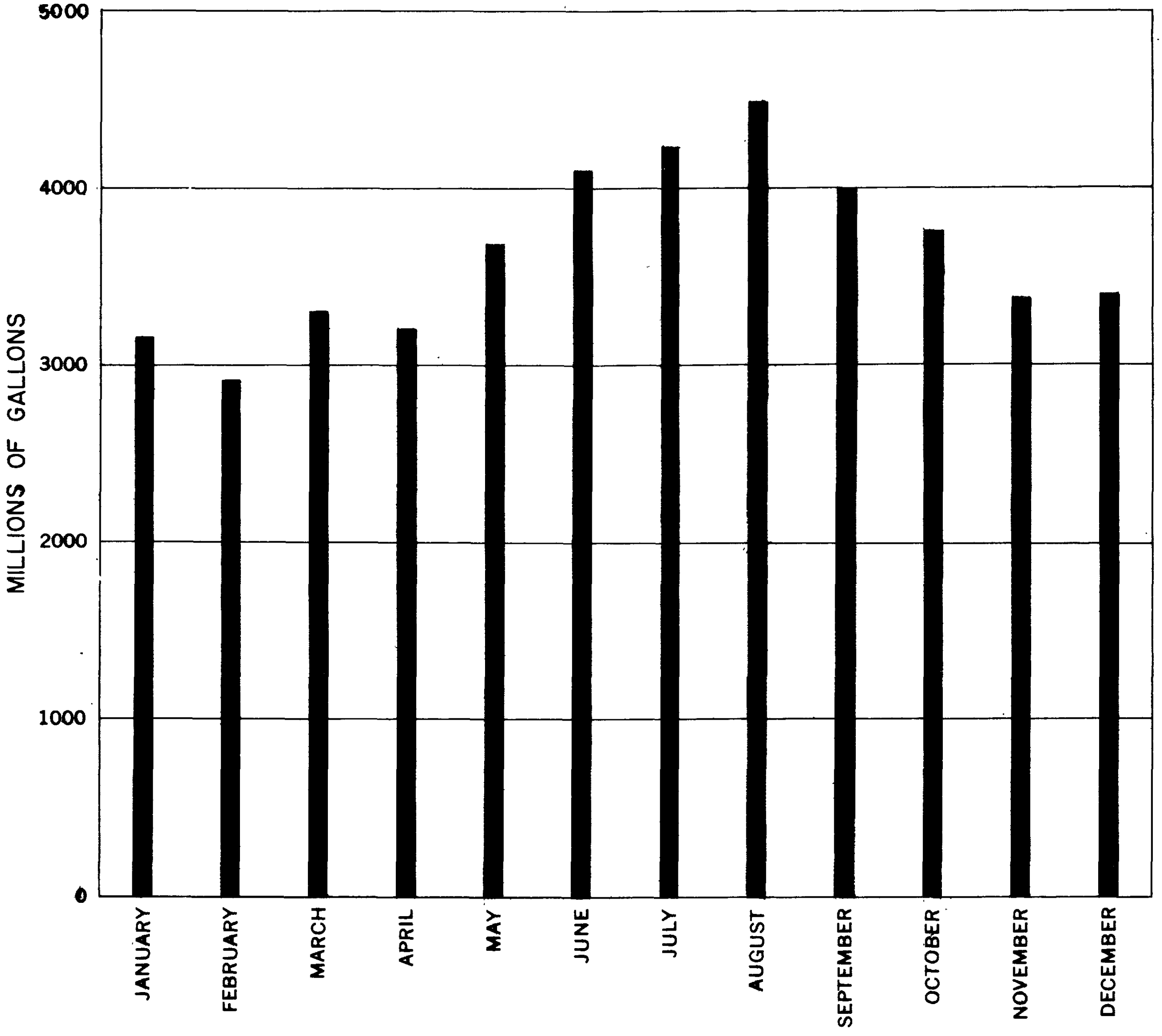

Figure 25.—Monthly pumpage at Milwaukee water works, 1950. (From Milwaukee water works data, 1950.)

typical industrial center, is growing rapidly and enlarging the manufacturing and transportation facilities. As a terminal for lake traffic and a gateway to a great part of the midwest, it feels the economic pulsations of a large area. Since 1940, the rising trend of water use has been especially marked in the industrial field, and indications are that it will continue to rise (fig. 23). Reduction of leakage throughout the system, sprinkling control, improved equipment, and observation of other water-conserving practices have decreased the volume of water classified as public and operational pumpage by the Milwaukee water works.

Conflicting Uses

Except for the few miles of their lower commercialized reaches, the three rivers of Milwaukee have been highly developed as recreational areas in the form of boulevards and parks. The large concentration of population demands a good-sized recreational area within easy driving distance, and it was early recognized that the rivers and lakeshore were desirable for park and recreation development.

Milwaukee County parks number over eighty with a total area of 6,729 acres and offer a great variety of recreational facilities. Long-range plans of the County Park Commission call for further development of the natural waterways for public use. Because of this improvement along the river, flanking land values have risen. Consequently, these areas have become extremely desirable for modern residential expansion and are generally not available for industrial development.

POTENTIALITIES

Lake Michigan-Huron

Lake Michigan-Huron affords Milwaukee an almost unlimited supply of good quality, cold, fresh water.

The following example indicates its magnitude. The top inch of Lake Michigan-Huron contains about 789,000 million gallons of water. At a withdrawal rate of 120 mgd, average city water pumpage rate for 1950, it would take 18 years to lower the level of the lake an inch, ignoring all other factors governing the volume of the lake. The increased use of lake water seems to be an engineering problem involving transportation, purification, and distribution rather than one stemming from any shortage of raw-water supply.

Rivers

The average flow of the Milwaukee River since 1915 is 386 cfs or 249 mgd. However, storage facilities would be necessary to make available a steady supply of anything near that size. From figure 9 it is noted that the river is a potential source of at least 0.058 cfs per square mile or 38.3 cfs (24.8 mgd) for 95 percent of the time. However, the present location of industry along reaches of the river affected by backwater from the lake and the use of the upper reaches as parkways make it unlikely that the river will be developed to any great extent as an industrial source of water.

Much of the Menomonee River drainage area is urban or industrial and serviced by storm sewers. The Kinnickinnic offers little possibility for future development as a water supply because of its extremely low flow and, like the Menomonee, its present utilization in parkways. The Fox and Root Rivers flow away from Milwaukee, draining small parts of Milwaukee County in their upper reaches. With the immediate and unlimited supply of Lake Michigan water, it is unlikely that development of these streams would be economical except where small quantities of water are needed near the stream.

Ground Water

The rate of pumping from deep wells in 1950, about 23 mgd, can be continued with about 35 feet of additional decline in water levels by 1960 if the distribution of pumpage remains about the same. If, however, the rate of pumping is increased to about 28 mgd by 1960 and the distribution remains unchanged, the decline of static water levels may be as much as 65 feet in the Wauwatosa area. Dispersal of wells to the west of present centers of pumpage in Milwaukee and Waukesha Counties, that is, toward the recharge area, would be more effective in reducing water-level decline than dispersal in any other direction. Water levels in the Milwaukee area will continue to decline as long as the rate of withdrawal continues to increase.

It is estimated that the immediate recharge area for the sandstone aquifer in the Milwaukee area is about 400 square miles. If about 10 percent of the annual precipitation reaches the water table in the recharge area, the total available recharge at the recharge area would be about 60 mgd. This figure at least indicates the size of the available recharge to the Milwaukee area. Additional ground water could be obtained in many parts of the area through proper development of Niagara dolomite and Pleistocene deposits.

WATER LAWS

There are no legal restrictions on the use of water for public water supply. There is a state statute (3134) which requires those maintaining a dam on any navigable stream to pass at all times at least 25 percent of the natural low flow. The Public Service Commission of Wisconsin maintains regulatory control of navigable state waters, protects the riparian rights of all adjacent property owners, and has jurisdiction over the construction and operation of dams, power plants, etc.

A Federal law prohibits deposition of refuse into navigable waters of the United States or their tributaries. There are a number of state statutes relating to the discharging of wastes into surface and ground waters. Under sections 144.03 and 144.53 the State of Wisconsin has general supervision over the administration and enforcement of all laws relating to the pollution of the surface and underground waters (including portions of Lake Michigan bordering Wisconsin). A State water pollution committee is authorized to conduct experiments, investigations, and research in connection with surface water pollution and industrial waste disposal. It may issue orders and adopt regulations concerning municipal or industrial wastes. A state statute provides that any county containing a city of the third class, may improve the water supply in any river within the city, including the reduction of discharge of noxious matter from streets and highways.

By virtue of state statute, the city of Milwaukee has jurisdiction over pollution entering Lake Michigan via the Milwaukee, Menomonee, and Kinnickinnic Rivers. The Park Commission has authority under State Statutes 27.05 (1) and (6) to investigate pollution of the water courses with respect to its parks and make recommendations to the Metropolitan Sewerage Commission or the State Board of Health.

A state statute prohibits vessels from discharging certain wastes and refuse into any waters in the states jurisdiction.

Federal laws concerning navigation are intended to prevent obstruction to navigation in waters declared navigable by the Department of the Army.

State Statutes 162, 144.02, 144.03 and 144.04 provide for regulation of the water resources and of well construction by the Wisconsin State Board of Health. Perhaps the most important statute affecting groundwater development in the Milwaukee area is 144.03 (6), (7), and (8) which requires a permit for the construction or reconditioning of any well which will pump over 100,000 gpd either singly or in combination with other wells on the property. It is further provided that no permit may be obtained if the proposed well will adversely affect the availability of water to a public supply.

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