Water Resources of the Green Bay Area Wisconsin

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1499-G

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By DOYLE B. KNOWLES, FREDERICK C. DREHER, *and* GEORGE W. WHETSTONE

WATER RESOURCES OF INDUSTRIAL REGIONS

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A summary of the source, occurrence, availability, and use of water in the area

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WATER RESOURCES OF THE GREEN BAY AREA, WISCONSIN

By Doyle B. Knowles, Frederick C. Dreher, and George W. Whetstone

ABSTRACT

The Green Bay area comprises an area of about 525 square miles in eastern Wisconsin at the south end of Green Bay. It includes the western three-fourths of Brown County and the eastern one-ninth of Outagamie County. In 1960, the population of the area was estimated at 124,000.

The most prominent topographic feature is the northwest-facing, southwestward trending Niagara escarpment. The area northwest of the escarpment drains into Green Bay via the Fox River, Suamico River, Duck Creek, and their tributaries. The area southeast of the escarpment is drained by streams that flow into Lake Michigan.

The chief sources of surface water in the Green Bay area are the Fox River, Green Bay, and Lake Michigan. Smaller amounts of water are available from the East and Suamico Rivers and other streams. A sandstone aquifer is the principal source of the ground-water supply. The Niagara dolomite, although largely undeveloped, is potentially an important aquifer in the eastern part of the area. Small amounts of water are obtained also from the Platteville formation and from deposits of Pleistocene and Recent age. Water from the surface- and ground-water sources is moderately hard to very hard.

The Fox River, tributary to Lake Michigan at Green Bay, is a significant source of water for industrial use in the Green Bay area. The Menasha Dam, which controls release of water from the Lake Winnebago pool, is the major regulation on the Fox River, and it has considerable effect in reducing peak flows and supplementing low flows in the lower Fox River. The average discharge of the lower Fox River for the period 1898–1959, as measured at the gaging station at Rapide Croche Dam, was 2,687 mgd (million gallons per day). The longest consecutive period during which the discharge averaged less than 500 mgd was 80 days. The average discharge can be expected to fall below 700 mgd about once every 5 years for a 7-day period. In 1959, the average withdrawal of water from the Fox River was about 62 mgd. The water in the river is of the calcium magnesium bicarbonate type and is hard.

The small streams in the area are utilized chiefly for stock watering; some of the water, however, is used for irrigation. The water in the small streams is more highly mineralized than the water in the Fox River and is very hard.

Large quantities of water are available from Green Bay, but the disposal

of industrial waste into the bay has restricted the use of the water. The major withdrawal is for condenser cooling, and, in 1959, it averaged about 415 mgd. The water from Green Bay is moderately hard but is of better chemical quality than the water from the Fox River and the small streams in the area.

The only withdrawals of water from Lake Michigan for use in the Green Bay area are made by the city of Green Bay. In 1959, these withdrawals averaged 7.8 mgd.

The lower Fox River is not subject to extremes of flow owing to the dampening effect of the Lake Winnebago pool and the regulation of flow at Menasha Dam. Cloudbursts over the lower Fox River valley below Menasha Dam, however, have occasionally caused extremely high water, as in 1922, when the discharge at the mouth of the Fox River was estimated to be about 50,000 mgd. Daily discharges greater than about 13,000 mgd occurred only 7 times in the period 1918–59. The 50-year flood of 15,500 mgd represents an average runoff of less than 2.6 mgd per square mile of drainage area, a relatively low runoff for a 50-year flood in Wisconsin.

The sandstone aquifer is the principal source of ground water in the Green Bay area and furnishes water for public supply and industrial use. This aquifer includes rocks of Late Cambrian age, and the Prairie du Chien group and St. Peter sandstone of Ordovician age; it ranges in thickness from 550 to 640 feet. Ground water is found in openings along fractures and bedding planes and in the interstices between sand grains.

The sandstone aquifer can support additional development of large supplies of ground water. Wells can be developed in most of the area that will yield 500 gpm (gallons per minute) or more, provided they are properly spaced and penetrate the entire thickness of the aquifer. It is estimated that the perennial yield of the sandstone in the Green Bay area could be at least 30 mgd if the aquifer is properly developed; only 5.4 mgd was withdrawn in 1959. The water from this sandstone aquifer is of the calcium magnesium bicarbonate type, is very hard, and, at a few places, contains objectionable amounts of iron.

The Niagara dolomite, potentially a source of moderate to large quantities of water in the eastern part of the area, probably will yield 500 gpm or more to wells.

In 1959, the average withdrawal of water for all uses was estimated at 495 mgd, of which 98.2 percent was from surface-water sources and 1.8 percent was from wells. About 485 mgd of water was withdrawn for industrial use, 6 mgd for public supply, and 4 mgd for rural use. The industrial use of water averaged 441 mgd for condenser cooling, 38 mgd for processing by the paper industry, and 6 mgd for other industrial uses. The city of Green Bay used 7.8 mgd of water from Lake Michigan; other public supplies in the area used 2.6 mgd from wells. Of the withdrawals of water for rural use, about 75 percent was from wells and about 25 percent was from streams.

The discharge of wastes into the lower Fox River and its tributary streams has altered the quality of the natural water. The wastes consist chiefly of treated municipal sewage and treated and untreated wastes from the paper industry, rendering plants, a sugar mill, and other industries. The industrial waste makes up about 90 percent of the oxygen-demand loading in the lower Fox River, and treated municipal sewage accounts for about 10 percent. The dissolved-oxygen concentration of water in the lower Fox River decreases rapidly in the vicinity of Green Bay during the summer when the river water is warm. If the periods when the river water is warmest, generally during July and early August, were to coincide with periods of lowest annual streamflow, generally in late August, the river would be unable to assimilate the loading of decomposable organic matter.

In an emergency, industrial and public supply wells could supply at least 6 mgd for a sustained period and probably as much as 10 mgd for a period of several days. Six of the wells that formerly supplied the city of Green Bay are maintained in operating condition and could furnish about the same quantity of water as the industrial and other public supply wells. Small streams in the area would be supplemental sources of water, and the water in the Fox River and Green Bay is easily accessible.

INTRODUCTION

PURPOSE AND SCOPE

Information on the water resources of an area is essential to the orderly planning for municipal and industrial development, emergency water supply, and conservation of water in the interest of national security. Industrial and municipal growth depend on an adequate supply of good quality water to satisfy the needs of an expanding economy and population. The purpose of this report is to summarize the available information on the water resources of the Green Bay area, Wisconsin.

The report contains information on the source, availability, use, and quality of the water resources of the Green Bay area. It includes information on the ground- and surface-water sources of supply, the chemical character of selected ground and surface waters, water-supply systems, use of water, emergency water supplies, and the possibility of further development.

This report is intended to serve as a guide for selecting the most suitable source of water for a particular need. It should adequately guide the overall planning for location or expansion of industrial and municipal water facilities and be of assistance in planning for the location of emergency water supplies. More comprehensive and detailed information than is given in the report probably will be necessary to solve specific water-supply problems.

Most of the information used in the preparation of this report was collected over a period of many years by the Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey, Wisconsin Public Service Commission, Wisconsin Highway Commission, and the Wisconsin State Board of Health—committee on Water Pollution. Acknowledgment is made to the Wisconsin State Laboratory of Hygiene for records on the chemical character of ground-water supplies. Data on water use and water-supply systems were furnished by industries and municipalities.

The description by Drescher (1953) of the geology of the Green Bay area and its relation to the occurrence of ground water has served as

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the chief source of material in the discussion of the geology and ground water in this report.

The report was prepared under the general direction of C. L. R. Holt, Jr., district geologist, Branch of Ground Water; K. B. Young, district engineer, Branch of Surface Water; and G. W. Whetstone, district chemist, Branch of Quality of Water. Technical coordination and editorial guidance was furnished by K. A. MacKichan, Chief, Hydrologic Studies Section, Branch of General Hydrology.

LOCATION AND EXTENT OF AREA

The Green Bay area includes the western three-fourths of Brown County and the eastern one-ninth of Outagamie County (fig. 1). The area is in eastern Wisconsin at the south end of Green Bay and lies between lat 44°15′ and 44°40′ N., and long 87°54′ and 88°15′ W. The area, comprising about 525 square miles, is about 29 miles from north to south and about 18 miles from east to west.

The population of the Green Bay area in 1960 was estimated to be 124,000. The population of the principal cities and villages was as follows: Green Bay, 62,888; De Pere, 10,045; Howard, 3,485; Pulaski, 1,540; and Wrightstown, 840.

TOPOGRAPHY AND DRAINAGE

The most prominent topographic feature in the Green Bay area is a northwest-facing escarpment of Niagara dolomite that trends southwestward, roughly parallel to Green Bay and the Fox River (fig. 1). The top of the escarpment ranges in altitude from about 700 to about 950 feet, and in some places cliffs are more than 100 feet high.

A broad trough of low relief lies immediately northwest of the Niagara escarpment and extends northeastward from the southwest corner of the area through the cities of Wrightstown, De Pere, and Green Bay. The trough is drained by the Fox River and its tributary streams into Green Bay, a large arm of Lake Michigan. Northwest of this trough the land surface rises from an altitude of about 600 feet at Wrightstown and 580 feet at the city of Green Bay to an altitude of about 800 feet at Pulaski. The area is gently rolling and is drained by Duck Creek and the Suamico River into Green Bay. Except near its mouth, the direction of flow of Duck Creek is largely controlled by two eskers that parallel the stream and are the most prominent topographic features west of the Fox River.

The area southeast of the escarpment is rolling and is drained by the headwaters of streams that flow eastward or southeastward into Lake Michigan.

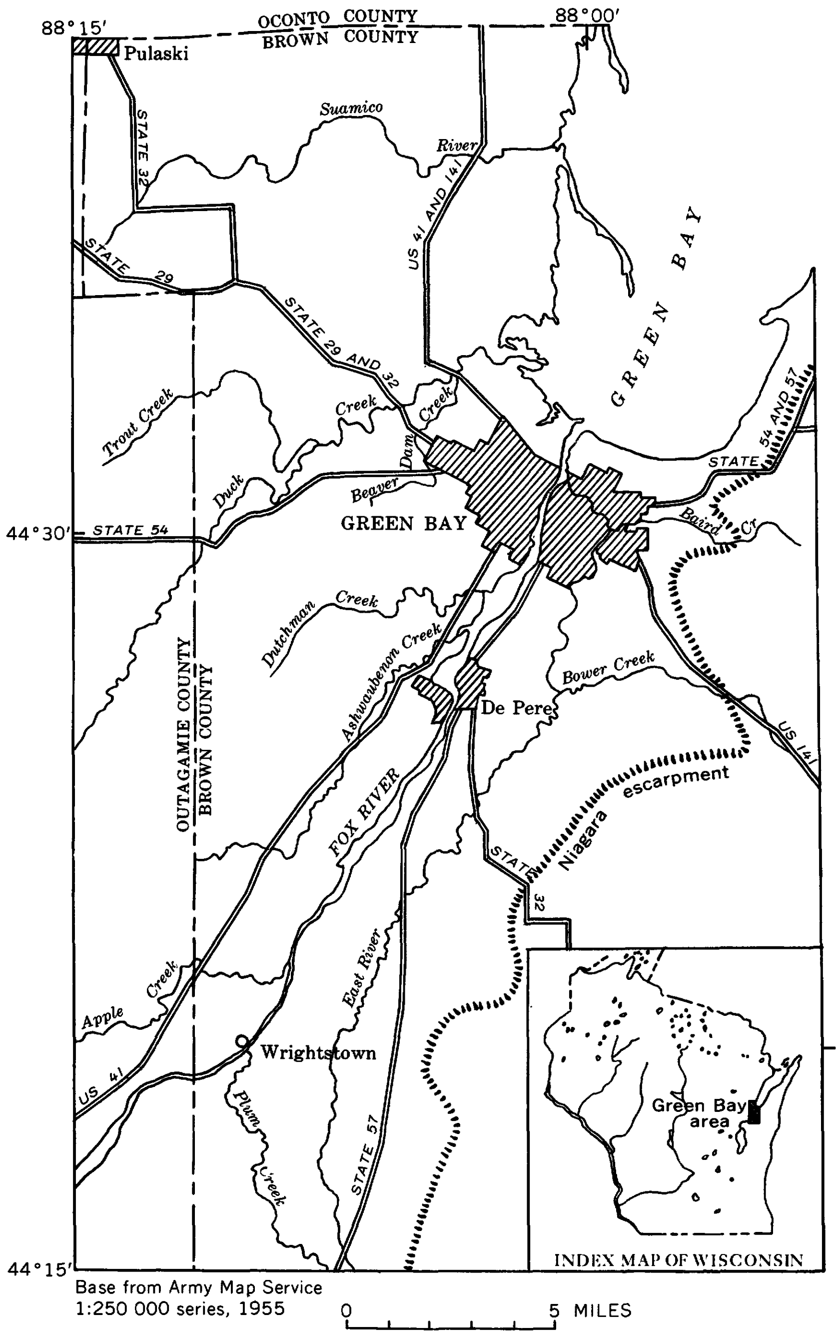


Figure 1.—Map showing Green Bay area, Wisconsin.

CLIMATE

The Green Bay area is characterized by cold winters and mild summers. The average annual temperature at the city of Green Bay during the period of record, 1887–1959, was 44.4° F. Average monthly temperatures ranged from 16.5° F in January to 70.4° F in July. The record-low temperature, −36° F, occurred in January 1888; and the record-high temperature, 104° F, in July 1936.

The average annual precipitation at the city of Green Bay during the period of record, 1887–1959, was 28.36 inches. The annual precipitation ranged from 16.31 inches in 1930 to 38.03 inches in 1914. June has the greatest precipitation, with an average of 3.41 inches; January has the least, with an average of 1.36 inches.

The average monthly precipitation and temperature and the annual precipitation for the period of record, 1887–1959, are summarized graphically in figure 2.

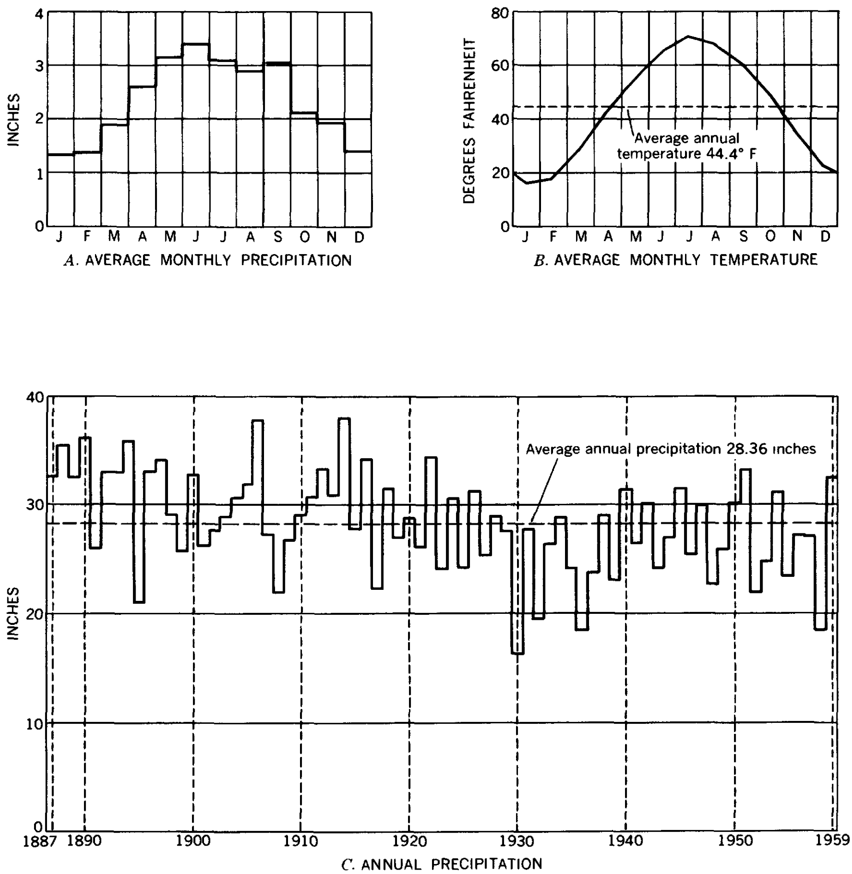


FIGURE 2.—Graphs showing precipitation and temperature at Green Bay, Wis., 1887–1959: *A*, average monthly precipitation; *B*, average monthly temperature; *C*, annual precipitation.

GEOLOGIC SETTING

The Green Bay area is underlain by a basement complex of crystalline rocks of Precambrian age. A thick sequence of consolidated rocks of Cambrian, Ordovician, and Silurian ages overlies the crystalline rocks. The consolidated rocks are divided, in ascending order, into: the Dresbach group, Franconia sandstone, and Trempealeau formation of Cambrian age; the Prairie du Chien group, St. Peter sandstone, Platteville formation, and Maquoketa shale of Ordovician age; and the Niagara dolomite of Silurian age. Unconsolidated deposits of Pleistocene and Recent overlie the older rocks throughout the area. The Platteville formation, as the name is used in this report, includes the Decorah formation and the Galena dolomite, which are units that can not be differentiated in the subsurface in the Green Bay area. A stratigraphic outline and summary of the water-bearing properties of the rocks underlying the Green Bay area is given in table 1.

The only rocks in the Green Bay area that contain little or no recoverable water are the rocks of Precambrian age and the Maquoketa shale. The rocks or the Dresbach group, Franconia sandstone, Trempealeau formation, Prairie du Chien group, and St. Peter sandstone are connected hydraulically and can be considered to form one aquifer, which Drescher (1953) called the sandstone aquifer. The sandstone aquifer is the principal source of groundwater supply in the Green Bay area.

The thickness and altitude of the rock units underlying the Green Bay area are shown graphically in the stratigraphic sections in figures 3 and 4. The stratigraphic section shown in figure 3 is approximately down the dip of the bedrock formations and extends from Pulaski through Green Bay to Denmark. The section shown in figure 4 extends from Kaukauna along the Fox River valley to Green Bay and is approximately parallel to the strike of the formations.

The consolidated rocks dip southeast at about 25 to 35 feet per mile. Because the dip of the beds is greater than the slope of the land surface, the formations lie at progressively greater depths to the southeast.

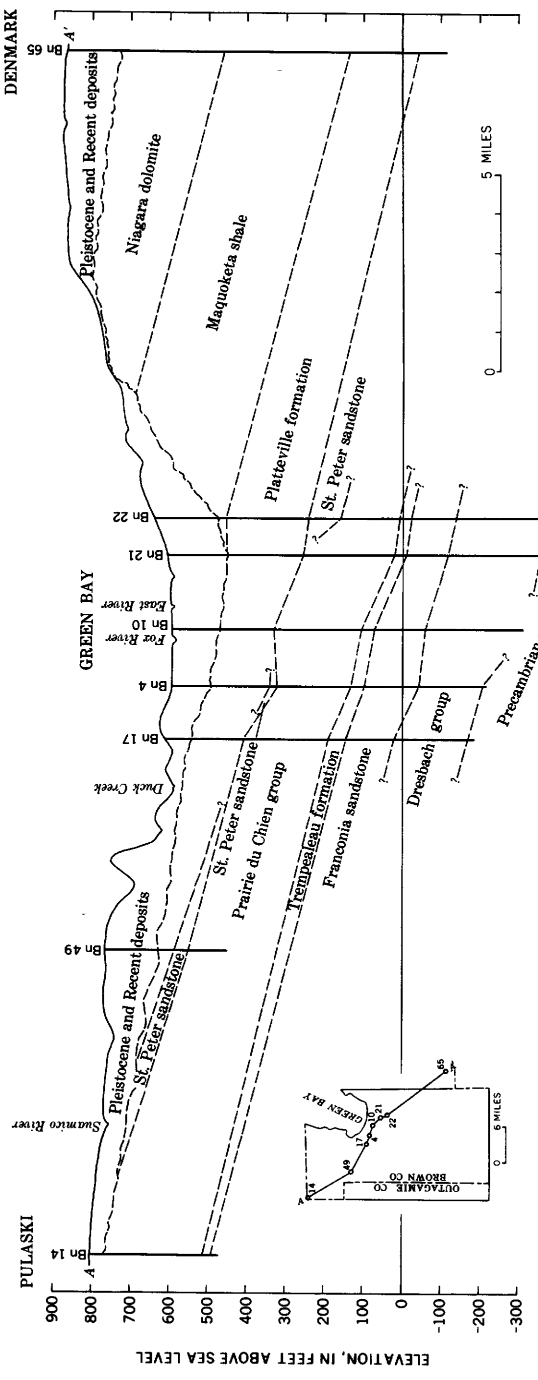
USE OF WATER

The city of Green Bay is a major Great Lakes port and is also the rail center for northeastern Wisconsin. The principal industries in the area include shipping, foundry, canning, meatpacking, cold storage, power generation, and the manufacture or processing of paper, dairy products, sugar, soap, fur, leather, and beer. Dairy farming is the principal occupation in the rural part of the Green Bay area, and

TABLE 1.—*Stratigraphic outline and summery of water-bearing properties of rocks underlying the Green Bay area, Wisconsin*

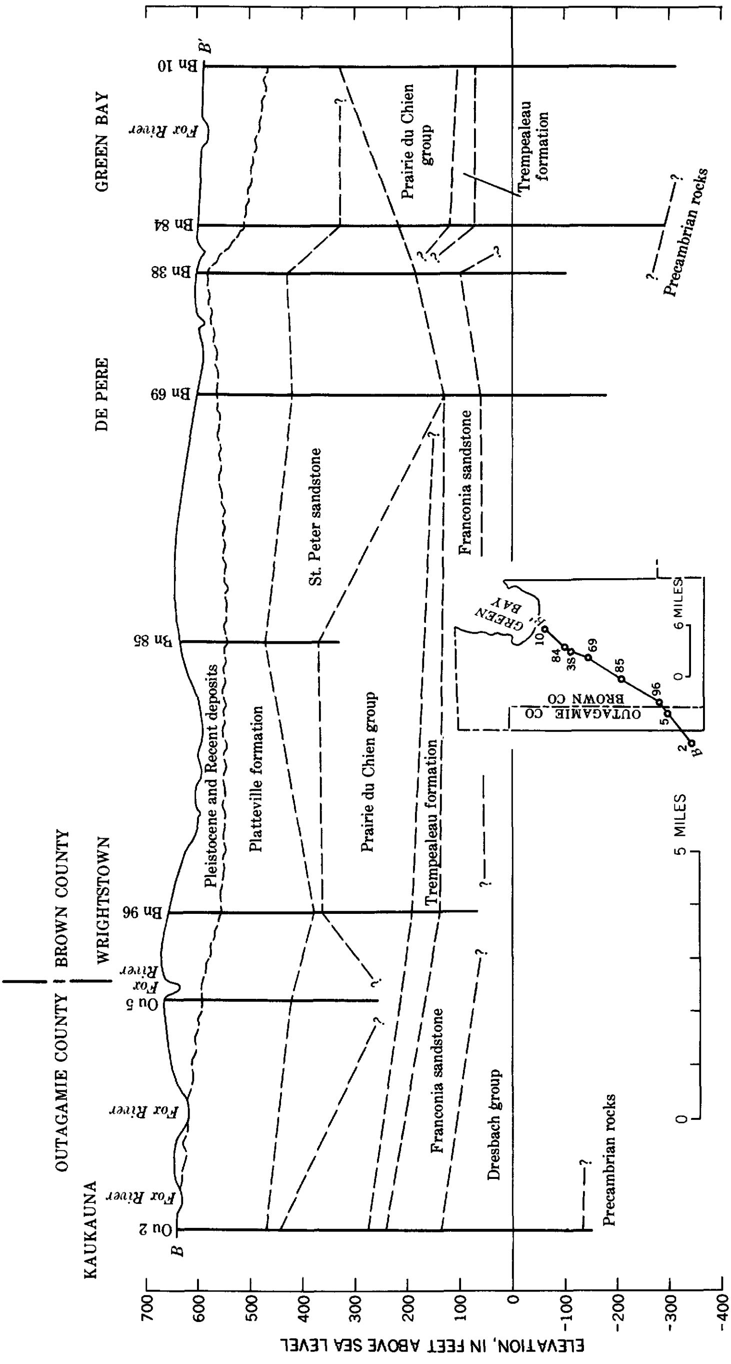
[Thicknesses based on well logs]

System	Rock Unit	Maximum thickness (feet)	Lithology	Water-bearing properties
Quaternary	Pleistocene and Recent deposits.	235	Unstratified till, and stratified clay, silt, sand, and gravel.	Generally yield only small quantities of water. Locally yields larger quantities where deposits of sand and gravel are thick.
Silurian	Niagara dolomite	360	Dolomite, light-gray, fine-grained, thinly bedded to massive. Some chert.	Yields moderate quantities of water to wells and springs from solutionally enlarged openings along fractures and bedding planes.
Ordovician	Maquoketa shale	325	Shale, blue-gray, compact. Some thin dolomite beds.	Yields little water to wells. Relatively impermeable.
	Platteville formation.	213	Dolomite, thin- to medium-bedded. Some chert and shale.	Yields small quantities of water to wells.
	St. Peter sandstone.	290	Sandstone, white to pink, fine- to medium-grained, dolomitic. Poorly cemented in places. Thin beds of red shale are common near base.	Yields moderate to large quantities of water to wells where unit is thick.
	Prairie du Chien group.	265	Dolomite, light-gray to white, thinly bedded to massive, and a few layers of chert, sandstone, and shale.	Yields small quantities of water to wells.
Cambrian	Trempealeau formation.	55	Sandstone, light-gray to pink, fine- to medium-grained and a few beds of pink to red siltstone and sandy dolomite.	Yields moderate to large quantities of water, depending on permeability and thickness. Rocks of Dresbach group reported to be most productive.
	Franconia sandstone.	155	Sandstone, light-gray, fine- to coarse-grained, well-cemented, dolomitic, glauconitic.	
	Dresbach group	270	Sandstone, light-gray to white, fine- to coarse-grained, well-cemented, hard.	
Precambrian		?	Granite, red, pink, and gray, and other crystalline rocks. Weathered at top.	Virtually impermeable except in weathered zone. Yields little or no water to wells.



(After Drescher 1953)

FIGURE 3.—Stratigraphic section from Pulaski to Denmark, Wis.



(After Drescher, 1953)

Figure 4.—Stratigraphic section from Kaukauna to Green Bay, Wis.

several small cheese factories employ a limited proportion of the agrarian population.

The city of Green Bay obtains its water supply from Lake Michigan. All other public-water supplies in the area are from ground-water sources, including supplies for the cities or villages of De Pere, Howard, Pulaski, and Wrightstown, and the towns of Allouez, Ashwaubenon, and Preble.

The largest industrial use of water in the Green Bay area is for condenser cooling. In 1959 the use of water for cooling was estimated to average 437 mgd, which is about 90 percent of the withdrawal for all uses in the Green Bay area. Industrial use of water, chiefly for processing operations, accounted for more than half the water supplied by the water-supply system of the city of Green Bay; however, the industrial water supplied by the city of Green Bay was only about 1 percent of the total withdrawal for industrial use in the area. In 1959, about 99 percent of the industrial water was obtained from surface-water sources and about 1 percent was obtained from ground-water sources.

The quantity of water withdrawn in the rural areas, chiefly for domestic use, watering stock, limited irrigation, and dairy-products processing, is estimated to be about 4 mgd.

SOURCES OF WATER

The chief sources of surface water in the Green Bay area are the Fox River, Green Bay, and Lake Michigan. Smaller amounts of water are available from the East and Suamico Rivers, Duck Creek, and other small streams in the area.

Fox River and Green Bay are the chief sources of large quantities of water for industrial use. Lake Michigan is a practically unlimited source of water. Owing to the distance that the water must be transported, however, Lake Michigan will probably be utilized only for public supply and some industrial purposes.

The sandstone aquifer is the source of all public water supplies except that of the city of Green Bay. It also supplies many industries that require processing water of a uniform quality and temperature. Sand and gravel deposits of Pleistocene and Recent age generally supply adequate water for farm and domestic use. Locally adequate water can be obtained for small municipal and industrial uses, especially where the deposits are thick. The Niagara dolomite is an important source of water in the eastern part of the area, east of the Niagara escarpment. The Platteville formation generally supplies adequate water for domestic and stock needs in the western part of the area but is little used as a source of water in the eastern part.

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Surface water and ground water are closely related. Pumping ground water may deplete the flow of a stream, and diversions from a stream may affect the storage of ground water. Both surface water and ground water are derived from precipitation. Part of the precipitation flows into streams and lakes as direct runoff; part returns to the atmosphere through evaporation and transpiration; and part seeps downward through the soil and rocks to become ground water, later to be discharged into bodies of surface water by seepage or springs or into the atmosphere by evaporation or transpiration by plants. The low flow of most streams in the Green Bay area consists chiefly of ground-water discharge.

The kind and amount of dissolved and suspended material in water in the Green Bay area affect the usefulness of the water for some purposes and may increase the cost of processing the water for specific purposes. There is a natural range in dissolved and suspended material in water. When runoff to streams is rapid, the amount of dissolved material is generally relatively small, and the amount of suspended material relatively large. During periods of low streamflow, when a large part of the streamflow is from ground-water discharge, the concentrations of dissolved material are commonly higher and the suspended material lower than during periods of high surface runoff. In the Green Bay area, changes in quality also are brought about by the discharge of industrial and domestic wastes into streams or underground reservoirs. The source and significance of dissolved mineral constituents and the physical properties of natural waters are given in table 2.

The location of the wells tapping the sandstone aquifer, streamflow measuring sites, and surface-water sampling sites are shown in plate 1.

TABLE 2.—*Significance of dissolved mineral constituents and physical properties of natural water*

Constituent or physical property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils, usually in small amounts from 1 to 30 ppm. High concentrations, as much as 100 ppm, generally occur in highly alkaline water.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of steam turbines. Inhibits deterioration of zeolite-type water softeners.
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment. More than 1 or 2 ppm of soluble iron in surface water usually indicate acid wastes from mine drainage or other sources.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, dyeing, bleaching, ice manufacture, brewing, and other processes. Federal drinking water standards state that iron and manganese together should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not as common as iron. Large quantities often associated with high iron content and with acid water.	Same objectionable features as iron. Causes dark brown or black stain. Federal drinking water standards provide that iron and manganese together should not exceed 0.3 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.

TABLE 2.—*Significance of dissolved mineral constituents and physical properties of natural water*—Continued

Constituent or physical property	Source or cause	Significance
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in ancient brines, sea water, some industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine water and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Federal drinking water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in ancient brines, sea water, and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal drinking water standards recommend that the chloride content should not exceed 250 ppm.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual. (Maier, F. J., 1950, Fluoridation of public water supplies, Jour. Am. Water Works Assoc., vol. 42, part 1, p. 1120–1132.)

Nitrate (NO_3)	Decaying organic matter, sewage, and nitrates in soil.	Concentrations much greater than the local average may suggest pollution. There is evidence that more than about 45 ppm of nitrate (NO_3) may cause a type of methemoglobinemia in infants, sometimes fatal. Water of high nitrate content should not be used in baby feeding (Maxey, K. F., 1950, Nat. Research Council, Bull. San. Eng., p. 265, App. D). Nitrate has shown to be helpful in reducing intercrystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes any organic matter and some water of crystallization.	Federal drinking water standards recommend that the dissolved solids should not exceed 500 ppm. Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most water, nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Water of hardness up to 60 ppm is considered soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; more than 200 ppm, very hard.
Specific conductance (micromhos at 25°C).	Mineral content of the water	Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents. Varies with temperature; reported at 25°C.
Hydrogen ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides and phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals.

TABLE 2.—*Significance of dissolved mineral constituents and physical properties of natural water*—Continued

Constituent or physical property	Source or cause	Significance
Temperature		Affects usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground waters from moderate depths usually are nearly constant in temperature, which is near the mean annual air temperature of the area. In very deep wells the water temperature generally increases on the average about 1°F with each 60 foot increment of depth. Seasonal fluctuations in temperatures of surface waters are comparatively large depending on the depth of water but do not reach the extremes of air temperature.
Dissolved oxygen (O_2).	Dissolved in water from air and from oxygen given off in the process of photosynthesis by aquatic plants.	Dissolved oxygen increases the palatability of water. The amount necessary to support fish life varies with species and age, with temperature, and concentration of the other constituents in water. Under average stream conditions, 4 ppm is usually necessary to maintain a varied fish fauna in good condition. For industrial uses, zero dissolved oxygen is desirable to inhibit corrosion.
Hydrogen sulfide (H_2S).	Dissolved in water from reduction of sulfates and organic refuse.	Hydrogen sulfide imparts odor and taste of "rotten eggs" to water. May give color to water.

FOX RIVER

DESCRIPTION

The Fox River, tributary to Lake Michigan at Green Bay, drains about 6,500 square miles of east-central Wisconsin. The river is divided into two distinct parts by Lake Winnebago (fig. 5). Upstream from Lake Winnebago the basin is fairly flat and is drained by the Fox River and its principal tributary, the Wolf River. The upper Fox River, which has a length of about 120 miles, descends about 40 feet in the 107 miles from Portage to the Lake Winnebago pool. The slight fall affords little opportunity for power development. The river banks are low and floods are frequent. The U.S. Army Corps of Engineers maintains several navigation locks in the upper Fox River. The lower reaches of the Wolf River are characterized also by low banks and a relatively flat slope. In the upper 90 miles, however, the Wolf River drops almost 700 feet and flows within fairly high, well-defined banks.

The Winnebago pool, which includes six lakes and connecting channels in addition to Lake Winnebago, is controlled by the Menasha Dam. It has a surface area of about 265 square miles at the elevation of the crest of the dam. In the interest of navigation and the development of water power, authority is vested in the Corps of Engineers to regulate release of water through the Menasha Dam. The limits of regulation, which have been in effect for more than 70 years, are from 21¼ inches above the crest of the dam down to the crest during navigation season and down to 18 inches below the crest at other times. The U.S. Army Corps of Engineers (1922, p. 91) tries to maintain the stage at the upper limit "* * * as far as the capacity of the Fox River below Menasha and the security of government works will allow."

In the lower Fox River valley, below Menasha Dam, there is a concentration of industry, power development, and population. The lower Fox River descends about 167 feet in the 38 miles from Menasha Dam to Green Bay. Hydroelectric plants take advantage of this gradient, creating a series of river-run ponds. Nineteen locks, operated by the Corps of Engineers, facilitate navigation in this reach of the river. A navigation channel 6 feet in depth is maintained above the city of Green Bay, and 22 feet in depth from the city into Green Bay. Fluctuation in river stage is minimized by the controlled release of water from the Lake Winnebago pool.

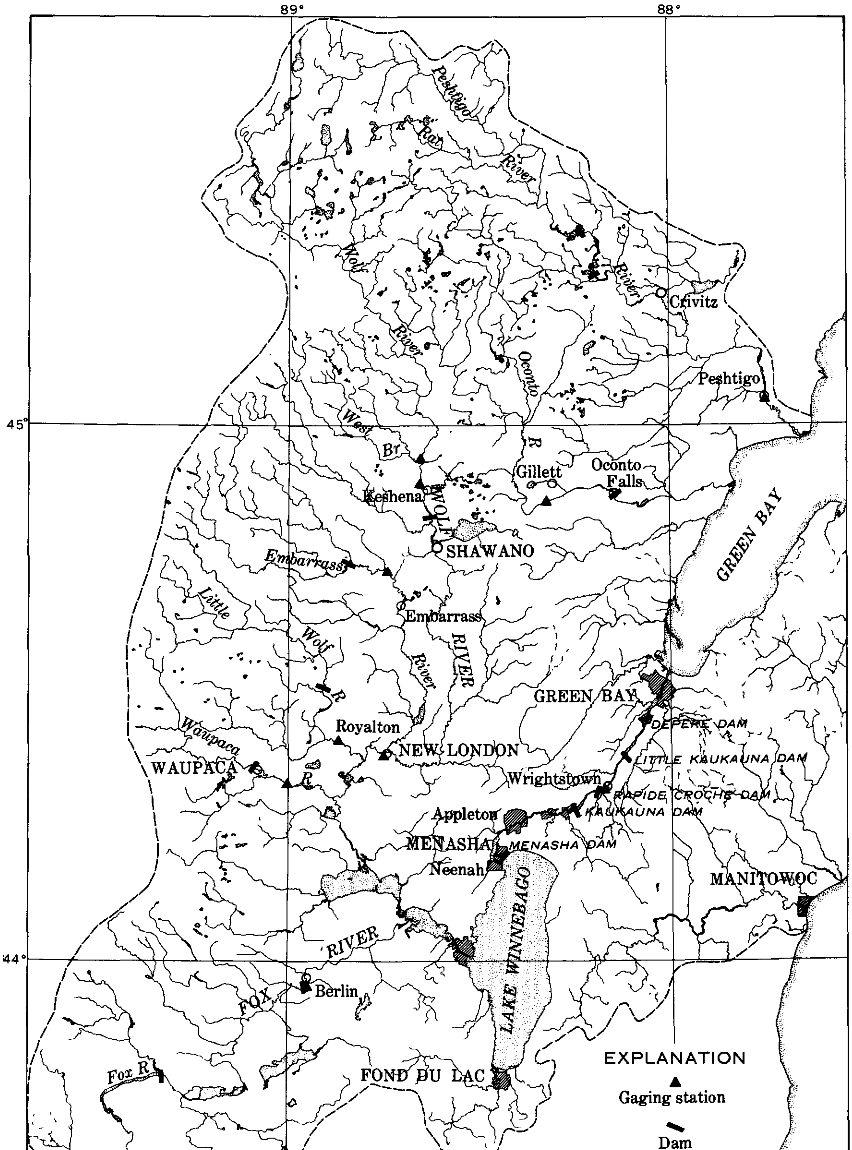

Figure 5.—Map of Lake Michigan drainage basin from Peshtigo to Manitowoc, Wis.

Data obtained at the following gaging stations show the general runoff characteristics of the basin above Green Bay:

Gaging station	Drainage area (sq mi)	Period of record
Fox River at Berlin	1,430	1898–1959
Wolf River at New London	2,240	1896–1959
Little Wolf River at Royalton	485	1914–1959
Waupaca River at Waupaca	305	1916–1959
Lake Winnebago at Oshkosh	6,030	1857–1959 [1]
Fox River at Rapide Croche Dam [2]	6,150	1896–1959 [3]

[1] Records for 1857–1938 in files of U.S. Army Corps of Engineers.
[2] Located within the area of this report.
[3] Records for 1896–1917 show monthly discharge only.

STORAGE IN LAKE WINNEBAGO POOL

The Menasha Dam, about 19 miles upstream from the gaging station at Rapide Croche Dam, is the only major regulation on the Fox River, but it has considerable effect in reducing peak flows and supplementing low flows in the lower Fox River. The capacity of the Lake Winnebago pool is shown in figure 6. The useable capacity is 25,000 million cubic feet (582,000 acre feet). The monthly change in storage of the pool and the monthly mean discharge of the Fox River at Rapide Croche Dam for the 1959 water year are listed in table 3. The adjustment to the observed flow at Rapide Croche Dam makes no allowance for such factors as evaporation or perched ice. In regulating release from the dam, the Corps of Engineers uses current reports on precipitation, ice, and soil conditions as well as stage and discharge data collected both above and below the dam.

TABLE 3.—*Effect of Lake Winnebago storage on monthly mean discharge of Fox River at Rapide Croche Dam for the 1959 water year*

[Datum of Oshkosh gage is 745.05 feet above mean tide at New York, N.Y.]

Date	Lake Winnebago					Fox River at Rapide Croche Dam	
	Gage height at Oshkosh		Storage above elevation of 744 feet (mcf)	Change in storage (mcf)	Equivalent change in storage (cfs)	Unadjusted mean discharge (cfs)	Adjusted mean discharge (cfs)
	Above datum of gage (ft)	Above mean tide (ft)					
1958							
9/30/	2.10	747.15	22,040				
10/31	2.08	747.13	21,880	−160	−60	1,446	1,386
11/30	2.14	747.19	22,340	+460	+177	1,528	1,705
12/31	2.04	747.09	21,580	−760	−284	1,562	1,278
1959							
1/31	1.85	746.90	20,170	−1,410	−526	2,073	1,547
2/28	1.66	746.71	18,780	−1,390	−575	2,704	2,129
3/31	.82	745.87	12,700	−6,080	−2,270	4,521	2,251
4/30	3.06	748.11	29,340	+16,640	+6,420	7,027	13,447
5/31	3.05	748.10	29,270	−70	−26	5,336	5,310
6/30	2.72	747.77	26,740	−2,530	−976	3,501	2,525
7/31	2.49	747.54	24,990	−1,750	−653	1,946	1,293
8/31	2.32	747.37	23,700	−1,290	−482	1,724	1,242
9/30	2.20	747.25	22,800	−900	−347	1,761	1,414
Water year				+760	+24	2,923	2,947

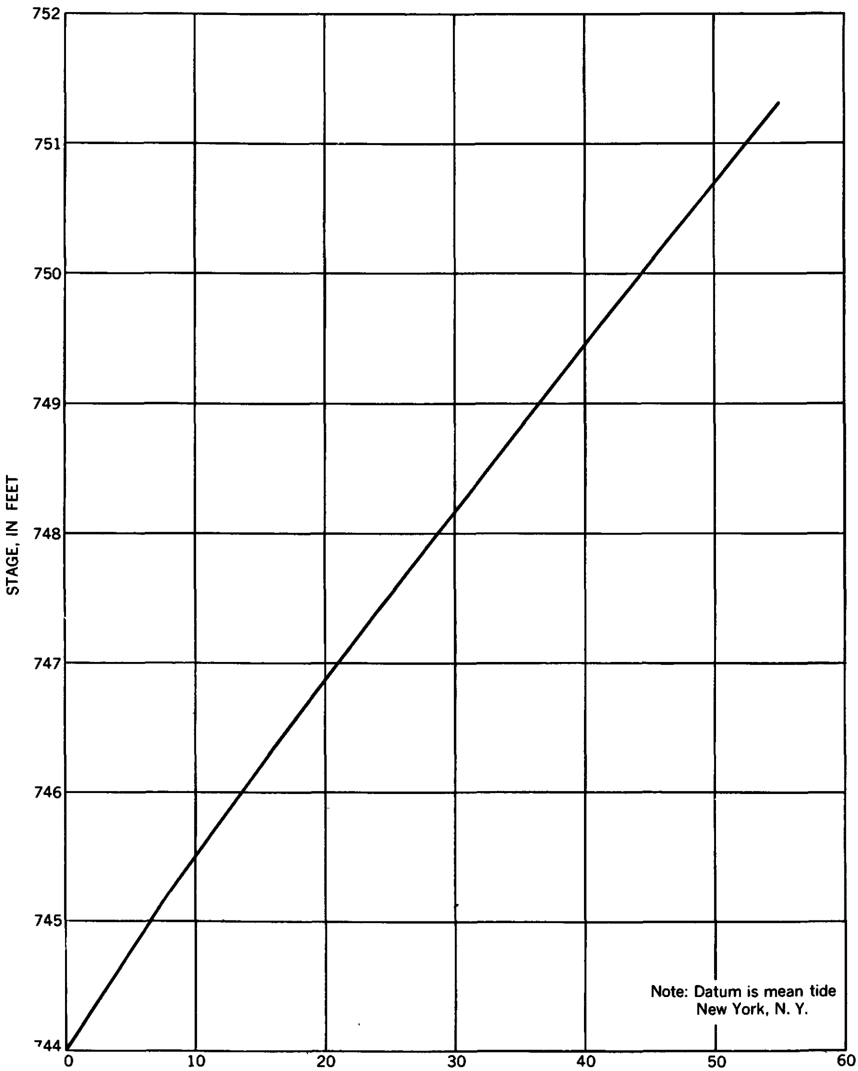

FIGURE 6.—Capacity curve for Lake Winnebago pool.

The effect of changes in storage in the Lake Winnebago pool on the flow of the Fox River is shown in the hydrograph of inflow and outflow of Lake Winnebago for the 1959 water year (fig. 7). The inflow was computed from records of the daily discharge at four gaging stations above the pool. The drainage area upstream from the gaging stations constitutes about 75 percent of the drainage area above Menasha Dam. The outflow was computed from records of daily dis-

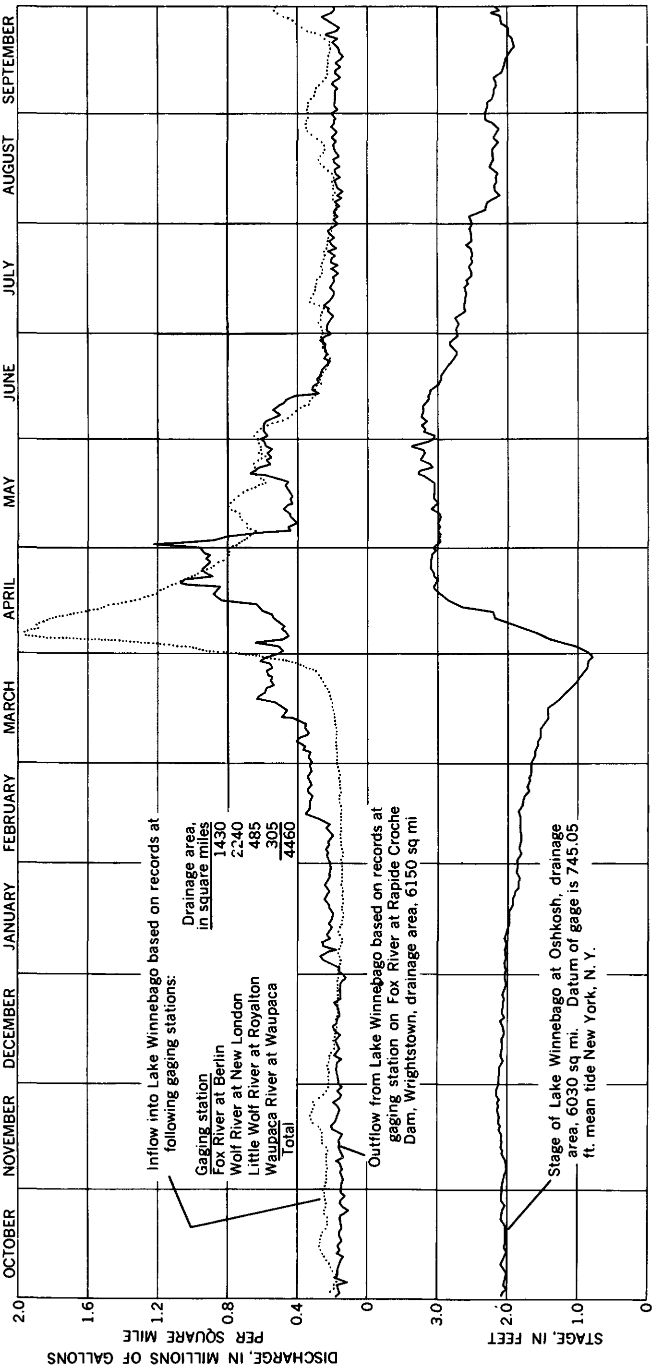

FIGURE 7.—Measured inflow, outflow, and stage of Lake Winnebago for 1959 water year.

charge at Rapide Croche Dam, where the drainage area is only about 2 percent larger than that at Menasha Dam. Some water was stored in the late fall and was released steadily throughout the winter to supplement the decreasing flow in the lower Fox River and to lower the pool in anticipation of high spring runoff. Much of the spring runoff from the upper part of the basin was then stored in the Lake Winnebago pool. The stage of the pool rose about 2 feet from March 30 to April 18. The flow at Rapide Croche Dam was kept fairly uniform throughout the summer as the level of Lake Winnebago fluctuated with the runoff from the upper part of the basin.

FLOW CHARACTERISTICS

The discharge of the Fox River at the Rapide Croche Dam gaging station is generally representative of the flow of the lower Fox River between Menasha Dam and Green Bay. The rather uniform flow characteristics of the Fox River are shown in figure 7. The additional drainage area between the gaging station and Green Bay causes an increase of flow of about 5 percent. The runoff into the lower Fox River from this drainage area is generally low but can be excessive when heavy rains occur locally. The average discharge for the period 1898–1959 was 2,687 mgd. The maximum discharge was 15,500 mgd on April 18, 1952; the minimum discharge of 89 mgd on August 2, 1936, was the result of regulation.

The duration curve (fig. 8) of daily flow at the gaging station at Rapide Croche Dam for the period 1918–59 shows the percentage of time during which a specified discharge was equaled or exceeded. Although the curve is a record of the past flow of the stream, it can be used to estimate future availability of water if it is assumed that the flow in 1918–59 is representative of the long-term flow. Precipitation records at the city of Green Bay for 1887–1959 show that the average precipitation from 1918 to 1959 was below the average for the period of record (fig. 2). Additional regulation or change in the pattern of regulation of the Fox River above the gaging station will affect the flow duration, especially the extremes of flow. The flow-duration curve does, however, show that the lower Fox River has a high sustained flow, which has made the river valuable for power development, pulp and paper processing, and sewage dilution in the Green Bay area.

Discharge-availability curves also are useful, especially in evaluating low-flow characteristics. The curves in figure 9 representing the discharge of the Fox River for 1918–59 show the longest period of time during which the discharge was less than a specified rate and the lowest average discharge for specified periods. For example, the longest consecutive period during which the discharge at Rapide

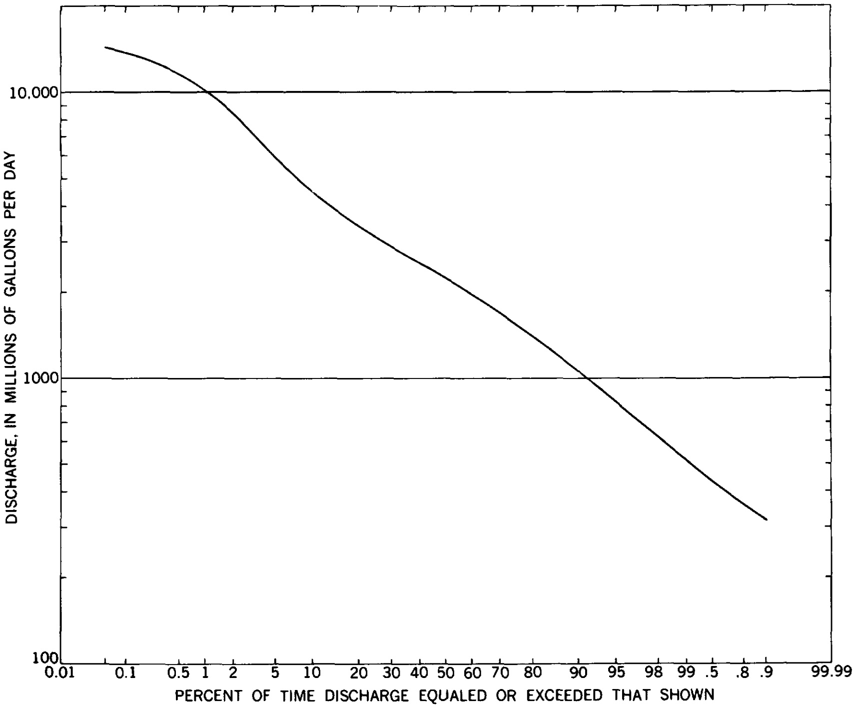

FIGURE 8.—Duration curve of daily flow of Fox River at Rapide Croche Dam near Wrightstown, Wis., 1918–59.

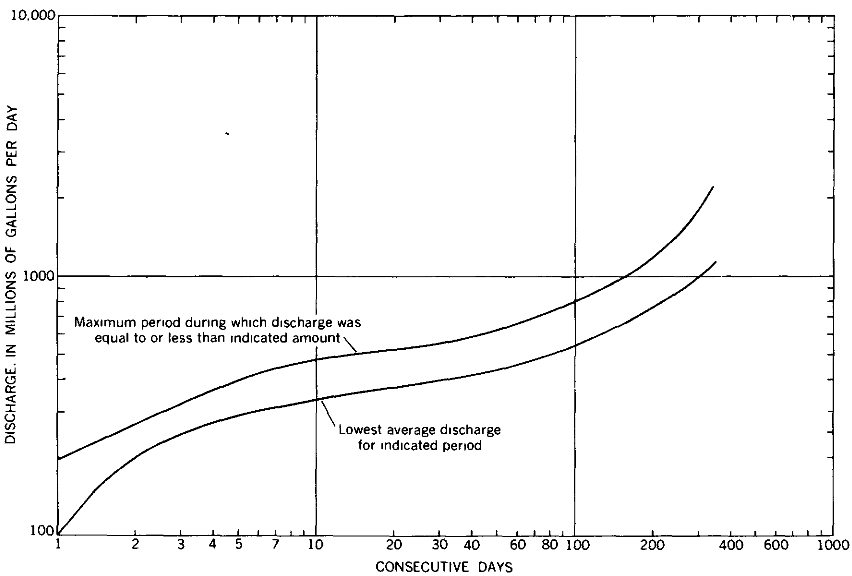

FIGURE 9.—Availability of discharge for Fox River at Rapide Croche Dam near Wrightstown, Wis., 1918–59

Croche Dam was less than 500 mgd was 14 days, and the longest period during which the discharge averaged as low as 500 mgd was 80 days. Users of the river water can usually tolerate isolated days of low flow, but long consecutive periods of low flow may produce hardships.

The frequency of low flows for 7- and 30-day periods at Rapide Croche Dam in 1918–59 is shown in figure 10. For example, the average flow can be expected to fall below 700 mgd about once every 5 years for a 7-day period and about once every 6 years for a 30-day period.

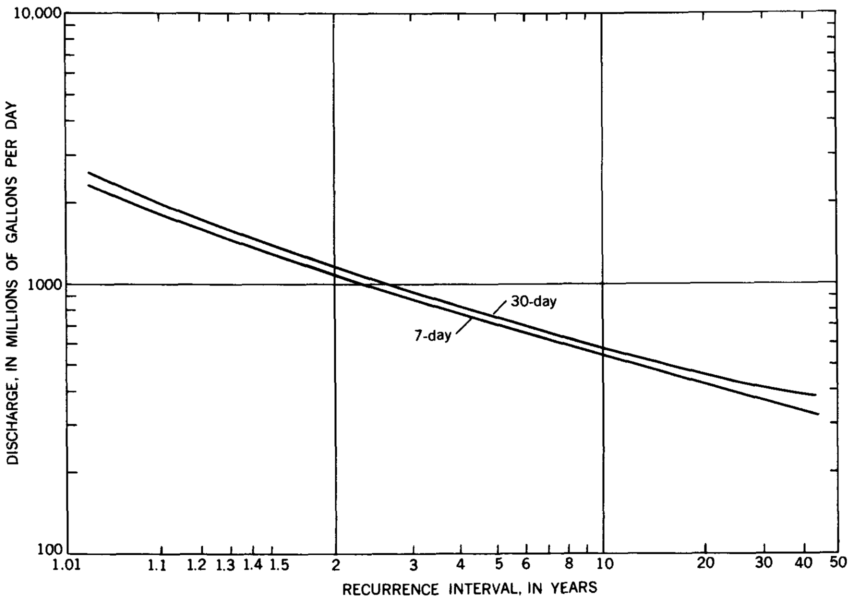

FIGURE 10.—Low-flow frequency curves for Fox River at Rapide Croche Dam near Wrightstown, Wis., 1918–59.

Several potential reservoir sites on the Wolf River have been investigated, but none have been developed. It has been estimated by the Wisconsin State Planning Board (1938a, b) that a reservoir system on the Wolf River would supplement the low flow of the lower Fox River by as much as 800 mgd for a period of 120 days every year.

Another plan, also suggested by the Wisconsin State Planning Board (1938a, b), for supplementing the low flow of the lower Fox River is to divert water at Portage, Wis., from the Wisconsin River into the upper Fox River. A navigation canal connects the two basins at Portage, where the Wisconsin River at low stages is about 6 feet higher than the Fox River, and about 20 feet higher at high stages. In 1959, an average of about 13 mgd was diverted into the Fox River at Portage for local sewage-dilution purposes.

FLOODS

The lower Fox River is not subject to extremes of flow, owing to the dampening effect of Lake Winnebago and the regulation of the flow at Menasha Dam. When high water is anticipated in the upper part of the basin, sluicing operations are begun at Menasha Dam, and, if possible, a flow of less than 9,800 mgd is maintained. Cloudbursts over the lower Fox River valley have occasionally caused extremely high water below Menasha Dam. During a flood in 1922, the instantaneous discharge at the mouth of the Fox River was estimated to be about 50,000 mgd (Wisconsin State Planning Board, 1938a, p. 22). This was almost four times the flow that results from the most rapid sluicing at Menasha Dam. Only 2,600 mgd was being sluiced at Menasha Dam when the peak of the 1922 flood reached Green Bay, indicating that the flood originated on the lower Fox River.

A profile of the stage of the lower Fox River during a flood in 1881 as compared to the standard low stage is shown in figure 11. Annual peak flows generally occur between late March and early June. The largest daily discharges, greater than about 13,000 mgd at Rapide Croche Dam in 1918–59, are listed in table 4.

The flood-frequency curve (fig. 12) shows the recurrence interval, in years, for floods on the Fox River at Rapide Croche Dam that equaled or exceeded a daily mean discharge of 4,500 mgd. For example, a daily mean discharge of 11,600 mgd or more occurred at an average

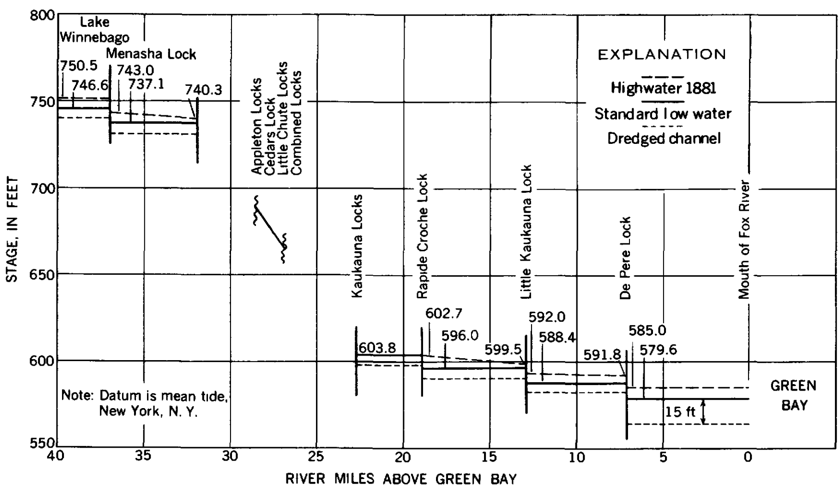

FIGURE 11.—Profile of stage of Fox River from Lake Winnebago to Green Bay, Wis.

TABLE 4.—*Largest daily discharges of the Fox River at Rapide Croche Dam, 1918–59*

Date	Discharge	
	(cfs)	(mgd)
Apr. 18, 1952	24, 000	15, 500
June 6, 1943	21, 300	13, 800
Mar. 27, 1946	21, 300	13, 800
Apr. 4, 1929	20, 600	13, 300
Apr. 26, 1951	20, 400	13, 200
Apr. 23, 1922	20, 100	13, 000
June 12, 1942	19, 800	12, 800

of once every 6 years. When using the curve in figure 12 to predict high flows, the probability is stated as follows: "Based on the experience of 1918–59, a daily mean discharge of 11,600 mgd or more will probably occur 16 or 17 times in 100 years." The 50-year flood of 15,500 mgd represents an average runoff of less than 2.6 mgd per square mile of drainage area. This is a relatively low runoff for a 50-year flood in Wisconsin.

BACKWATER

The stage of the lower Fox River and its tributary, East River, below De Pere Dam is frequently affected by backwater from Green Bay. When a wind from the northeast pushes the shallow waters of the bay into the river mouth, the effect of backwater is noticeable. The irregularity of the reversals of flow caused by backwater from Green Bay indicate that they are caused by atmospheric conditions, wind action, and seiche (oscillation). Owing to the reversal of flow near the mouth of the Fox River, industrial wastes and sewage are carried up the Fox and East Rivers for short periods of time and cause sewage-dilution problems.

CHEMICAL AND PHYSICAL CHARACTER OF WATER

More than 30 pulp and paper mills, the greatest concentration of pulp and paper mills in the State, are located in the lower Fox River valley. The discharge of industrial waste into the Fox River from these mills has significantly altered the quality of the natural water. The water released from the Lake Winnebago pool also affects the quality of water in the lower Fox River.

The water in the Fox River is of the calcium magnesium bicarbonate type and it is hard (table 5). Chemical analyses reported by Weidman and Schultz (1915) and Lohr and Love (1954) indicate that the dissolved mineral constituents do not vary annually over a wide range. Records of the hardness of the water in the Fox River, obtained by the cities of Appleton and Neenah, show that the hardness ranges annually from about 150 to 200 ppm (parts per million). The

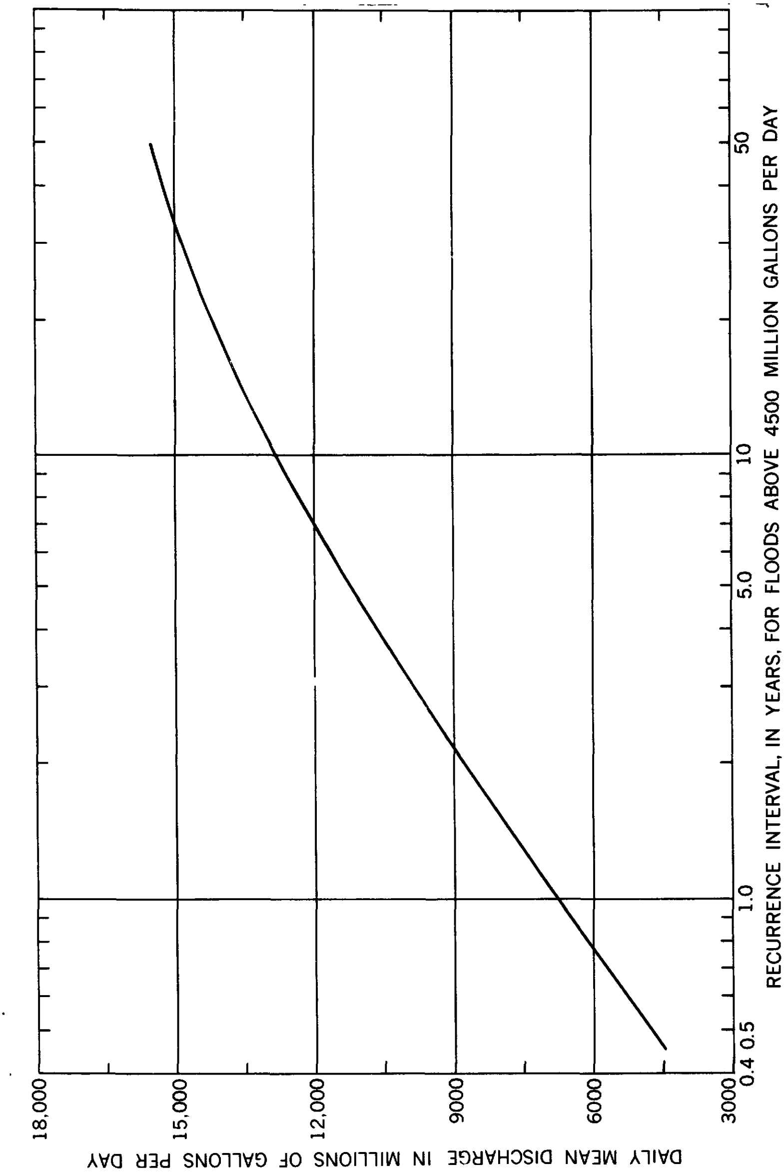

FIGURE 12.—Frequency of floods on Fox River at Rapide Croche Dam near Wrightstown, Wis., 1918–59.

water from Lake Winnebago at Oshkosh has about the same annual range in hardness.

The wastes discharged into the lower Fox River and its tributary streams below Lake Winnebago consist chiefly of wastes from the pulp and paper industry and from municipal sewage. All of the municipal sewage and a large part of the industrial wastes are treated before being discharged into the river. Other sources of pollution include rendering plants and a sugar mill.

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TABLE 5.—*Chemical analyses of water from selected surface-water sources in the Green Bay area*

[Results in parts per million except pH, color, specific conductance and percent saturation of dissolved oxygen]

Surface water sampling site	Surface-water source	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness (as $CaCO_3$)		Specific conductance (micromhos at 25°C)	pH	Color	Dissolved oxygen	
																Calcium, magnesium	Noncarbonate				ppm	Percent saturation
1	Suamico River	6- 3-60	------	------	0.00	------	------	------	------	302	37	6.0	0.1	1.2	------	290	42	526	7.7	50	------	------
2	Duck Creek	6- 3-60	3.3	0.11	.07	88	28	6.2	4.1	320	68	8.5	.2	1.5	424	335	72	606	7.5	140	9.8	106
3	Dutchman Creek	6- 3-60	------	------	.00	------	------	------	------	318	33	5.0	.0	1.6	------	298	37	535	8.0	85	------	------
4	Ashwaubenon Creek	6- 3-60	------	------	.00	------	------	------	------	288	60	14	.0	2.1	------	329	92	641	7.4	20	------	------
5	Apple Creek	6- 3-60	------	------	.00	------	------	------	------	322	94	13	.0	2.2	------	362	98	690	7.4	25	9.4	104
7	Plum Creek	6- 3-60	------	------	.00	------	------	------	------	382	123	41	.0	1.5	------	428	115	900	7.5	17	------	------
9	Bower Creek	6- 4-60	------	------	.00	------	------	------	------	280	48	10	.0	2.6	------	280	50	547	7.2	30	------	------
10	Baird Creek	6- 4-60	------	------	.00	------	------	------	------	330	108	24	.0	2.0	------	387	116	751	7.7	80	------	------
11	Trout Creek	6- 3-60	------	------	.00	------	------	------	------	302	66	1.0	.0	1.8	------	323	75	573	7.7	100	------	------
12	Beaver Dam Creek	6- 3-60	------	------	.00	------	------	------	------	282	27	24	.1	7.1	------	269	38	555	7.5	80	------	------
13	Fox River	6- 3-60	1.3	.14	.08	35	15	4.4	2.0	158	22	7.0	.2	.4	180	149	20	303	7.1	30	7.7	82
14	East River	6- 3-60	------	------	.00	------	------	------	------	314	46	9.0	.0	3.3	------	309	51	583	7.4	55	6.4	71
------	Green Bay	1- 4-52	6.5	.3	------	32	10	2.5	1.8	129	21	4.0	.3	.2	166	122		------	7.6	40	------	------
------	Lake Michigan	2-11-52	------	------	------	36	10	2.4	1.2	134	24	8.5	------	.4	154	132		------	------	------	------	------

In 1955, the pollution of the lower Fox River was studied intensively by the Wisconsin Committee on Water Pollution (1956) in cooperation with the Sulphite Pulp Manufacturers' Research League. The results of this investigation indicated that a considerable amount of organic pollution entered the lower Fox River from Lake Winnebago and caused a serious depletion of dissolved oxygen in the section of the river from Kaukauna to De Pere. At the mouth of the Fox River, the water was generally low in dissolved oxygen, except in April when the flow of the river was high and the water temperature was low (fig. 13). The streamflow during April 1955 was two to three times the quantity recorded during the other survey periods. As the total pollution load of the Fox River remains fairly constant, a high runoff generally brings about an improvement in water quality. During the April 1955 survey, there was sufficient dissolved oxygen in the water at each station on the Fox River to support biologic activity at all levels. The surveys conducted during June 1955 indicated that the water in the reach of the Fox River between Kaukauna and Green Bay was deficient in dissolved oxygen. About the same conditions were recored during the July and October surveys.

The dissolved-oxygen content of water from the Fox River at Rapide Croche Dam in June 1960 (table 5) was similar to the content recorded during the April 1955 survey by the Wisconsin State Committee on Water Pollution. In May and early June of 1960, the discharge of the Fox River at the gaging station at Rapide Croche Dam was above normal.

The concentration of suspended material in the lower Fox River is generally low (fig. 14), probably owing to a considerable quantity of suspended sediment being trapped in the Lake Winnebago pool. Water entering the lower Fox River from the Lake Winnebago pool generally has a suspended-sediment concentration of less than 10 ppm. This concentration generally increases slightly downstream, owing to local runoff and the discharge of industrial-waste solids into the river. During periods of low flow, the inorganic suspended materials are less than 1 ppm. The volatile-suspended solids (organic wastes) are generally more than 50 percent of the total suspended-solids concentration.

During the 1955 study by the Wisconsin State Committee on Water Pollution, the maximum concentration of suspended material, recorded in April, was 36 ppm, or equivalent to about 600 tons per day. About half of the suspended material was composed of clay-sized particles of inorganic matter. During the June, July, and October surveys, the suspended load averaged about 100 tons per day.

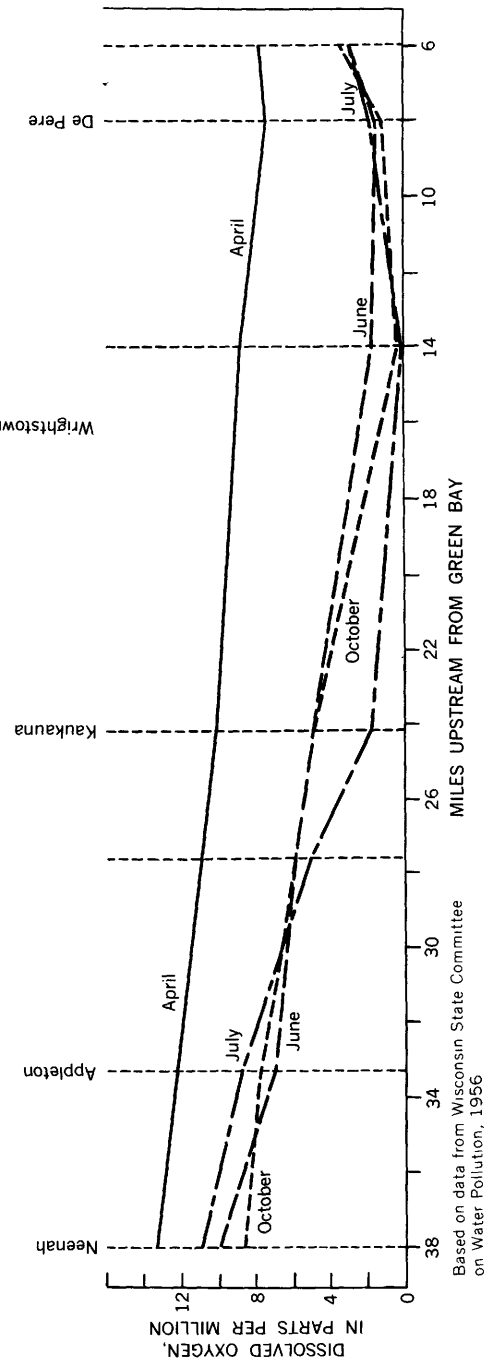

FIGURE 13.—Dissolved-oxygen concentration of the lower Fox River, 1955.

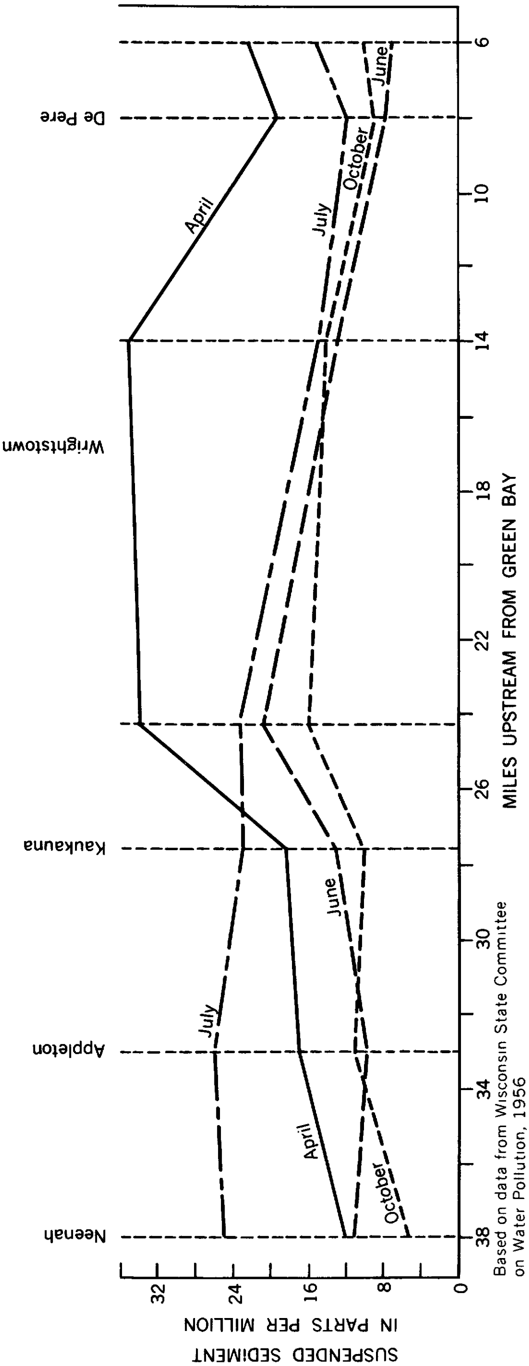

FIGURE 14.—Suspended sediment in the lower Fox River, 1955.

The quality of the Fox River water limits its use by some industries. The water generally requires softening before it is used in high-pressure boilers (to prevent formation of scale), and sometimes may require special treatment to reduce the color, turbidity, and content of iron and manganese. Some industrial uses may require additional treatment. Water quality criteria for domestic and selected industrial uses are given in table 6.

The large papermills treat the processing water to help maintain the quality of the paper product. This processing water is screened and then, as it passes through a settling basin, it is treated with alum (a flocculating agent to remove clays) and chlorinated. Cooling water requires only screening.

All of the large papermills treat their wastes before discharging them into the Fox River. One company operates a yeast-fermentation plant utilizing the sulfite liquor from pulping operations. Other companies employ savealls, lagoons, and recirculation practices to reduce the release of wastes into the streams and to reduce the biochemical-oxygen-demand load discharged into the river. One of these companies also has an evaporation and burning plant for sulfite-waste liquor collected from the pulping operation.

Municipal sewage treatment plants are located on the lower Fox River at Wrightstown, De Pere, and Green Bay, and a paper company has a high-rate filter-type plant for the treatment of its domestic sewage. The plant at Green Bay, operated by the Green Bay Metropolitan Sewerage District, serves the city of Green Bay and parts of the towns of Allouez, Howard, and Preble. In 1959 it discharged an average of 12.06 mgd at the mouth of the Fox River. The plant is of the high-rate rock-filter type and has effluent disinfection facilities. The average monthly discharges of sewage into the Fox River by the treatment plants at Green Bay and De Pere are given in table 7.

Data obtained by the Wisconsin State Committee on Water Pollution (1956) from a survey of sewage and industrial-waste loadings of the Fox River below Lake Winnebago indicate that the industrial-waste load forms about 90 percent of the oxygen-demand loading and treated municipal sewage accounts for about 10 percent. The survey also showed that the dissolved-oxygen concentration of water in the Fox River decreases rapidly in the vicinity of the city of Green Bay. If the periods when the river water is warm in July and August were to coincide with periods of low flow, the river would then be unable to assimilate the loading of decomposable organic matter. The maximum water temperatures, however, generally occur in July and early August; and the periods of low flow occur in late August, when the water temperature is falling quite rapidly. Even so, increased

Table 6.—*Quality of water criteria for domestic and selected industrial uses*

[Source of data: U.S. Public Health Service, 1946, Public Health Reports, reprint 2697. California State Water Pollution Control Board, 1952, Water quality criteria: California State Water Pollution Control Board pub. 3. Results are in parts per million, except taste and odor, color, pH, and temperature]

Constituent or property	Drinking water standards (maximum allowable concentration)	Boiler feed waters (suggested limits of tolerance, for boilers of indicated pressures)				Food processing (range of recommended threshold values)	Pulp and paper (recommended ranges)	Cooling water (limiting concentrations)
		Pounds per square inch						
		0–150	150–250	250–400	>400			
Metals:								
Iron (Fe)						0.2		0.5
Manganese (Mn)						.2	0.1–0.5	.5
Iron and Manganese	0.3					.2	Trace	.5
Aluminum oxide (Al_2O_3)		5	0.5	0.05	0.01			
Silica (SiO_2)		40	20	5	1			
Magnesium (Mg)	125							
Sulfate (SO_4)	250							
Chloride (Cl)	250						<175	
Fluoride (F)	1.5					1.0		
Sodium chloride (NaCl)						1,000–1,500		
Alkalinity:								
Bicarbonate (HCO_3)		50	30	5	0		<400	
Carbonate (CO_3)	120	200	100	40	20		<10	
Hydroxide (OH)		50	40	30	15			
Hardness (as $CaCO_3$)		80	40	10	2	50–85 (General) 100–200 (Fruits and vegetables) 200–400 (Peas)	<200	50
Solids:								
Total	[1] 500	3,000–500	2,500–500	1,500–100	50			
Suspended								
Gases:								
Hydrogen sulfide (H_2S)		5	3	0	0	1.0		
Oxygen, dissolved		2.0	.2	.0	.0			
Oxygen, consumed		15	10	4	3			
Taste and odor						None—low		
Organic materials: Phenols (as C_6H_5OH)	.001							
Color	20	80	40	5	2		10–50	
Turbidity	10	20	10	5	1	1.0–10	10–50	50
Corrosion (as pH)	10.6	>8.0	>8.4	>9.0	>9.6	>7.5		6.5–7.5
Temperature							<75°F	

[1] 1,000 ppm permitted if no other water available.

TABLE 7.—*Average monthly discharge of sewage into the Fox River by the Green Bay and De Pere sewage-treatment plants, 1959*

Month	Green Bay (mgd)	De Pere (mgd)
January	8.06	0.91
February	8.72	.95
March	12.08	1.30
April	15.10	1.60
May	13.05	1.45
June	11.48	1.26
July	12.79	1.24
August	12.89	1.07
September	12.27	1.14
October	13.11	1.16
November	12.81	1.26
December	12.17	1.29
Average	12.06	1.22

release of water from Lake Winnebago in late summer would be extremely beneficial as the water generally contains about 8 ppm of dissolved oxygen and would furnish about 6,700 pounds of dissolved oxygen per day per 100 mgd of water discharged. Reaeration equipment has been installed in the turbines of hydroelectric equipment on the Fox River to increase the dissolved-oxygen concentration.

The temperature of the water of Lake Winnebago at Oshkosh ranges from about 32° to 77°F and averages about 53°F. The temperature of the Fox River water may be as much as several degrees warmer in the summer than the water of Lake Winnebago, especially in the lower reaches of the river; however, only limited data on the temperature of water from Fox River are available. The temperatures of samples of water collected in April–October 1955 by the Wisconsin State Committee on Water Pollution ranged from 49° to 86°F.

For cooling purposes, industries prefer water having a temperature of 50° to 60°F, but generally can utilize water having a maximum temperature of 75° to 85°F. From April to October, the temperature of Fox River is generally between 50° to 85°F; from November to March, however, the water temperature is probably only slightly above 32°F.

USE OF WATER

There are two general classifications of water use—withdrawal and nonwithdrawal. Withdrawal use can be either consumptive or nonconsumptive; nonwithdrawal use is nonconsumptive. The major withdrawal use of Fox River water is by the paper industry for use in producing pulp or finished paper products. Water also is withdrawn for cooling and other uses. Only a very small part of the water is lost by consumptive use. Nonwithdrawal use of Fox River water includes power production, navigation, recreation, and pollution abatement. Low-head hydroelectric plants are at Rapide Croche, Little Kaukauna, and De Pere Dams.

In 1959, the average withdrawal for processing and cooling by the paper industry in the Green Bay area was 62 mgd. More than 60 percent of the water was used for processing operations. One of the largest paper companies for example, reported that its average withdrawal of water for processing was 19.6 mgd, and that its withdrawal for cooling during the period of turbine condenser use, May 1 to November 15, was 20.2 mgd. The monthly withdrawal of water from the Fox River during 1959 for processing operations by two of the large paper companies is shown in figure 15.

Water is also withdrawn from the Fox River for irrigation of golf courses and fruit orchards, and, occasionally, for fire fighting. The Public Service Commission of Wisconsin has issued a few licenses for lawn or fruit orchard irrigation at rates of about 125 gpm (gallons per minute) during the growing season. In 1959, the Wisconsin State Reformatory withdrew only 367,000 gallons for irrigation. The withdrawals for irrigation, however, are extremely small when compared with the withdrawals for industrial use.

LAKE MICHIGAN

Lakes Michigan and Huron are essentially a single lake—the connection through the Straits of Mackinac being so broad and deep that the flow is almost imperceptible. The surfaces of the two lakes are at the same altitude, averaging 579.87 feet above mean sea level for 1900–59. The maximum recorded depth of Lake Michigan is 923 feet, a depth of 343 feet below mean sea level. Lake Michigan has an area of 22,400 square miles, is approximately 307 miles long, and, in the vicinity of Milwaukee, Wis., is about 85 miles wide. During 1900–51, the average inflow from Lake Superior through the St. Mary's River was 73,200 cfs (cubic feet per second), and the average outflow from Lake Michigan-Lake Huron was 181,400 cfs. The average navigation season, governed by the opening and closing of the Straits of Mackinac, is from April 12 to December 15.

The level of Lake Michigan is subject to considerable seasonal and annual fluctuation depending on runoff, and lesser short-term fluctuations caused by wind storms or abrupt changes in atmospheric pressure.

The water from Lake Michigan is of better chemical quality than the water from the Fox River and the other streams in the Green Bay area (table 5). Because of the large amount of water stored in Lake Michigan, seasonal changes in the chemical quality are small.

Most of the municipalities and many of the industries located adjacent to Lake Michigan use the lake as a source of water supply. The

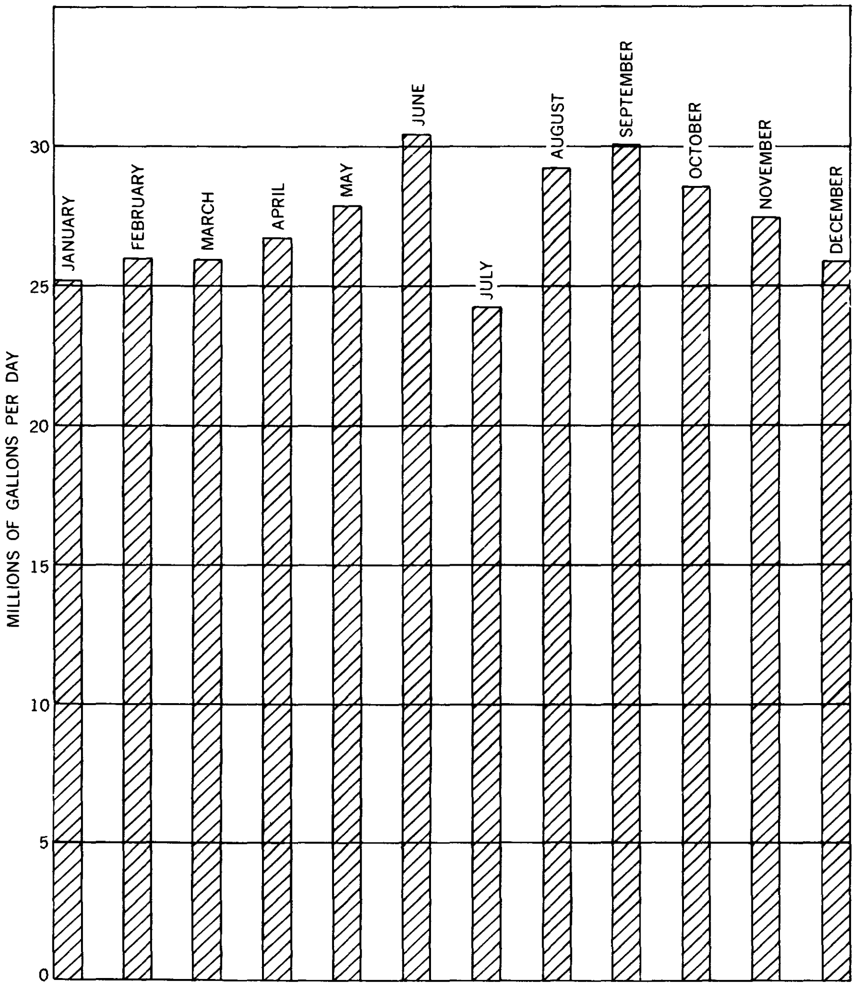

FIGURE 15.—Withdrawal of water from the Fox River in 1959 for processing by two of the larger paper companies.

city of Green Bay obtains its water supply from Lake Michigan. In 1959, the withdrawals by the city averaged 7.8 mgd.

GREEN BAY

The Fox River empties into Green Bay at the city of Green Bay. The bay broadens rapidly but remains fairly shallow (pl. 1). The bottom of Green Bay slopes northward, reaching depths of 100 to 150 feet at its junction with the floor of Lake Michigan, about 100 miles northeast of the city of Green Bay.

A sand bar almost crosses the bay 4 or 5 miles northeast of the city, creating a shallow inner bay. A dredged navigation channel 22 feet deep extends through the bay into the lower Fox River. The average navigation season is from about mid-April to about mid-December. The waters of Green Bay are used extensively for commercial and sport fishing, boating, swimming, and duck hunting.

The stage of Green Bay is virtually at the stage of Lake Michigan, which undergoes considerable seasonal fluctuations depending upon runoff. High seasonal stages occur in summer or early fall, generally July; lows occur in winter, generally February. The average seasonal range in stage is about 1.1 foot. The fluctuations of the stage of Green Bay for 1954–60 are shown in figure 16. The daily stage of Green Bay for the 1959 water year is shown in figure 17. Large short-term fluctuations are experienced owing to changes in atmospheric pressure or strong winds of northeasterly or southwesterly direction, particularly during seasonal high or low stages.

The water from Green Bay is moderately hard but is of better chemical quality than the water from the Fox River and other streams in the area (table 5).

The major withdrawal of water from Green Bay is for cooling at the Wisconsin Public Service Corporation's Pulliam Plant, the third largest steam-electric power generation plant in Wisconsin. In 1959 the average withdrawal was 415 mgd. About 1 percent of the water goes into the steam cycle and is recirculated. The company has an intake at a depth of 21 feet in a dredged channel to avoid difficulties in pumping at low stage. The warmed water is returned to the dredged channel to prevent formation of anchor ice during the winter.

SMALL STREAMS

EAST RIVER

The East River, which has a drainage area of about 143 square miles and is about 27 miles long, flows 2 to 3 miles east of and roughly parallel to the lower Fox River (fig. 1). It drains the Niagara escarpment, which is roughly parallel to the Fox River, and the lowlands on the east side of the Fox River valley. The drainage area is long and narrow and averages about 5 miles in width. The gradient is steep in the range of the tributaries that head in the escarpment and relatively flat where the river passes through the lowland in the Fox River valley. The stream descends about 350 feet, of which almost 300 feet occurs in the upper reaches.

In the city of Green Bay, the East River turns northwest and flows through a predominantly commercial and industrial district, emptying into the Fox River about a mile upstream from Green Bay. Near its mouth, the East River is about 150 feet wide and has a depth of 6 to 8 feet.

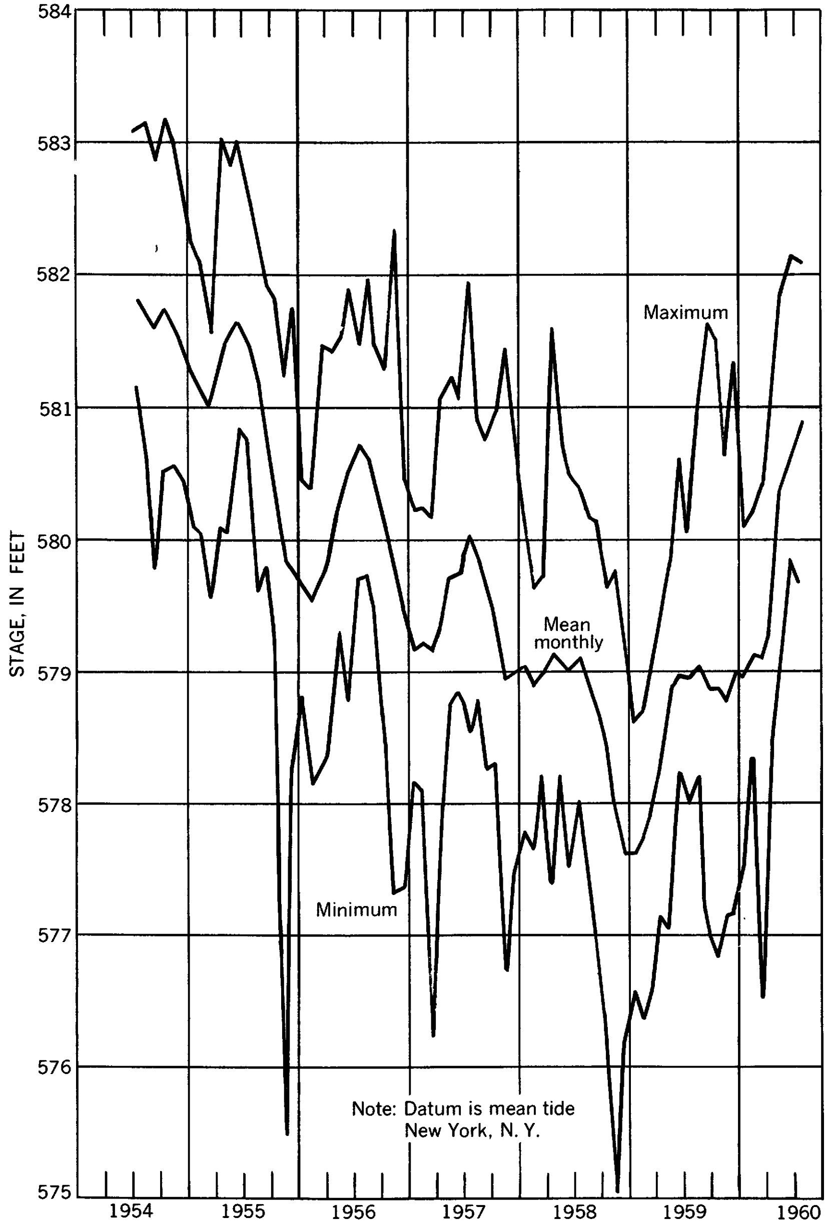

FIGURE 16.—Stage of Green Bay, 1954–60.

The major tributaries of the East River are Baird Creek, which joins the East River about 1½ miles upstream from its mouth, and Bower Creek, which joins the East River east of De Pere (fig. 1). The drainage areas of Baird and Bower Creeks at the streamflow measuring sites (pl. 1) are 19 and 34 square miles, respectively. Discharge measurements were made on the East River and on Baird and Bower Creeks by the Wisconsin State Board of Health in the spring of 1939 and by the U.S. Geological Survey in 1960. Based on these data, the estimated discharges to be expected 60, 70, and 80 percent of the time at the streamflow measuring sites are given in table 8. The estimates are not considered as reliable as those computed from gaging-station records. Bower and Baird Creeks become dry during periods of deficient precipitation, generally in late summer. The periods of no flow rarely exceed 2 weeks.

TABLE 8.—*Estimated flow-duration data for East and Suamico Rivers and Bower, Baird, and Duck Creeks*

Stream	Streamflow measuring site	Drainage area (sq mi)	Discharge (mgd) equaled or exceeded for percent of time shown		
			60	70	80
East River near De Pere, Wis	8	65	2.40	1.60	1.10
Bower Creek near De Pere, Wis	9	34	.13	.09	.06
Baird Creek near Preble, Wis	10	19	.20	.14	.09
Suamico River near Suamico, Wis	1	62	1.00	.50	.25
Duck Creek near Howard, Wis	2	114	2.60	1.80	1.10

The lower part of the East River is in the backwater reach of the Fox River and Green Bay and has reversals of flow throughout the year owing to seiche action in the bay. The effect of the reversals of flow has been noted as far as 5 miles upstream. In 1939, a recording gage was installed about one-half mile above the mouth of the East River to determine the magnitude of the changes in stage caused by the reversals of flow (fig. 18). Reversals of flow were noted several times daily and changes in stage of as much as 2 feet in 12 hours were recorded. During low-flow periods, the peaks and valleys of the seiche, as experienced in the East River, indicate the points at which the river flow changes from an "in" or upstream movement to an "out" or recession. A valley indicates the time at which the current was changing from an "out" to an "in." A continuous "out" for 17 hours on November 18–19, 1957, caused a drop in stage of 4.35 feet. When high runoff on the river coincides with an "in," a "piling up" or rise in stage generally occurs.

The water in the East River and its tributary streams, Bower and Baird Creeks, is more mineralized than the water from the Fox River (table 5). The water is of the calcium magnesium bicarbonate type and is very hard. The chemical analyses of samples of water shown

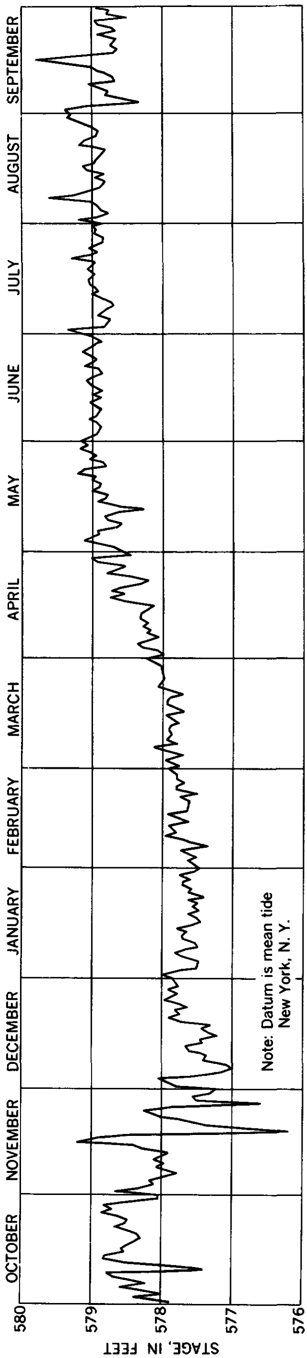

FIGURE 17.—Daily stage of Green Bay for 1959 water year.

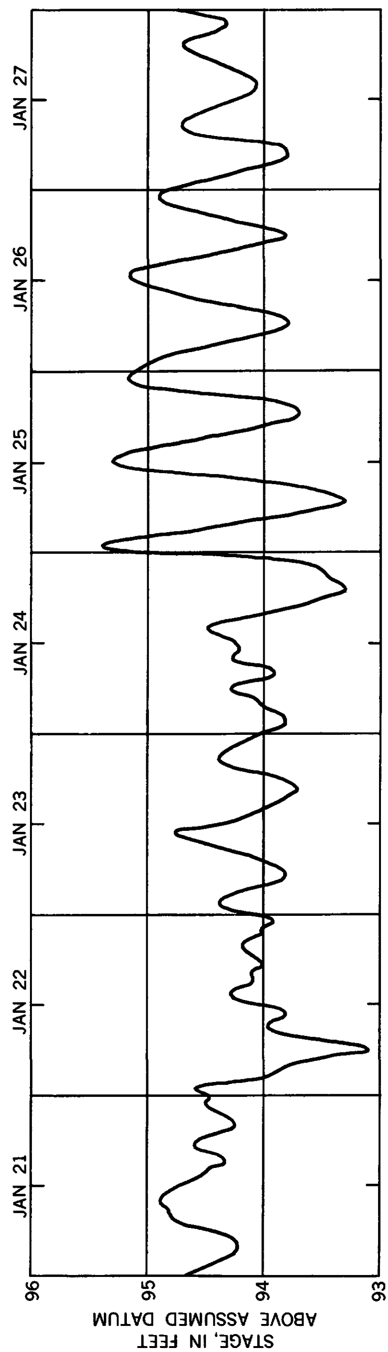

FIGURE 18.—Fluctuations in stage of the East River at Green Bay, January 21–27, 1939.

in table 5 were collected during a period of median streamflow and are considered to represent average conditions.

Beginning in the winter of 1957 and continuing through the summer of 1958, the city of Green Bay (1958) made an extensive survey to determine the source and amount of pollution of the East River between the Mason Street bridge and the Monroe Street bridge. The survey also included the Fox River below the mouth of the East River and Baird Creek from the mouth to about 4 miles upstream. A summary of the results of these studies is given in table 9. The dissolved-oxygen content was very low in all samples collected in May–August 1958. Hydrogen sulfide was present in significant amounts during August and was present in many of the samples collected from May to July.

TABLE 9.—*Chemical analyses of water from the East River at Green Bay, 1958*

[Results in parts per million except temperature; analyses by city of Green Bay]

Station	Month of collection, 1958	Number of samples	Temperature, °F		Dissolved oxygen (O_2)			Hydrogen sulfide (H_2S)		
			Avg.	Range	Avg.	Range	Number of samples showing no O_2	Avg.	Range	Number of samples containing H_2S
Monroe Street	August	18	78	70–81	0.01	0.0–0.2	17	2.77	0.00–25.00	10
Webster Avenue	May	11	67	62–70	.12	.0– .8	9	.02	.00– .10	4
	June	25	72	63–77	.32	.0–2.0	19	.27	.00– 2.50	11
	July	26	78	72–82	.14	.0–1.8	19	1.09	.00– 3.50	16
	August	26	78	70–82	.00	0.0	26	5.40	.00–30.00	24
Main Street	May	11	66	62–68	.16	.0–1.0	8	.06	.00– .50	3
	June	25	70	63–77	.34	.0–3.2	19	.49	.00– 3.50	10
	July	26	78	72–81	.59	.0–3.6	16	.87	.00– 5.00	11
	August	26	78	68–82	.04	.0–1.1	25	7.80	.00–30.00	22
Baird Street	June	16	71	66–77	1.12	.0–4.6	10	.43	.00– 2.50	8
	July	26	77	72–81	1.52	.0–5.1	10	.36	.00– 3.00	8
	August	26	78	71–82	.64	.0–2.8	15	2.53	.00–14.00	12

The backwaters of the East River exhibit a high biochemical-oxygen demand, with the highest demand being found just above the river mouth. Because of the low natural discharge of the East River and the reversals of flow, waste discharged into the Fox River is, at times, carried into the East River. Suspended solids, principally wood fibers, settle out and decompose in the lower 1¼ miles of the river, producing further oxygen demand and unsightliness.

In the upper part of the drainage basin, water from the East River is used chiefly for watering stock and for limited irrigation. Along the lower reaches of the river, chiefly within the city limits of Green Bay and in that part of the river affected by backwater, the river water is used for condenser cooling and for industrial-waste dilution.

SUAMICO RIVER

The Suamico River, located northwest of the city of Green Bay, is about 21 miles long, flows northeastward, and empties into Green Bay, about 6½ miles north of the mouth of the Fox River. The backwater effect from the bay extends upstream about 3 miles above the mouth. Above this point the river drains an area of about 62 square miles. The Suamico River gradually descends more than 250 feet and flows through wooded areas, swamps, pastures, and some farmland. The stream is ice covered every winter. Discharge records are available at a site about 3 miles above the mouth of the river for the period June 1951–July 1952. The maximum daily discharge during this period was 2,000 cfs (1,290 mgd) on April 1, 1952; the minimum discharge was 1.4 cfs (0.9 mgd) on August 2–5, 1951, and July 29–31, 1952. According to a farmer who has lived near the river since 1920, the highest stage between 1920 and 1952 was about 6 feet higher than the stage of the flood of April 1, 1952. Estimated flow-duration data for the Suamico River are summarized in table 8.

The water in the Suamico River is more mineralized than the water in the Fox River (table 5). The chemical analysis of the sample of water shown in table 5 was collected during a period of median streamflow and is considered to represent average conditions. The water is of the calcium magnesium bicarbonate type and is very hard.

In 1952, the city of Green Bay investigated the possibility of utilizing the Suamico River to supplement its supply of water from the sandstone aquifer, but decided to use Lake Michigan as the supply source for all of its water needs. The only present withdrawals of water from the Suamico River are used for small-scale irrigation and stock watering.

DUCK CREEK

Duck Creek flows northeastward and empties into Green Bay about 2 miles north of the mouth of the Fox River. It drains an area of about 140 square miles. At the streamflow measuring site (pl. 1) above the reach of the Green Bay backwater, the drainage area includes 114 square miles. The flow-duration data given in table 8 was estimated from several discharge measurements taken at the streamflow measuring site.

Both Duck Creek and one of its tributaries, Trout Creek, generally become dry in late summer when little or no precipitation occurs. The period of no flow may last as long as 3 or 4 weeks.

The water in Duck Creek and its tributaries, Trout and Beaver Dam Creeks, is more mineralized than the water in the Fox River (table 5). It is of the calcium magnesium bicarbonate type and is very hard. The samples of water analyzed in table 5 were collected during a period of median streamflow and are considered to represent average conditions.

DUTCHMAN, ASHWAUBENON, APPLE, AND PLUM CREEKS

Dutchman, Ashwaubenon, and Apple Creeks drain the west side of the lower Fox River valley and discharge into the Fox River between the city of Green Bay and Wrightstown. Dutchman Creek is frequently nonflowing, but water stands in long pools in its lower reaches. During most years, all these streams become dry in late summer. Plum Creek drains a small area on the east side of the Fox River and discharges into the Fox River about 1¾ miles downstream from Rapide Croche Dam. The measured discharges of Dutchman, Ashwaubenon, Apple, and Plum Creeks in September 1960 and their drainage areas above the streamflow measuring sites (pl. 1) are given in table 10.

The water in Dutchman, Ashwaubenon, Apple, and Plum Creeks is more mineralized than the water in the Fox River (table 5). It is of the calcium magnesium bicarbonate type and is very hard. The chemical analyses given in table 5 are for water samples that were collected during a period of median streamflow and are considered to represent average conditions.

Water from these streams is used only for watering stock and for limited irrigation.

TABLE 10.—*Discharge of Dutchman, Ashwaubenon, Apple, and Plum Creeks, September 1960*

Stream	Streamflow measuring site	Drainage area (sq mi)	Discharge (mgd)	Date
Dutchman Creek near Green Bay, Wis	3	26	Dry	9-9-60
Ashwaubenon Creek near West De Pere, Wis	4	26	2.60	9-9-60
Apple Creek near Wrightstown, Wis	5	47	.10	9-9-60
Plum Creek near Wrightstown, Wis	7	21	.27	9-8-60

SANDSTONE AQUIFER

DESCRIPTION

The sandstone aquifer includes rocks of Late Cambrian age and the Prairie du Chien group and St. Peter sandstone of Ordovician age. In the Green Bay area, the sandstone aquifer ranges in thickness from 550 to 640 feet.

The rocks of Late Cambrian age constitute the largest part of the sandstone aquifer and, in the Green Bay area, range in thickness from about 320 to 415 feet. They are divided in ascending order into the Dresbach group, the Franconia sandstone, and the Trempealeau formation. The Dresbach group includes the Mt. Simon, Eau Claire, and Galesville sandstones, but these units have not been differentiated in the subsurface in the Green Bay area.

The rocks of the Dresbach group are present throughout the Green Bay area and unconformably overlie crystalline rocks of Precambrian age. They consist of well-cemented fine- to coarse-grained sandstone that is generally light gray to white but includes a few zones that are pink. The Dresbach group ranges in thickness from 165 to 270 feet, and in some places it is very hard and makes drilling difficult.

The Franconia sandstone conformably overlies the rocks of the Dresbach group throughout the Green Bay area and consists of about 50 to 155 feet of fine- to coarse-grained dolomitic glauconitic sandstone. It is mostly light gray, but white, pink and red hues are seen in places. The Franconia sandstone is well cemented, but it is not as difficult to drill as the Dresbach group.

The Trempealeau formation conformably overlies the Franconia sandstone and consists of light-gray to pink fine- to medium-grained sandstone and a few thin beds of pink to red siltstone and sandy dolomite. It ranges in thickness from 15 to 55 feet except in the vicinity of De Pere where it was removed by pre-St. Peter erosion (fig. 4).

The rocks of the Prairie du Chien group conformably overlie the Trempealeau formation and consist of thinly bedded to massive dolomite that contains some layers of chert, sandstone, and shale. The dolomite is light gray to white and fairly hard. The rocks of the Prairie du Chien group vary greatly in thickness within relatively short distances, as the top of the unit is a very irregular erosional surface. Although generally ranging in thickness from about 100 to 265 feet, the rocks of this group are missing in the vicinity of De Pere and Howard owing to removal by erosion before the succeeding St. Peter sandstone was deposited (figs. 3 and 4).

The St. Peter sandstone unconformably overlies the rocks of the Prairie du Chien group. It consists of white to pink fine- to medium-grained sandstone that is dolomitic in some places. Thin beds of red shale are common near the base of the formation. The St. Peter sandstone was deposited on the eroded surface of the Prairie du Chien group and thus has an irregular lower surface. The upper surface, however, is relatively even, and the combined thickness of the St. Peter sandstone and the rocks of the Prairie du Chien group is fairly uniform. That is, where the Prairie du Chien group is uncommonly thick, the St. Peter is generally thin or absent. Similarly, where the rocks of the Prairie du Chien group are thin or missing, the St. Peter sandstone is thick. The St. Peter is thin or missing in the sections penetrated by many of the wells in the city of Green Bay, but it reaches its greatest thickness in the report area a short distance away in the vicinity of De Pere and Howard.

WATER-BEARING CHARACTERISTICS

The sandstone aquifer is the principal source of ground water in the Green Bay area in that it yields large quantities of water for public supply and industrial use. Ground water in the sandstone is found in openings along fractures and bedding planes and in the interstices between the sand grains. The permeability of the sandstone aquifer is variable, especially vertically, because of changes in the sorting of the sand and the presence of the dolomite strata in the upper part of the aquifer. The beds of sandstone in the lower part of the aquifer probably have the greatest permeability and the most productivity. The beds of dolomite contribute only minor amounts of water from openings along fractures and bedding planes.

The sandstone aquifer is recharged by the infiltration of precipitation at or near the outcrop area west and northwest of the Green Bay area in eastern Outagamie and Shawano Counties and southern Oconto County. The water percolates to the sandstone aquifer through the overlying glacial drift and possibly through the Platteville formation where it is thin and weathered. The sandstone aquifer also receives some water by downward leakage from the Platteville formation at those places in the Green Bay area where the water level for the standstone aquifer is lower than it is with respect to the Platteville.

The amount of water that can be withdrawn perennially from the ground-water reservoir in the Green Bay area depends chiefly upon the capacity of the aquifer to transmit water from the areas of recharge to the points of withdrawal, the amount of recharge, and the amount of water available from storage in the aquifer as the water level declines.

The rate at which water is transmitted depends on the coefficient of transmissibility of the aquifer and on the hydraulic gradient. The coefficient of transmissibility is the rate of flow of water, at the prevailing temperature, in gallons per day, through a vertical section of the aquifer 1 mile wide extending the full height of the aquifer under a hydraulic gradient of 1 foot per mile. The amount of water available from storage as the water level declines depends on the coefficient of storage. The coefficient of storage of an aquifer is defined as the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The coefficients of transmissibility and storage are used in estimating the rate and amount water levels will decline for various pumping rates and distributions of wells. Several aquifer tests were made in the vicinity of Green Bay and De Pere by Drescher (1953, p. 25–28) to determine the coefficients of transmissibility and storage of the sandstone aquifer. The results of these tests indicated average coefficients of transmissibility and storage of about 12,000 gallons per day per foot and 0.00025, respectively.

The rates of discharge of municipal and industrial wells tapping the sandstone aquifer range from about 200 to more than 1,000 gpm (table 11). Wells penetrating the entire thickness of the sandstone aquifer throughout the area probably could yield from 500 to 1,000 gpm each.

TABLE 11.—*Rates of discharge and specific capacities of municiapl and industrial wells tapping the sandstone aquifer in the Green Bay area*

[Data for wells Bn-1, -3, and -7 obtained from aquifer test]

Well Bn-	Rate of discharge (gpm)	Specific capacity (gpm per ft)	Well Bn-	Rate of discharge (gpm)	Specific capacity (gpm per ft)
1	1, 055	5. 7	45	180	3. 0
2	800	4. 0	48	200	3. 3
3	830	5. 4	66	200	6. 2
4	670	2. 5	84	195	2. 8
7	780	4. 4	100	1, 130	4. 5
10	300	3. 8	105	350	3. 5
14	300	2. 6	109	302	2. 5
19	234	1. 4	113	912	16. 0
21	421	2. 0	114	222	2. 3
22	300	3. 5	127	460	6. 9
24	503	5. 4	128	850	4. 2
27	400	2. 9	130	508	8. 8
34	250	7. 8	131	508	3. 5
38	180	4. 5	132	700	5. 7

The relation between the rate of discharge and the resultant drawdown of the water level in a pumped well is known as the specific capacity and is generally expressed in gallons per minute per foot of drawdown. For example, if a well is pumped at 1,000 gpm and the water level declines 200 feet, the specific capacity of the well is 5 gpm per foot of drawdown. In a like manner, if the specific capacity of a well is 5 gpm per foot of drawdown, within certain limits, the discharge of the well will be increased 5 gpm for each foot of increased drawdown.

The specific capacity of a well depends on the coefficients of transmissibility and storage and the construction and development of the well. Specific capacities that were determined for the wells pumped during the aquifer tests at Green Bay, or that were reported by well owners or well drillers for wells in other parts of the Green Bay area, are given in table 11. The locations of the wells are shown in plate 1.

The withdrawal of water from a well causes a decline in the water level around the well, thus creating a hydraulic gradient that increases in slope toward the well. The hydraulic gradient forms an inverted cone, centered at the well, known as the cone of depression. This cone becomes larger as the discharge from the well continues. Other factors being equal, the quantity of water moving toward a well is proportional to the gradient of the cone of depression. Two or more wells in the same area may compete for the available water if they are closely spaced and their cones of depression overlap. The sandstone aquifer in the Green Bay area has a relatively low transmissibility, and it is essential for wells tapping this aquifer to be properly spaced to avoid excessive mutual interference.

CHEMICAL AND PHYSICAL CHARACTER OF WATER

Precipitation contains relatively little dissolved mineral matter. Upon reaching the ground, the water begins to dissolve minerals from the soil and rocks. The character and amount of dissolved minerals contained in ground water depend chiefly on the type of organic material in the soil, the kind and amount of soluble material in the rocks through and over which the water moves, and the temperature and pressure of the water. Contamination by sewage or industrial wastes or induced encroachment of water from another source by pumping may affect the chemical and physical character of ground water.

Chemical analyses of water from selected wells tapping the sandstone aquifer are listed in table 12. The concentration of iron, chloride, fluoride, and dissolved solids in the water and its hardness (the characteristics of principal interest to municipal and industrial users) are summarized in table 13. The water from the sandstone aquifer is of the calcium magnesium bicarbonate type except for the water from well Bn-22 at Preble which is of the calcium magnesium sulfate type and is very hard. The iron content is variable from well to well, and objectionable amounts occur in the water from some wells. The fluoride content of the water samples analyzed ranged from 0.1 to 2.4 ppm.

The water from wells tapping the sandstone aquifer is slightly more mineralized and harder than the water from the Fox River, Green Bay, and Lake Michigan. The well water has about the same mineral content as the water from the small streams in the area. Wells tapping the sandstone aquifer are a better source of water supply for most uses than are the small streams, however, because water from properly constructed wells is generally free from surface pollution and turbidity and has a fairly constant year-round temperature. The temperature of the water from wells tapping the sandstone aquifer averages about 53°F.

The highest concentration of dissolved solids reported for any well tapping the sandstone aquifer in the Green Bay area was found in water from the old railroad well at Askeaton. The well, about 15 miles

TABLE 12.—*Chemical analyses of water from selected wells tapping the sandstone aquifer in the Green Bay area*

[Results in parts per million, except pH; Analyses of samples from wells 14, 22, 23, 85, 127, 130, 131, and 132 by Wisconsin State Laboratory of Hygiene]

Well Bn-	Owner	Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids	Hardness (as $CaCO_3$)	pH
1	City of Green Bay	1-10-52	7.5	0.17	0.00	49	21	15	4.4	240	36	12.0	2.0	0.1	259	210	8.0
2	do	1-10-52	7.3	.79	.00	57	22	40	6.0	194	110	43.0	2.4	.0	395	234	7.8
3	do	1-10-52	7.0	.38	.00	56	26	14	4.6	281	37	11.0	1.6	.1	292	250	7.8
4	do	2-26-52	7.4	.58	.00	56	22	15	4.9	258	40	10.0	1.3	.2	282	232	8.1
5	do	1-10-52	6.5	.44	.00	50	20	23	6.0	210	65	17.0	2.4	.2	296	208	7.8
6	do	1-10-52	8.1	.40	.00	49	20	18	4.3	224	48	11.0	1.6	.2	268	205	7.8
7	do	1-10-52	7.5	.49	.00	60	29	35	4.5	265	51	58.0	1.6	.0	385	272	7.7
14	Village of Pulaski	2-25-59	------	1.50	.00	62	33	3	------	339	24	4.0	.4	.0	304	290	7.5
17	City of Green Bay	1-10-52	7.7	.68	.00	54	28	12	3.7	284	39	8.5	2.0	.1	291	251	7.8
22	Town of Preble	12-24-56	------	1.30	.00	61	43	------	------	349	58	5.0	.1	------	382	344	7.7
23	Town of Allouez	1- 8-59	------	.20	.00	58	24	60	------	242	170	10.0	.4	.0	458	237	7.6
85	Brown County Sanitarium	2- 8-57	------	.20	.00	78	26	------	------	209	130	18.0	1.9	------	------	325	7.6
127	Town of Howard	3-13-59	------	.15	.00	57	23	------	------	268	41	7.0	2.1	------	284	236	7.4
130	Fox River Heights Sanitary District	1-18-60	------	.30	.00	52	23	16	------	251	41	15.0	2.1	------	286	226	7.1
131	Austin Straubel Airport	9-30-59	------	.60	.00	57	31	------	------	298	33	10.0	1.8	------	302	270	7.2
132	City of De Pere	10- 6-59	------	.20	.00	55	26	26	------	220	71	30.0	2.1	------	346	240	7.8

TABLE 13.—*Summary of chemical analyses of water from wells tapping the sandstone aquifer in the Green Bay area*

[Results in parts per million]

	Number of analyses	Most frequently occurring concentration	Minimum	Maximum
Iron (Fe)	48	0.15	0.00	4.4
Chloride (Cl)	48	9.0	2.0	254
Fluoride (F)	48	2.3	.1	2.8
Dissolved solids	48	301	182	1,890
Hardness (as $CaCO_3$)	48	249	130	550

south of the city of Green Bay, reportedly was 1,000 feet deep and yielded water containing 1,890 ppm of dissolved solids (Weidman and Schultz, 1915). The dissolved solids were chiefly calcium sulfate.

WATER-LEVEL FLUCTUATIONS AND THEIR SIGNIFICANCE

The static (nonpumping) water level at De Pere in 1886, when the first deep well tapping the sandstone aquifer was drilled, was 92 feet above the land surface (Weidman and Schultz, 1915, p. 246). The static water level at the city of Green Bay reportedly was 97 feet above the land surface. By about 1905, water levels had declined to 28 feet above the land surface at De Pere and 21 feet at Green Bay. As withdrawals of ground water for public supply and industrial use continued to increase, the levels in wells continued to decline. In well Bn–9, in downtown Green Bay near the center of the cone of depression, nonpumping ground-water levels had declined to about 300 feet below the land surface by 1949 and about 340 feet below the land surface by 1957 (fig. 19). In well Bn–11, at De Pere on the south flank of the cone of depression, nonpumping levels had declined to about 130 feet below the land surface by 1949 and about 170 feet below the land surface by 1957 (fig. 20).

Records of water levels in observation wells tapping the sandstone aquifer in the Green Bay area show a persistent long-range trend of declining water levels to August 1957 as a result of the gradually increasing pumpage. The large withdrawals of ground water, chiefly in the vicinity of the city of Green Bay, resulted in declines in water levels a relatively great distance from the city; for example, the level in well Dr–11, in southwestern Door County about 20 miles northeast of Green Bay, declined about 20 feet from 1950 to 1957.

In August 1957, the city of Green Bay began using Lake Michigan as a source of water and discontinued pumping from wells tapping the sandstone aquifer. The cessation of pumping by the city resulted in a decrease in withdrawal of ground water in the Green Bay area from about 13.1 mgd in the first half of 1957 to about 5.3 mgd in the last half (a decrease of about 60 percent) and a rapid recovery in water levels.

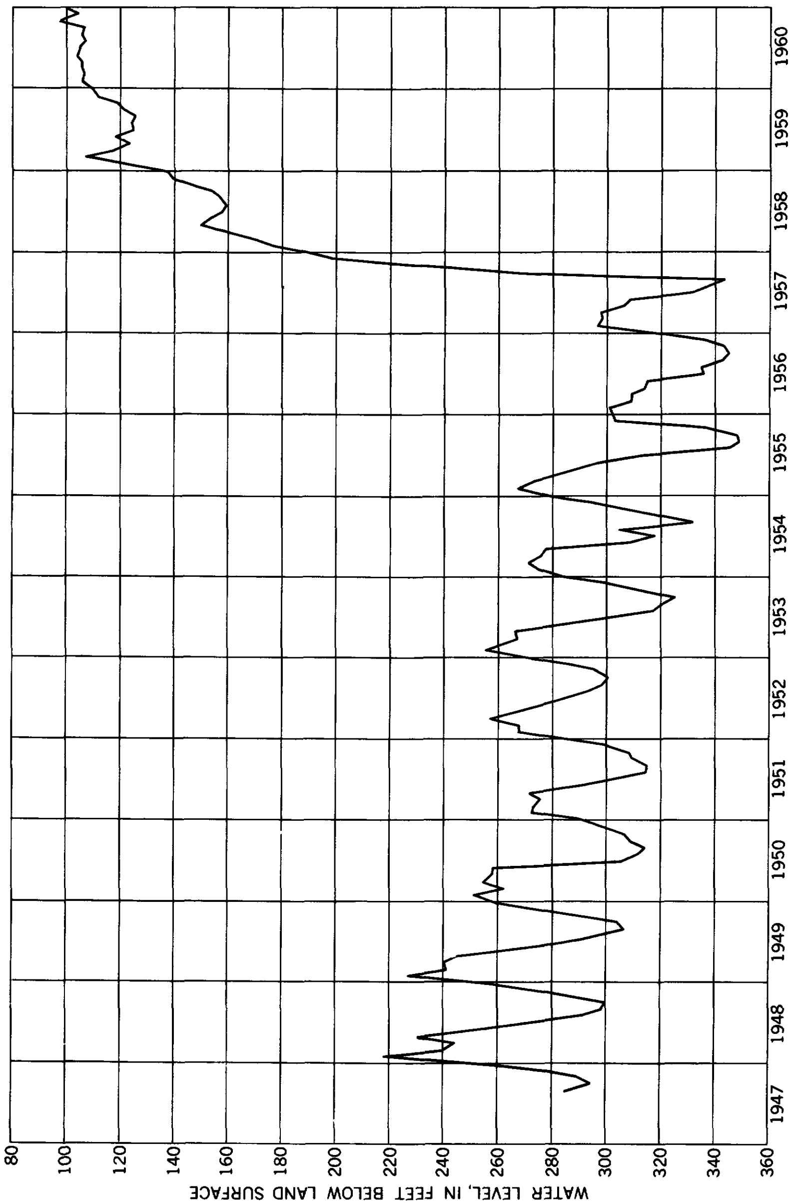

FIGURE 19.—Changes in water level in well Bn-9 tapping the sandstone aquifer at Green Bay, 1947–60.

The water level in well Bn–9, near the center of pumping, had recovered about 150 feet by December 1957 and about 240 feet by September 1960 (fig. 19). Rises in water levels in observation wells were recorded throughout the Green Bay area, the magnitude of the rises being dependent on the distance from the Green Bay public-supply wells.

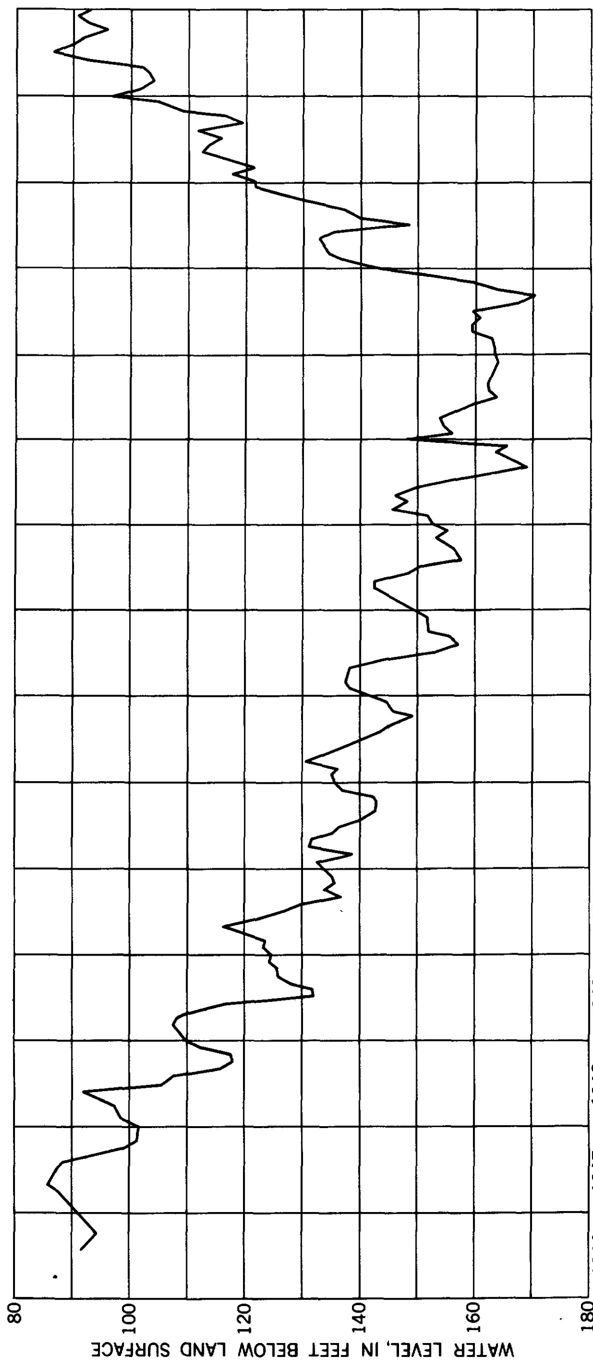

FIGURE 20.—Changes in water level in well Bn-11 tapping the sandstone aquifer at De Pere, 1946-60.

A map showing contours on the piezometric surfaces, as shown by the water levels in wells tapping the sandstone aquifer, was drawn for two different times. The piezometric surface in August 1957, immediately before pumping was discontinued from the city of Green Bay wells, is shown in plate 1. A deep cone of depression that had a relief of at least 200 feet was centered in downtown Green Bay. By September 1960, the small residual cone of depression had a relief of less than 50 feet (pl. 1). This cone also was centered in downtown Green Bay in the area of concentrated ground-water withdrawals for industrial use. Pumping levels were as deep as about 500 feet below the land surface at Green Bay and about 470 feet at Preble in July-August 1957. By August 1960, the pumping levels at Preble had recovered to about 300 feet below the land surface.

USE OF WATER

Ground-water withdrawals from wells tapping the sandstone aquifer began when the first deep well was drilled at De Pere in 1886. Pumping of water for public supply and industrial use gradually increased in response to the needs of an expanding population and the industrial development of the area. Withdrawal of water averaged about 6 mgd in 1940, about 10 mgd in 1950, and about 13 mgd in the first half of 1957. Before August 1957, more than 50 percent of the withdrawal was by the city of Green Bay. About one-half the water pumped by the city of Green Bay was supplied to industries. From August 1957 to 1959, withdrawal of water from the sandstone aquifer remained relatively constant at about 5½ mgd. About 40 percent of the pumpage was from public-supply wells, and about 60 percent was from privately owned industrial wells. The amount of water pumped for industrial use in 1959 is given in table 14 by type of industry; the amount withdrawn for public supply is listed in table 15.

TABLE 14.—*Pumpage of ground water by type of industry from the sandstone aquifer in the Green Bay area, 1959*

Type of industry	Pumpage (mgd)
Paper manufacturing	0.91
Food canning and processing	.18
Cold storage and ice manufacturing	.37
Dairy products	.89
Soap manufacturing	.06
Brewing	.19
Meatpacking	.38
Hospitals and institutions	.29
Miscellany	.03
Total	3.30

TABLE 15.—*Pumpage of ground water for public supply from the sandstone aquifer in the Green Bay area, 1959*

Public supply	Pumpage (mgd)
Allouez	0.54
Ashwaubenon	.15
De Pere	.85
Howard	.11
Preble	.32
Pulaski	.10
Wrightstown	.04
Total	2.11

The withdrawal of ground water from the sandstone aquifer by the city of Green Bay, other public supplies, and self-supplied industries for 1886–1959 are shown in figure 21. The pumpage in the area before 1947 is based on estimates by Drescher (1953).

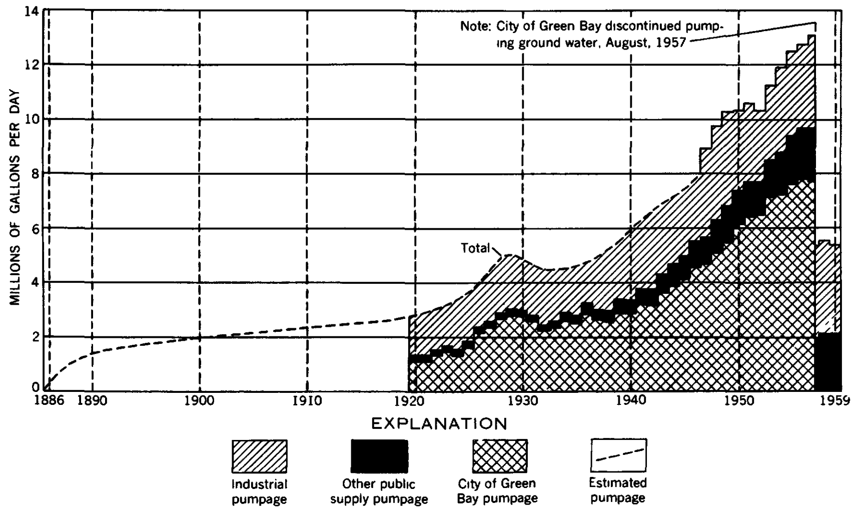

FIGURE 21.—Pumpage of ground water from the sandstone aquifer in the Green Bay area, 1886–1959.

PLATTEVILLE FORMATION

The Platteville formation overlies the sandstone aquifer throughout the Green Bay area. It conformably overlies the St. Peter sandstone in most of the area; however, where the St. Peter is absent, as in some of the wells at Green Bay (figs. 3 and 4), the Platteville rests unconformably on the rocks of the Prairie du Chien group. West of the East River, the Platteville formation is overlain by a varying thickness of Pleistocene and Recent deposits and crops out at a few places along Duck Creek and the Suamico River; to the east it is overlain by the Maquoketa shale.

The Platteville formation consists of about 60 to 213 feet of thin- to medium-bedded dolomite that contains some chert and shale. Water occurs in openings along fractures and bedding planes in the formation. The Platteville is little used as a source of water supply in the eastern part of the Green Bay area, where it is overlain by the Maquoketa shale. In the western part of the area, small quantities of water from this unit are used, chiefly for domestic and stock consumption. Although a paper company in the city of Green Bay formerly obtained part of its water supply from the Platteville formation, further study is needed to determine the actual value of the unit as a source of water supply.

NIAGARA DOLOMITE

The Niagara dolomite is present in the eastern part of the Green Bay area where the western edge of its outcrop area forms the prominent northwest-facing Niagara escarpment. The Niagara dolomite unconformably overlies the Maquoketa shale and is unconformably overlain by a varying thickness of Pleistocene and Recent deposits.

The Niagara dolomite consists of thinly bedded to massive light-gray dolomite that is fine grained and contains some chert. Records are not available on the thickness of the formation in the area, but the section penetrated by the public-supply well at Denmark in southeastern Brown County was 360 feet thick.

Ground water in the Niagara dolomite is found in openings along fractures and bedding planes. The formation yields water to many farm and domestic wells in the eastern part of the area and to the municipal well at Denmark. The municipal well at Denmark was test pumped at 500 gpm and had a specific capacity of 13 gpm per foot of drawdown. Wells in the Niagara dolomite yielding 500 gpm or more probably could be developed in the eastern part of the area. Because of the variable size and extent of the water-bearing openings in the dolomite, however, test drilling and test pumping would be required before large-scale development was attempted.

PLEISTOCENE AND RECENT DEPOSITS

Unconsolidated deposits of Pleistocene and Recent age overlie the consolidated rocks in most of the Green Bay area. These deposits, largely of glacial origin, consist of stratified clay, silt, sand and gravel, and unstratified till. Till is an unstratified and unsorted mixture of sediments. The unconsolidated deposits range in thickness from a veneer to about 235 feet. In general, the deposits are thickest along the East River and thinnest east of the Niagara escarpment and in the northwestern part of the area along the Suamico River. Deposits of sorted sand occur at some places along the Fox River from De Pere northward and along the shores of Green Bay.

Beds of unconsolidated sand and gravel generally supply small amounts of water to domestic and stock wells, and locally can supply larger amounts. The city of Preble obtains part of its water supply from two wells tapping the Pleistocene and Recent deposits. Both wells had natural flows when they were drilled in 1954 and 1956 and static water levels of 46 and 35 feet above the land surface. One of the wells was test pumped at 760 gpm for 48 hours and had a drawdown in water level of 84 feet, indicating a specific capacity of about 9 gpm per foot of drawdown. The combined withdrawal of water from the two wells averaged about 0.5 mgd in 1959. The Preble municipal wells are the only large-capacity wells tapping the Pleistocene and Recent deposits in the Green Bay area for which records are available.

Information on the chemical character of the water in the Pleistocene and Recent deposits is available only for the water from well Bn–112 at Preble. The water from this well is of the calcium magnesium sulfate type and is very hard. Containing 712 ppm of dissolved solids, it is more mineralized than the water from the sandstone aquifer.

PUBLIC WATER-SUPPLY SYSTEMS

GREEN BAY

The city of Green Bay supplied water to a population of about 63,000 in 1960. It obtains its water supply from Lake Michigan through an inlet 6,000 feet from the shore at a depth of about 60 feet below lake level consisting of nine 42-inch intakes. The lake water flows by gravity to a wet well at a pumping station located near the shore of Lake Michigan about 26 miles east of the city of Green Bay. There the water passes through screens of aluminum floor grating set in steel channel guides, is chlorinated, and is then pumped 15 miles through a 42-inch pipeline to the filtration plant. The pumping equipment consists of four vertical centrifugal pumps, two rated at 8 mgd and two at 5.5 mgd. The filtration plant is 362 feet above the floor of the pumping station.

At the filtration plant the water enters two mixing basins where liquid alum and carbon, when needed, are added. The water then passes through a 3-million-gallon-capacity settling basin and one of 8 filters (capacity, 2.5 mgd each). The water is chlorinated and fluoridated before leaving the plant. Storage facilities at the filtration plant consist of a 2-million-gallon underground reservoir and a 150,000-gallon elevated tank. The elevated tank is used chiefly for backwashing the filters. The capacity of the filtration plant is 20 mgd.

The withdrawals by the city of Green Bay for 1920–59, divided according to type of use for 1945–59, are shown in figure 22. An increase in pumpage of almost 250 percent occurred between 1942 and 1956. The monthly withdrawal by the city of Green Bay in 1959, and the maximum, minimum, and average monthly water temperatures at the filtration plant are shown in figure 23.

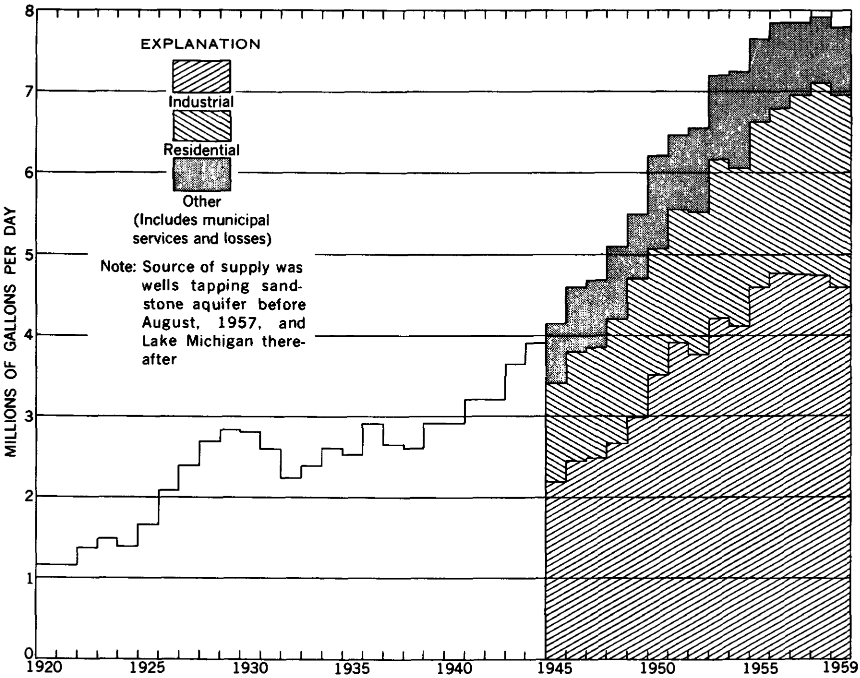

FIGURE 22.—Pumpage of water by city of Green Bay, 1920–59.

The average daily withdrawal by the city of Green Bay in 1959 was 7.78 mgd; the per capita consumption was about 120 gpd (gallons per day). The maximum withdrawal was 12.56 million gallons on September 8; the minimum was 4.15 million gallons on April 26.

ALLOUEZ

The water supply for the town of Allouez is obtained from wells Bn–23, Bn–24, and Bn–113 (pl. 1), which tap the sandstone aquifer and range in depth from 750 to 933 feet. The combined capacity of the pumping plants on the 3 wells is about 2.5 mgd. Storage facilities consist of 1.65 million gallons of ground storage in 5 reservoirs and 100,000 gallons of elevated storage in 1 reservoir. In 1959, pumpage ranged from 0.26 to 1.46 mgd, and averaged 0.54 mgd. Water treatment consists of chlorination.

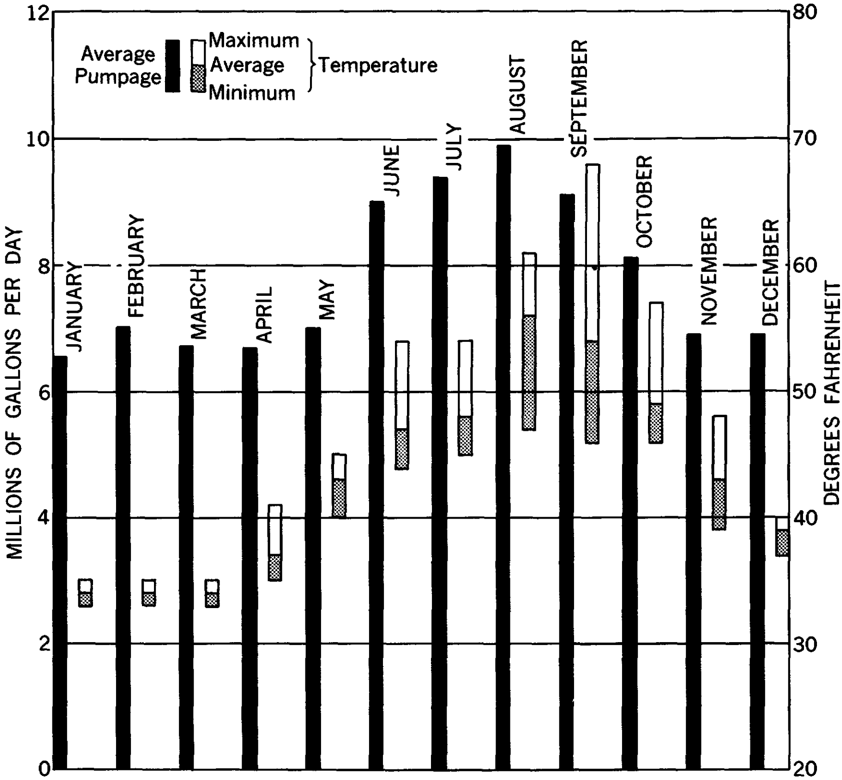

FIGURE 23.—Monthly pumpage of water by city of Green Bay and water temperatures at the filtration plant, 1959.

ASHWAUBENON

The town of Ashwaubenon is supplied with water from wells Bn–84 and Bn–130 (pl. 1), which are owned by Fox River Heights Sanitary District. The wells, tapping the sandstone aquifer and ranging in depth from 876 to 892 feet, are equipped with pumping plants having a combined capacity of 1.1 mgd. Storage facilities consist of 2 elevated reservoirs with a total capacity of 67,000 gallons. In 1959, pumpage ranged from 0.06 to 0.3 mgd and averaged 0.15 mgd. The water is chlorinated before entering the distribution system.

DE PERE

The water supply for the city of De Pere (population about 10,000 in 1960) is obtained from four wells (wells Bn–67, Bn–69, Bn–128, and Bn–132, pl. 1) tapping the sandstone aquifer. The wells range in depth from 765 to 812 feet, and their pumping plants have a combined capacity of 2.7 mgd. Storage facilities for 310,000 gallons consist of 2 ground reservoirs with capacities of 50,000 and 160,000 gallons, respectively, and 2 elevated reservoirs with capacities of 50,000 gallons each. In 1959, the pumpage ranged from about 0.45 to 1.65 mgd and averaged about 0.85 mgd. Per capita consumption averaged about 85 gpd. The water is chlorinated before entering the distribution system.

HOWARD

The water supply for Howard (population 3,485) is obtained from well Bn–127 (pl. 1). The well is 680 feet deep and taps the sandstone aquifer. Its pumping plant has a capacity of about 0.6 mgd. Storage facilities consist of a 100,000-gallon elevated reservoir. In 1959, pumpage ranged from about 0.04 to 0.28 mgd and averaged 0.11 mgd. Per capita consumption averaged 30 gpd. Water treatment consists of chlorination.

PREBLE

Preble, which obtains its water supply from 2 wells (wells Bn–21 and Bn–22, pl. 1) tapping the sandstone aquifer and from 2 wells in Pleistocene and Recent deposits of sand and gravel, supplied water to 2,818 customers in 1959. The wells tapping the sandstone aquifer range in depth from 973 to 1,007 feet, and the wells in the Pleistocene and Recent deposits range in depth from 75 to 126 feet. The combined capacity of the pumping plants on the 4 wells is about 3 mgd. Storage facilities consist of 3 ground reservoirs with a total capacity of 850,000 gallons and 2 elevated reservoirs with a total capacity of 150,000. In 1959, the pumpage ranged from about 0.47 to 1.69 mgd and averaged 0.82 mgd. Treatment consists of chlorination of the water from the sandstone aquifer and iron removal and chlorination of the water from the Pleistocene and Recent deposits.

PULASKI

The village of Pulaski (population 1,540) obtains its water supply from well Bn–14 (pl. 1), which is 330 feet deep and taps the sandstone aquifer. The pumping plant on well Bn–14 has a capacity of about 0.4 mgd. Storage facilities consist of a 95,000-gallon elevated tank. In 1959 pumpage ranged from about 0.05 to 0.31 mgd, and averaged about 0.1 mgd. Per capita consumption averaged about 60 gpd. The water is chlorinated before entering the distribution system.

WRIGHTSTOWN

The water supply for Wrightstown (population 840) is obtained from well Bn–66 (pl. 1), which is 570 feet deep and taps the sandstone aquifer. The pumping plant on well Bn–66 has a capacity of about

0.35 mgd. Storage facilities consist of a 75,000-gallon elevated reservoir. In 1959, pumpage ranged from about 0.02 to 0.10 mgd and averaged 0.04 mgd. Per capita consumption averaged about 40 gpd. The water is chlorinated before entering the distribution system.

USE OF WATER

Large quantities of water are used for public supply and industrial purposes in the Green Bay area. In 1959, the average withdrawal for all uses was estimated to be 495 mgd, of which 98.2 percent was from surface-water sources and 1.8 percent was from wells (fig. 24). Of the water from surface sources, 12.6 percent was obtained from the Fox River and 0.2 percent from small streams, 83.8 percent was obtained from Green Bay, and 1.6 percent was obtained from Lake Michigan.

In the Green Bay area in 1959, industrial use accounted for 98.0 percent of the total withdrawals, public supply for 1.2 percent, and rural use for 0.8 percent.

INDUSTRIAL USE

About 485 mgd of water was used by industries in the Green Bay area in 1959, of which 85.6 percent was obtained from Green Bay, 12.8 percent from the Fox River, and 0.9 percent from Lake Michigan, and 0.7 percent was pumped from wells tapping the sandstone aquifer (fig. 25).

The largest industrial use of water is for condenser cooling by the paper industry and a steam-electric power generation plant. It is estimated that in 1959 the average use for cooling was 441 mgd (90.9 percent of the total industrial use). Most of the water used for cooling is later discharged into the Fox River or Green Bay, slightly warmer than when withdrawn but otherwise unimpaired in quality. Water used for processing by the paper industry accounted for 38.2 mgd (7.9 percent) of the industrial water withdrawn in 1959; the remainder, about 5.6 mgd (1.2 percent), was for a variety of industrial uses, including food canning and processing, cold storage and ice manufacture, dairy-products processing, meat processing, metal working and fabrication, and brewing.

PUBLIC SUPPLY

The city of Green Bay obtains its water supply from Lake Michigan. All other public supplies are obtained from ground-water sources, chiefly from wells tapping the sandstone aquifer. The use of water for public supply in the Green Bay area, excluding water supplied to industry by the city of Green Bay, increased gradually from about 3.9 mgd in 1950 to about 5.8 mgd in 1959 (table 16), an

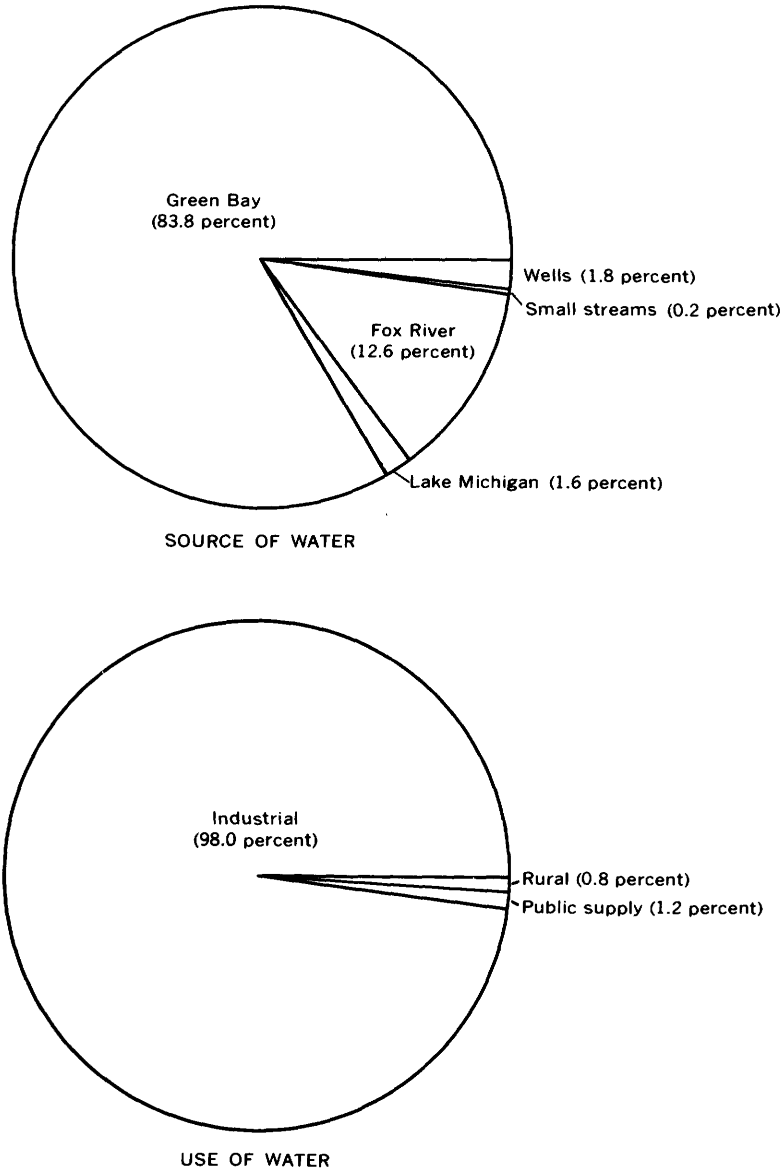

FIGURE 24.—Source and use of water in the Green Bay area, 1959.

increase of about 50 percent. In 1959, the use of water for public supply accounted for about 1.2 percent of the total withdrawal of water in the area.

In 1959, the withdrawal of water by the city of Green Bay for public supply was 3.2 mgd, which was 55.1 percent of the total withdrawal

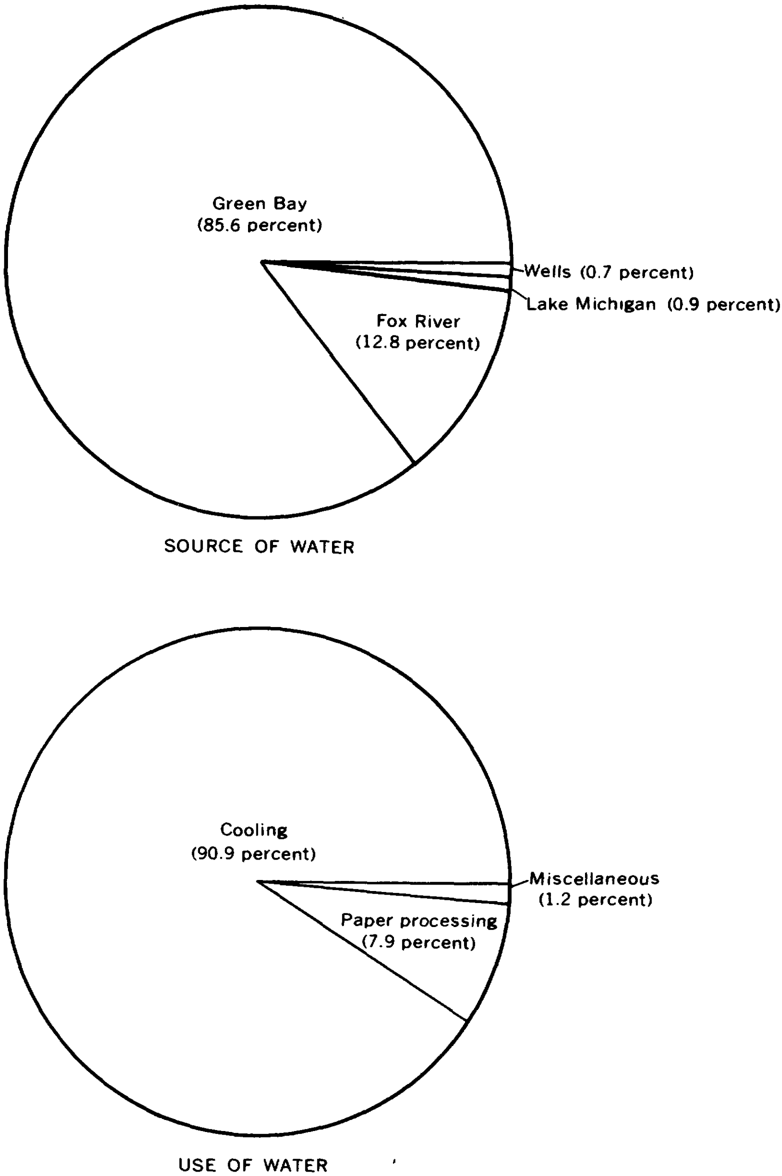

FIGURE 25.—Source and use of water by industry in the Green Bay area, 1959.

for public supply (fig. 26). In addition, the city of Green Bay supplied about 4.6 mgd to industry. Withdrawals by other public supplies ranged from 0.04 mgd (0.7 percent) at Wrightstown to 0.85 mgd (14.6 percent) at De Pere, and included a small amount of water supplied to industry.

TABLE 16.—*Use of water for public supply in the Green Bay area, 1950–59*

Municipality	Average use, in mgd									
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
Allouez	0. 22	0. 24	0. 28	0. 24	0. 33	0. 42	0. 44	0. 49	0. 53	0. 54
Ashwaubenon	. 04	. 04	. 04	. 05	. 06	. 07	. 10	. 15	. 13	. 15
De Pere	. 42	. 40	. 32	. 47	. 54	. 59	. 60	. 61	. 78	. 85
Green Bay	2. 69	2. 57	2. 78	2. 98	3. 12	3. 05	3. 06	3. 09	3. 18	3. 20
Howard	-----	-----	-----	-----	-----	. 03	. 05	. 07	. 09	. 11
Preble	. 39	. 37	. 41	. 49	. 55	. 70	. 74	. 79	. 85	. 82
Pulaski	. 10	. 09	. 07	. 07	. 06	. 07	. 08	. 09	. 10	. 10
Wrightstown	. 03	. 08	. 02	. 03	. 02	. 03	. 03	. 03	. 03	. 04
Total	3. 89	3. 79	3. 92	4. 33	4. 68	4. 96	5. 10	5. 32	5. 69	5. 81

RURAL USE

Rural use of water in the Green Bay area is chiefly for domestic purposes, watering stock, limited irrigation of fruit orchards, and processing of dairy products. In 1959, the withdrawal of water for rural use was estimated to be about 4 mgd. About 75 percent of the withdrawals were from ground-water sources and about 25 percent were from streams.

EMERGENCY WATER SUPPLIES

Adequate water is available for emergency supply from ground-water sources, at least for the period of time needed for decontamination of surface water. The small streams in the area would be supplemental sources of water if not contaminated. Information on the availability of water from the small streams in the area is given in the flow-duration data in tables 8 and 10.

In an emergency, adequate water for domestic and sanitary use in the Green Bay area could be obtained from industrial and public supply wells (pl. 1) as long as they remained operable. The industrial and public supply wells could supply at least 6 mgd for a sustained period and probably as much as 10 mgd for a period of several days. Standby power generators, driven by gasoline or diesel engines in case of electric power failure, are in place at many of the public supply and some of the industrial wells.

Additional sources of large emergency water supplies are the 10 wells that formerly supplied the city of Green Bay (pl. 1). Six of the wells, complete with pumping plants and power sources, are maintained in operating condition on a standby or emergency basis. Mr. H. L. Londo, city of Green Bay water superintendent, estimates that 10 mgd could be pumped from these wells for at least a week or 10

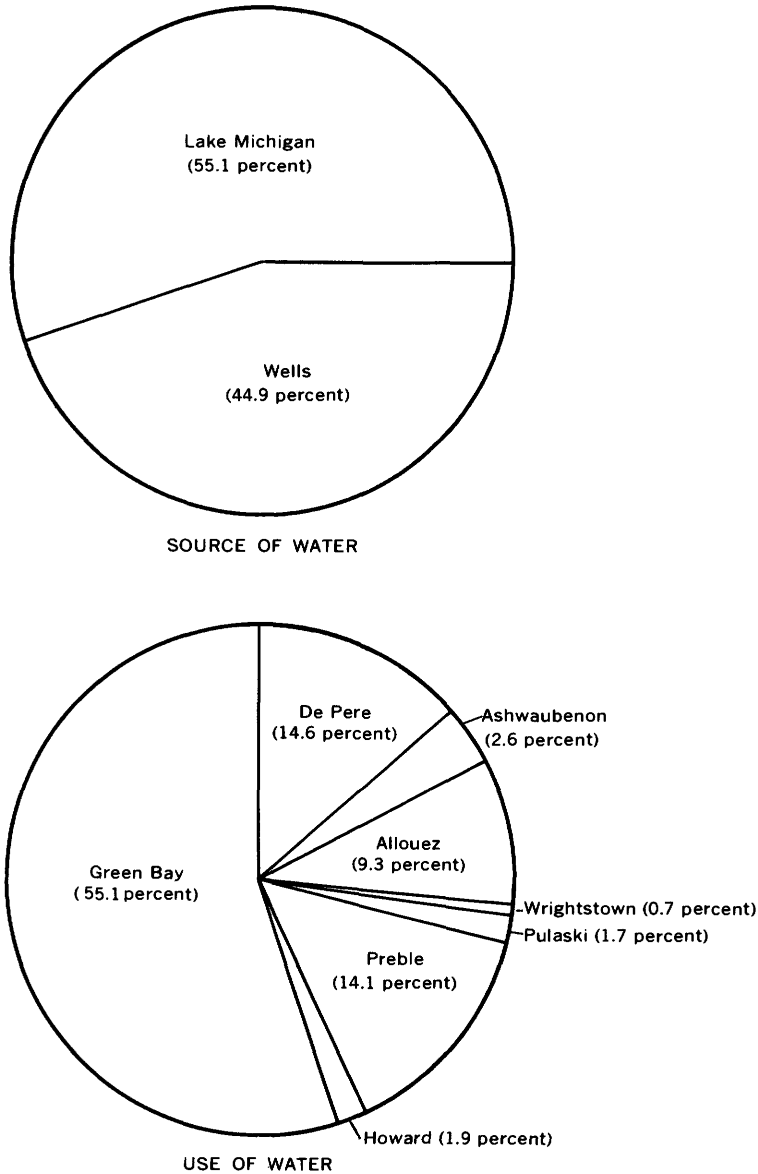

FIGURE 26.—Source and use of water for public supply in the Green Bay area, 1959.

days. The other four wells could be used as soon as pumping equipment could be installed.

The quantity of water available and its accessibility, not quality, are of primary importance in considering possible sources of water for emergency fire-fighting use. The city of Green Bay is favorably situated in having the Fox River flowing through the city and in being located adjacent to Green Bay.

POSSIBILITY OF FURTHER DEVELOPMENT

The discharge of the lower Fox River during the period of low flow in late summer and fall could be increased by the construction and regulation of reservoirs in the upper Wolf River basin. Development of such storage facilities, however, is not anticipated in the immediate future. The discharge during periods of low flow in the lower Fox River could be supplemented by an increased release of water from the Lake Winnebago pool made possible by changing the method of regulation at Menasha Dam.

Few of the small streams could be used the year round because of their intermittent nature. Although the feasibility of small storage reservoirs on a particular stream would have to be studied, the Suamico River appears to have the best possibilities for development of additional surface-water supplies.

Large amounts of water are available in Green Bay, but the disposal of industrial waste into the bay has restricted the use of the water in the area. Large quantities of good quality water also could be obtained from Lake Michigan, contingent only upon means of transmitting the water to the user.

The sandstone aquifer is a potential source of large additional quantities of water for the Green Bay area. Wells can be developed in most of the area that will yield 500 gpm or more. Drescher (1953) estimated that the recharge available to the sandstone aquifer is at least 30 mgd in the Green Bay area. Thus, if the aquifer is properly developed, the perennial yield of the sandstone aquifer could be at least 5 to 6 times the average withdrawal in 1959 of 5.4 mgd. The spacing of additional wells to enlarge the area of withdrawal would lessen the mutual interference between wells. Dispersal of wells westward toward the recharge area would be more effective in reducing mutual interference than dispersal in any other direction.

The Platteville formation supplies small amounts of water to wells in the Green Bay area. Further studies are needed, however to determine the potential of the Platteville as a source of moderate to large supplies of water.

The Niagara dolomite is a potential source of moderate to large supplies of water in the eastern part of the Green Bay area. Ground water is found in openings along fractures and bedding planes in the dolomite. Because of the varied size and extent of the openings, however, test drilling and test pumping would be required before large-scale development is attempted. It is probable that wells yielding

500 gpm or more could be developed in parts of the area where geologic and hydrologic conditions are favorable.

The Pleistocene and Recent deposits are not an important source of large supplies of water, except locally, as at Preble, where these deposits consist chiefly of sand and gravel. Detailed studies would be required to determine the potential of these deposits as a source of moderate to large supplies of water.

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