Water Resources of Racine and Kenosha Counties, Southeastern Wisconsin

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1878

Prepared in cooperation with University Extension—the University of Wisconsin Geological and Natural History Survey

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By RICKARD D. HUTCHINSON

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1970

UNITED STATES DEPARTMENT OF THE INTERIOR

WALTER J. HICKEL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. 79-608433

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington, D.C. 20402

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By Rickard D. Hutchinson

ABSTRACT

Urbanization and changes in regional development in Racine and Kenosha Counties are increasing the need for water-resources information useful for planning and management. The area is fortunate in having abundant supplies of generally good quality water available for present and projected future needs. Lake Michigan and ground-water reservoirs have great potential for increased development.

Lake Michigan assures the urbanized area in the eastern part of the two counties of a nearly inexhaustible water supply. In 1967 the cities of Racine and Kenosha pumped an average of 32.6 mgd (million gallons per day) from the lake. Water from Lake Michigan is of the calcium magnesium bicarbonate type, but it is less hard than water from other sources.

Discharge from Racine and Kenosha Counties into Lake Michigan is low and has little effect on the lake. The Root and Pike Rivers and a number of smaller streams contribute a mean flow of about 125 cfs (cubic feet per second) to the lake. Ground water, approximately 5 cfs, enters the lake as discharge from springs or as seeps.

The Des Plaines, Root, and Pike Rivers drain areas of relatively impermeable silty clay that promotes rapid surface runoff and provides little sustained base flow. Sewage sometimes accounts for most of the base flow of the Root River.

In contrast, the Fox River, which drains the western half of the area, has steady and dependable flow derived from the sand and gravel and the Niagara aquifers. Sewage-plant effluent released to the Fox River in 1964 was about 5 percent of the total flow.

A 5-mile reach of the Root River loses about 30,000 gpd (gallons per day) per mile to the local ground-water reservoir and is a possible source of ground-water contamination.

Thirty-five of the 43 lakes in the area are the visible parts of the ground-water table, and their stages fluctuate with changes in ground-water levels. The rest of the lakes are perched above the ground-water table.

Flooding is a recurring but generally minor problem along occupied reaches of flood plains of all the streams. However, in 1960 a flood on the Fox River, which had a recurrence interval of 60 years, caused considerable damage near the village of Silver Lake. At the same time, a flood on the Root River, which had a recurrence interval of 100 years, caused damage in Racine.

The sandstone aquifer, a major artesian reservoir underlying all of Racine and Kenosha Counties, is used as a water supply for industries, institutions, and three communities. Pumpage for these uses was about 3.3 mgd in 1967. The greatest decline of water levels, attributed to both local and regional pumping, was 7 feet per year at Burlington.

The specific capacities of wells developed in the Mount Simon Sandstone are about 5 gpm (gallons per minute) per foot of drawdown; in the Galesville and Franconia Sandstones, about 4 gpm per foot of drawdown; and in the St. Peter Sandstone, about 1 gpm per foot of drawdown. Yields of more than 1,000 gpm are obtained from wells tapping the Galesville and Franconia Sandstones and penetrating large crevices in the Trempealeau Formation near Burlington and Union Grove.

About 2.5 mgd of ground water in the sandstone aquifer was diverted from the two-county area toward the Milwaukee and Chicago pumping centers in 1963—about 1.7 mgd moving from Racine County toward Milwaukee and 0.8 mgd moving from Kenosha County toward Chicago. Recent regional water-level declines in the sandstone aquifer have ranged from about 3 to 5 feet per year. This decline in water levels represents a ground-water depletion of about 0.5 mgd; however, the aquifer is not being dewatered, nor are water levels declining in the recharge area.

The sandstone aquifer receives about 80 percent of its recharge from its outcrop area west of the two counties. In 1963 about 3.5 mgd moved eastward laterally from the recharge zone in western Walworth County, and about 1 mgd leaked downward through the overlying shale.

Pollution of the sandstone aquifer is neither a present nor an expected future problem. The water is very hard and contains excessive iron in many places.

The Niagara Dolomite is the principal shallow aquifer in the area. In 1967 pumpage from this aquifer for small community, domestic, stock, irrigation, and industrial uses was about 6.8 mgd. Water levels in the aquifer are responsive only to local hydrologic conditions and do not reflect regional pumping. Specific capacities of wells range from near 0 to 71 gpm per foot of drawdown, and the median is about 1 gpm per foot of drawdown. The largest test yield, 1,500 gpm, is from a well 2 miles southeast of Wind Lake, Racine County; and the least yields generally are from wells near Lake Michigan. The water is principally a calcium magnesium bicarbonate type, but in southeastern Kenosha County the water has a high concentration of sodium sulfate or sodium bicarbonate.

The shallow sand and gravel aquifer is made up of discontinuous bodies of sand and gravel embedded at various depths in the glacial drift. Although the shallow sand and gravel aquifer is little used, those parts of it that are in buried rock channels and those in hydrologic continuity with the Niagara aquifer may be important water reservoirs.

A water budget indicates that, of the 32 inches of precipitation that the area annually receives, about 7 inches runs off, and about 25 inches returns to the air as evapotranspiration.

The water resources of Racine and Kenosha Counties are adequate for future years. Lake Michigan will continue to supply water for all uses in the eastern part of the area. Ground-water resources, which have great potential for large development, will supply water for most uses in the western parts of Racine and Kenosha Counties and for irrigation and some industrial uses in other parts of the counties.

INTRODUCTION

Racine and Kenosha Counties, part of an expanding urban area between Chicago and Milwaukee, are experiencing a rapid growth of population and industry. Urbanization and changes in regional development have created water-resource concerns, such as polluted streams, increased eutrophication of lakes, increased needs for water supply, flooding, poor water quality, and lowered ground-water levels. Consequently, a systematic and comprehensive appraisal of the water resources in the area is needed to aid water managers, planners, legislators, and others interested in water. This report is directed toward all these people.

PURPOSE AND SCOPE

The purpose of this report is to describe the water resources of Racine and Kenosha Counties, Wis. The report includes descriptions of the hydrogeology, the ground- and surface-water system, the quality of the water, and the adequacy of the resources, including their extent and dependability, for present and future needs. Special emphasis is given to the ground-water resources because of their expected heavy use in the future.

This investigation is part of a cooperative program of the U.S. Geological Survey and the University Extension—the University of Wisconsin Geological and National History Survey to assess the water resources of Wisconsin.

LOCATION AND EXTENT OF AREA

Racine and Kenosha Counties are in the southeast corner of Wisconsin (fig. 1), about one-third the distance from Milwaukee to Chicago. The counties are bounded on the east by Lake Michigan, on the north by Waukesha and Milwaukee Counties, on the west by Walworth County, and on the south by McHenry and Lake Counties, Ill. Racine and Kenosha Counties form a 610-square-mile rectangle, 273 square miles of which are in Kenosha County, and 337 square miles are in Racine County.

OTHER INVESTIGATIONS

The early investigations that deal with water resources of the area are reconnaissance studies: Chamberlin (1877), Kirchoffer (1905), and Schultz (1905). Goldthwait (1907) and Fenneman (1910) dealt mainly with the origin and explanation of shore features of southeastern Wisconsin; Birge and Juday (1911) described chemical characteristics; and Juday (1914) dealt with mapping of lake bottoms and described lake dimensions. Weidman and Schultz (1915) described the occurrence and distribution of water and gave a brief account of the geology in the area.

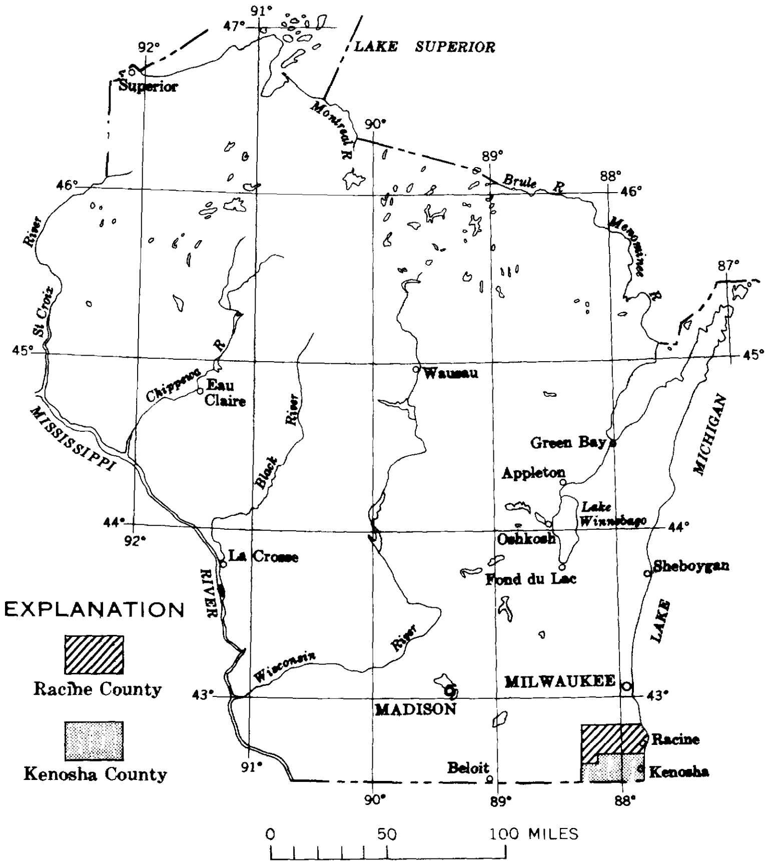


FIGURE 1.—Location of Racine and Kenosha Counties, southeastern Wisconsin.

Numerous geologic studies of the area included both detailed and reconnaissance work. The geologic investigation by Alden (1918) is still the principal source of information on the surface geology of southeastern Wisconsin. Alden gave a comprehensive bibliography of geologic investigations on the area before 1916 (p. 19–28). Other noteworthy geologic or geology-related reports include those of Whitbeck (1921), Geib and others (1922), Twenhofel, Raasch, and Thwaites (1935), Shrock (1939), and E. F. Bean (1949).

More recent reports include the inventories of wetlands (Wisconsin Conservation Department, 1960) and of surface-water resources (Poff and Threinen, 1961a, b) of Racine and Kenosha Counties; a comprehensive plan for the Root River watershed

(Southeastern Wisconsin Regional Planning Commission, 1966a); and water quality and flow of streams in southeastern Wisconsin (Southeastern Wisconsin Regional Planning Commission, 1966c).

Reports concerning ground water in surrounding areas include a description of the ground-water resources of the Milwaukee-Waukesha area (Foley and others, 1953), a report on the water resources of the Milwaukee area (Drescher and others, 1953), a report on ground-water supplies of Wisconsin and Illinois near Lake Michigan (Bergstrom and Hanson, 1962), and a report on water-level changes in the Milwaukee-Waukesha area (Green and Hutchinson, 1965).

ACKNOWLEDGMENTS

Many local residents, well drillers, and operators of public and industrial water supplies furnished valuable information and permitted collection of water samples and other data. Their help is gratefully acknowledged.

Special acknowledgment is made to the Wisconsin Department of Natural Resources for access to information on wells. Mr. Ralph Schmalling, water superintendent at Burlington, was helpful by granting the use of wells for an aquifer test in June 1964.

Acknowledgment of technical support is made to: Wisconsin State Laboratory of Hygiene for chemical analyses of water; Wisconsin Department of Natural Resources for information about the sanitary character of surface water and sources of waste disposal; Robert T. Sasman, Associate Engineer, Illinois State Water Survey, for ground-water data in northeastern Illinois; Southeastern Wisconsin Regional Planning Commission for material used in preparing base maps and for detailed information about sewage released in the Root and Fox River watersheds; and Public Service Commission of Wisconsin for pumpage records of public water utilities.

EFFECTS OF ENVIRONMENT ON HYDROLOGY

Physiography (including climate, topography, drainage, soils, and land use) and geology largely control the availability of water in Racine and Kenosha Counties. Climatic conditions determine the amount of water that reaches the land surface as precipitation. The topography, drainage, soils, land use, and geology govern the amount and rate of water runoff and infiltration.

PHYSIOGRAPHY

The variability of the area's climate determines the distribution of, and seasonal changes in, precipitation and runoff. More than half the average annual precipitation of 32 inches falls during the

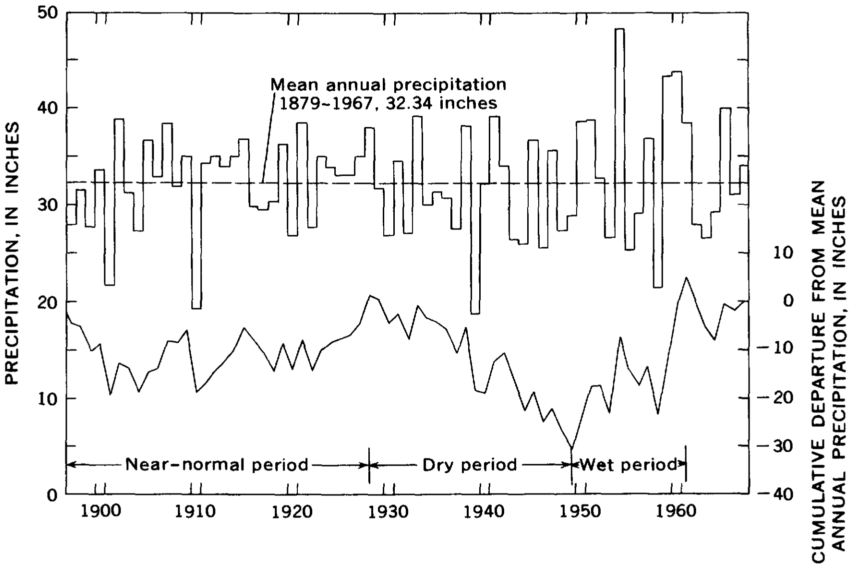


Figure 2.—Annual precipitation at Racine and cumulative departure from 1897–1967 mean. (Precipitation data from U.S. Weather Bur.)

growing season (May through September) and about one-sixth falls during the coldest period while the ground is frozen and snow covered (December through February). The 30-year (1930–59) mean annual temperature at the city of Racine was 9.3°C (Celsius) (48.7°F), and the mean annual precipitation was 31.90 inches; the 15-year (1945–59) mean annual temperature at the city of Kenosha was 9.2°C (48.4°F) and the mean annual precipitation was 29.86 inches. The annual precipitation at Racine and the cumulative departure from the 1897–1967 mean are shown in figure 2.

The topography, drainage, soils, and land use generally control the behavior of water on the land surface. Along with geology, they influence the recharge of water underground.

The land surface of Racine and Kenosha Counties is a gently undulating plain, which generally slopes eastward toward Lake Michigan. An uneven bedrock surface, sloping eastward about 10 feet per mile, controls the regional land form. Glacial action formed the present landscape, which has been modified slightly by later erosion. Low hills of glacial ground moraine and flat, poorly drained areas of pitted glacial outwash dominate the western third of the area. Low irregular north-south ridges of glacial moraine are the prominent features in the eastern two-thirds of the area. Land-surface altitudes range from about 940 feet in western Kenosha County to about 580 feet at Lake Michigan.

Land-surface drainage is in two major directions—southward into the Mississippi River system and eastward into the St. Lawrence River system. The Fox and Des Plaines Rivers flow southward into Illinois, draining 390 square miles that includes the western half of Racine County and nearly all of Kenosha County. The Root and Pike Rivers, plus many minor streams, flow into Lake Michigan and drain the rest of the area (220 sq mi).

Soils in the two counties are primarily grayish-brown silty clay loams derived from till; some black clays and organic matter occur in depressions; gray silty clays mark ancient lake plains; and sand and gravel occur in local beach deposits, in alluvium in stream valleys, and in small areas of outwash. Permeability of the silty clay loams is generally low, and drainage is poor. The sand and gravel in the valleys and in the beach deposits are the only deposits that have moderate to high permeability.

More than 65 percent of the land in Racine and Kenosha Counties is used for agriculture and agriculturally related purposes. Of the remaining 35 percent of the land, about 10 percent is covered by water and wetlands; about 8 percent consists of woodlands, open pits, and quarries; about 7 percent is residential; and the other 10 percent is used for commerce, industry, transportation, institutions, and recreation (Southeastern Wisconsin Regional Planning Commission, 1965a, p. 84).

Current changes in land use, such as the expansion of urban areas, the construction of highways, and the draining of wetlands, are having only local effects on the water system of the area.

GEOLOGY

Consolidated rocks of Precambrian, Cambrian, Ordovician, and Silurian ages underlie the area and have a wide range of lithologies and water-yielding characteristics. The dominant structural feature of these rocks is the general eastward dip of about 15 feet per mile (pl. 1, section *A–A′*). Gentle folding along the dip (pl. 1, section *B–B′*) has no apparent effect on the regional movement of ground water. Unconsolidated Quaternary glacial deposits overlie the consolidated rocks.

The geologic history of the area, beyond the scope of this report, was treated by Alden (1918), Potter and Pryor (1961), Buschbach (1964), and Ostrom (1964). The geology of the Milwaukee-Waukesha area, similar to that of Racine and Kenosha Counties, was described by Foley, Walton, and Drescher (1953) and by Green and Hutchinson (1965).

PRECAMBRIAN ROCKS

The Precambrian rocks are impermeable crystalline rocks that lie between 2,500 and 4,000 feet below land surface and that form the foundation, or basement, underlying the water-bearing rocks. The depth to the crystalline rocks, therefore, is the greatest possible depth of available ground water. No well in the study area is known to reach Precambrian rocks, although some wells are more than 2,000 feet deep.

Several authors have estimated the depth to Precambrian rocks in Racine and Kenosha Counties. Weidman and Schultz (1915, pl. 1) showed Precambrian rocks at altitudes of 1,000 and 1,500 feet below sea level at Burlington and Racine; Thwaites (1940, 1957) indicated only that these rocks are more than 2,000 feet below sea level in the two counties; and Beck (1965) and McGinnis (1966) estimated that the Precambrian rocks are about 1,800 feet below sea level at the southwest corner of Kenosha County and slope to about 3,750 feet below sea level at the southeast corner of the county.

CAMBRIAN AND ORDOVICIAN ROCKS

Cambrian rocks in the two counties are mostly sandstone and interbedded shale, siltstone, and dolomite. They are separated from bottom to top into the Mount Simon Sandstone, the Eau Claire Sandstone, the Galesville and Franconia Sandstones undifferentiated, and the Trempealeau Formation (pl. 1). Cambrian rocks include the most consistently productive water-yielding zones in the area and are tapped by wells for industrial water supplies and for public supplies at Burlington, Union Grove, and some subdivisions.

Although no well in the area is known to penetrate the entire thickness of the Cambrian rocks, their thickness is estimated to range from 2,000 feet in northwestern Racine County to 3,500 feet in southeastern Kenosha County.

Ordovician strata in the area are separated into three distinct hydrogeologic units, each with different water-yielding properties. From bottom to top, they are the St. Peter Sandstone, the Platteville-Galena unit, and the Maquoketa Shale.

The St. Peter Sandstone is mostly sandstone, although it also contains a variety of rock types ranging from conglomerate to shale. It is thickest where the underlying formations, primarily the Prairie du Chien Group and the Trempealeau Formation, were partly removed by erosion before the deposition of the sandstone. The greatest thickness, 150–200 feet, is in southern Kenosha County, and the least thickness, 45–100 feet, is in Racine County

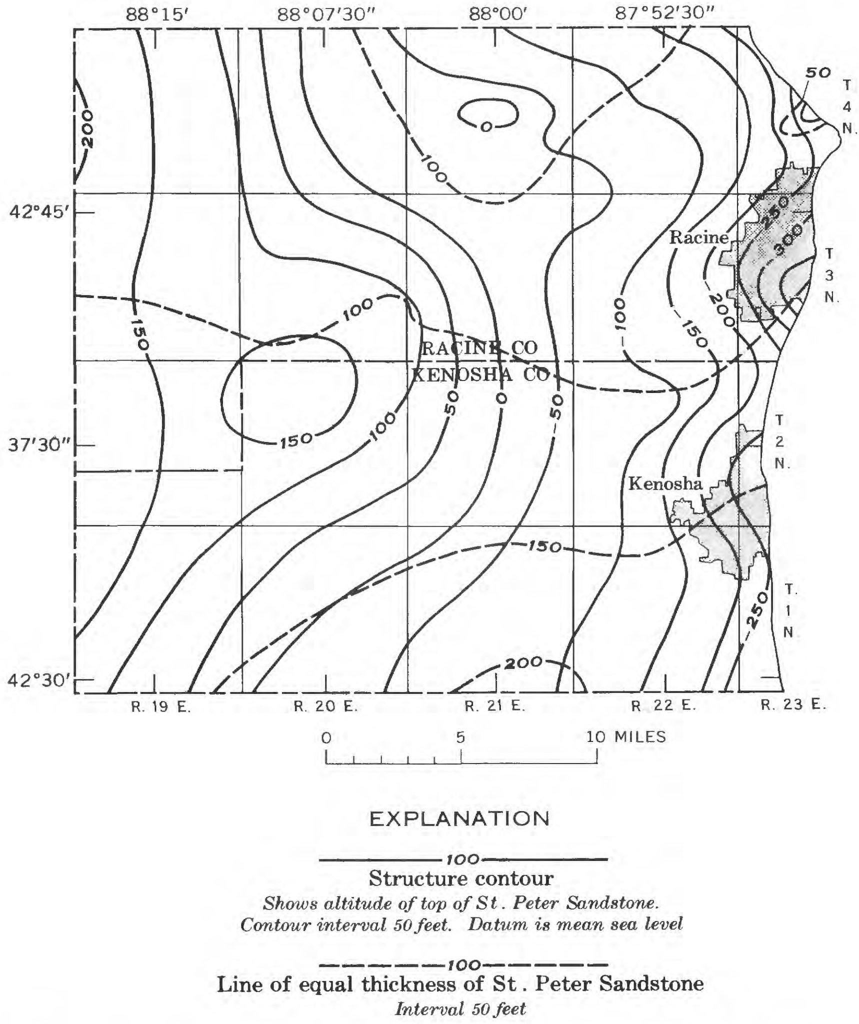
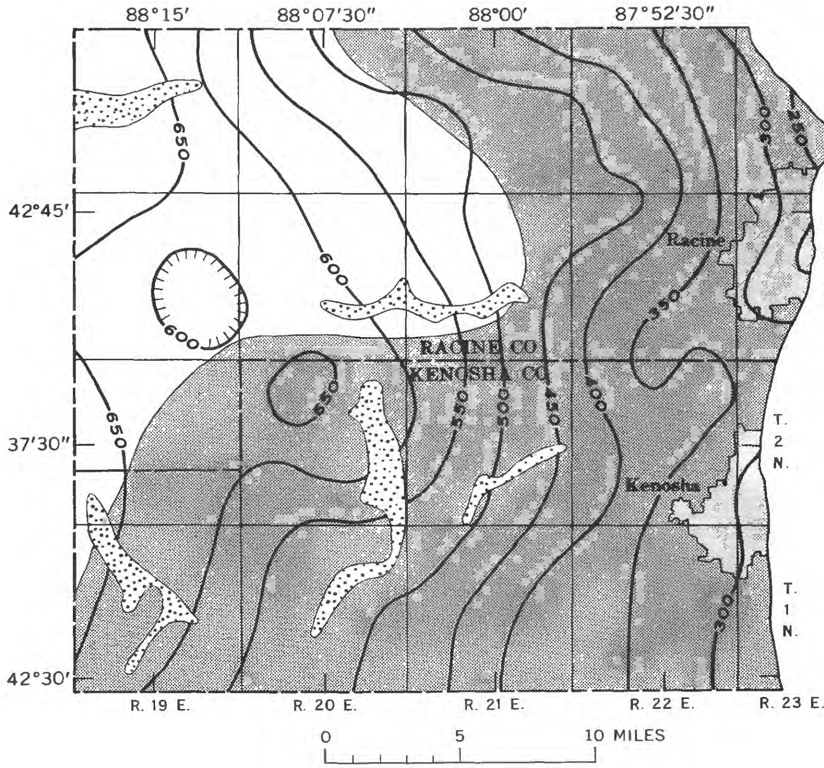


FIGURE 3.—Altitude of the top and thickness of the St. Peter Sandstone.

(fig. 3; pl. 1). The St. Peter Sandstone is the only Ordovician rock that yields water in significant amounts in Racine and Kenosha Counties. However, it is less productive than the sandstones of Cambrian age.

The Platteville Formation, Decorah Formation, and Galena Dolomite form the Platteville-Galena unit (pl. 1). Because of similarities in lithology and water-yielding characteristics, no differentiation is made between them. The unit, principally dolomite, yields small amounts of water from crevices, bedding planes, and solution channels but is not a dependable source of water.



EXPLANATION

Thickness, in feet

175-200

200-250

Bedrock valley

Showing areas where shale has been partially removed by erosion

300

Structure contour

Shows altitude of top of Maquoketa Shale. Contour interval 50 feet. Datum is mean sea level

FIGURE 4.—Altitude of the top and thickness of the Maquoketa Shale.

The Maquoketa Shale is dolomitic shale containing some thick beds of dolomite near the top. It yields some water from the dolomite beds near the top, but generally it has low permeability and forms a hydrologic barrier between the aquifers above and below. The Maquoketa Shale is at least 200 feet thick in nearly all of Kenosha County and in the eastern half of Racine County (fig. 4).

SILURIAN ROCKS

Silurian rocks in the area consist mostly of dolomite and have a maximum known thickness of 345 feet (table 1; pl. 1). Erosion has partly or completely removed the Silurian sequence; only the

TABLE 1.—*Summary of physical properties and water-yielding characteristics of rock units in Racine and Kenosha Counties, Wis.*

	Rock units and age	Physical properties	Thickness (ft)	Hydrologic units and water-yielding characteristics	
Quaternary	Pleistocene and Holocene deposits	Unsorted mixture of clay, silt, sand, gravel, and boulders; stratified sand and gravel; lake silt and clay; organic remains.	0–340	Sand and gravel aquifer	Small to moderate yields can be obtained from large sand and gravel aquifers.
Silurian	Niagara Dolomite and Alexandrian Series undifferentiated	Dolomite, fine- to medium-crystalline, and sandy chert nodules; some shale near base.	0–345	Niagara aquifer	Yields range from very small to large, depending upon size and number of crevices penetrated and development of wells.
Ordovician	Maquoketa Shale	Shale, dolomitic; fine- to medium-crystalline dolomite and interbedded shale common near the top.	180–250	Aquiclude	Shale yields small quantities of water; requires casing. Largest supplies can be obtained locally from interbedded dolomite.
Ordovician	Platteville, Decorah, and Galena Formations undifferentiated	Dolomite, fine- to medium-crystalline, dense, cherty; some sandstone and shale near base.	250–345		Yields small quantities of water from crevices; rarely used as the only source of supply.
Ordovician	St. Peter Sandstone	Sandstone, fine- to coarse-grained, cherty, friable; sandy dolomite and shale common in top; base may contain conglomerate or shale.	45–200		Yields moderate amounts of water; requires casing in some wells.
Ordovician	Prairie du Chien Group	Dolomite, sandy, cherty.	0–60		Water yield generally small.

TABLE 1.—*Summary of physical properties and water-yielding characteristics of rock units in Racine and Kenosha Counties, Wis.*—Continued

	Rock units and age	Physical properties	Thickness (ft)	Hydrologic units and water-yielding characteristics	
Cambrian	Trempealeau Formation	Dolomite, crystalline, sandy; may contain thin dolomitic sandstone and shale.	0–120		Water yield generally small, but exceptionally large yields are reported from cavities enlarged by solution.
	Franconia and Galesville Sandstones undifferentiated	Sandstone, fine- to medium-grained; fair sorting; friable; dolomite decreases toward base; grain size increases toward base; shale, siltstone, and dolomite common.	60–150	Sandstone aquifer	Yields moderate to large quantities from well-sorted sandstone near the base.
	Eau Claire Sandstone	Sandstone, fine- to medium-grained, well-sorted, dolomitic, compact; dolomitic shale and siltstone most common in the upper two-thirds of formation.	340–405		Only small quantities of water can be expected, but yields probably increase toward the north as the rock becomes coarser grained.
	Mount Simon Sandstone	Sandstone, fine- to coarse-grained, poorly cemented, friable; shale and siltstone up to 60 ft thick near Burlington.	637+ (Total thickness may be more than 1,500 ft.)		Yields moderate to large amounts of water where the rock contains only a few beds of fine-grained material.
Precambrian rocks		Unknown.	Unknown.		Not water bearing.

lower third remains near Burlington, and these rocks are silty, sandy, and thin bedded (pl. 1, *A–A′*). The uppermost remaining stratum at Racine is thick bedded and has fossil-reef structures.

Silurian dolomite forms the bedrock surface in most of the area, and the Maquoketa Shale forms this surface where the dolomite is absent (pl. 1).

Silurian rocks yield small to large amounts of water and are the principal source of water for hundreds of domestic wells.

Where both the unconsolidated deposits overlying the bedrock and the bedrock are permeable, interchange of water connects them hydrologically. Buried valleys in the bedrock surface may contain large quantities of saturated permeable sand and gravel.

QUATERNARY ROCKS

Quaternary rocks are unconsolidated glacial deposits of outwash, ice-contact materials, and till (pl. 2). These rocks are at land surface throughout most of Racine and Kenosha Counties. The glacial deposits are at least 100 feet thick throughout most of the two counties and may be as much as 340 feet thick in bedrock valleys (pl. 1). Where glacial sands and gravels are saturated, they may yield moderate amounts of water and be important local aquifers. Sands and gravels generally are in the western third of the area.

A thin layer of lake clay, peat, or beach sand and gravel deposits, formed during and after glaciation, overlies the glacial deposits in some places (pl. 2). Neither the lake clay nor the peat yields significant amounts of water to wells. Beach sands and gravels along the shore of Lake Michigan yield small amounts of water to wells.

WATER RESOURCES

Water available for man's use in Racine and Kenosha Counties is stored precipitation that has fallen on or near the two counties. The stored water may be either above or below land surface. Together, these two sources of water can be called the available water resource.

Precipitation on the two-county area may infiltrate the ground and remain as soil moisture, may percolate deeper and recharge the ground-water body, may return to the atmosphere as evaporation or transpiration, or may run off overland to surface-water bodies. Precipitation is the source of water, but evapotranspiration, interchange of water between surface- and ground-water bodies, and man's activities affect the distribution of the water within the area.

Water in Racine and Kenosha Counties is independent of county boundaries and is part of a water system that includes a large area of southeastern Wisconsin. About 380 cfs (cubic feet per second) enters the study area as streamflow from the north and west, and about 680 cfs leaves the area as streamflow to the south and east.

Ground water in the deeply buried sandstone aquifer enters the area from the west and moves as underflow toward local pumping centers or toward the large pumping centers in the Chicago and

Milwaukee metropolitan areas. Ground water in the two shallow aquifers is recharged locally. The opportunities for discharge are such that water in the two shallow aquifers seldom moves more than a few miles before discharging into a surface-water body or a pumping well.

GROUND WATER

Three aquifers in the area—the sandstone, the Niagara, and the sand and gravel—yield water to wells, springs, lakes, and streams. The deepest is the sandstone aquifer that lies beneath the semipermeable Maquoketa Shale. The shallow aquifers are the Niagara and the sand and gravel, which lie above the Maquoketa Shale.

SANDSTONE AQUIFER

The sandstone aquifer includes all of the Cambrian and Ordovician rocks between the Precambrian basement and the top of the Galena Dolomite. Because the water circulates between the various stratigraphic units of the sandstone aquifer, the aquifer acts as a single hydraulic unit. The Mount Simon and the Galesville Sandstones are the principal contributors of water, whereas the other stratigraphic units yield smaller and different amounts of water. The overlying semipermeable Maquoketa Shale acts as a semiconfining bed and maintains artesian pressure in the sandstone aquifer.

The depth to the top of the sandstone aquifer ranges from 500 to 800 feet. High-production wells in this aquifer within the study area average about 1,500 feet in depth.

RECHARGE, WATER MOVEMENT, AND DISCHARGE

Recharge to the sandstone aquifer in Racine and Kenosha Counties occurs by (1) water in the aquifer moving into the area from the west, (2) water seeping downward through the Maquoketa Shale into the sandstone aquifer, and (3) water leaking downward through wells that are open to the sandstone and to the rocks above.

Regional geologic and hydrologic conditions limit recharge to the sandstone aquifer in the report area. The main area of natural recharge to the sandstone aquifer is in Walworth County west of the west edge of the Maquoketa Shale (pl. 3), where the Platteville-Galena unit (Platteville, Decorah, and Galena Formations undifferentiated) underlies the glacial drift. Thus, most of the natural recharge to the sandstone aquifer enters rocks of the Platteville-Galena unit, percolates to the deeper formations, and then moves eastward toward Racine and Kenosha Counties.

Pumpage from the Platteville-Galena unit is relatively small in Racine and Kenosha Counties. Probably less than 25 wells in the area obtain their entire supply from the Platteville-Galena unit, and none of these wells are capable of yielding more than 100 gpm (gallons per minute). In the construction of wells tapping the sandstone aquifer, well drillers leave the Platteville-Galena unit uncased because the rock is competent enough to stand open and to take advantage of water that may be available.

The Maquoketa Shale is an imperfect barrier to water movement; it is completely saturated, and water seeps through it very slowly. The leakage of water through the Maquoketa Shale into the sandstone aquifer in the two counties during the fall of 1963 is estimated to have been about 1 mgd (million gallons per day).

A small amount of water recharges the sandstone aquifer through wells that are open to both the Niagara aquifer and the sandstone. Because water levels in the Niagara and the sand and gravel aquifers are higher than those in the sandstone, the water moves downward. About 25 wells are known to be open to both the Niagara and the sandstone aquifers. Most of these wells are near the cities of Racine and Kenosha, where the hydrostatic head between the two aquifers differs about 30 feet. The greatest head difference, about 150 feet, is in southwestern Kenosha County.

Water in the ground, as on the surface, moves downgradient from areas of recharge to areas of discharge. The natural hydraulic gradient of the sandstone aquifer in Racine and Kenosha Counties parallels the regional dip of the rocks, and the water generally moves from west to east; however, the effects of concentrated pumping cause the water to move northeast, toward Milwaukee, and southeast, toward Chicago.

The rate of water movement and the amount of water stored in an aquifer are related to the hydraulic characteristics of the aquifer, often expressed in terms of the coefficients of transmissibility and storage. The coefficient of transmissibility (T) is the rate of water flow, in gallons per day, through a vertical strip of the aquifer that is 1 foot wide and extends the full saturated height of the aquifer under a hydraulic gradient of 100 percent. The coefficient of storage (S) is the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in head. The coefficients are calculated from data of controlled aquifer tests by mathematical equations relating T and S to the rate of pumping, the drawdown of water levels in wells, the distance between observation wells and pumping wells, and the length of time since pumping began.

TABLE 2.—*Sandstone aquifer hydraulic coefficients from tests in and near Racine and Kenosha Counties*

County	Place	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Remarks
Kenosha	Bong Air Force Base.	15,000		USGS and WGS, well 1.[1]
Do	do	23,000		Driller's test, well 2.
Racine	Burlington	18,000		Driller's test, well 7.
Do	do	13,000		USGS and WGS test.[1]
Milwaukee [2]	Greendale	23,100	0.00036	USGS and WGS tests average.[1]
Do	Town of Lake	21,600	.00043	USGS and WGS tests average;[1] Mitchell Field area.
Waukesha [2]	Waukesha	25,400	.00036	USGS and WGS tests average.[1]
Lake [3]	Lake Bluff	16,000		Illinois State Water Survey test.
McHenry [3]	Crystal Lake	15,000		Illinois State Water Survey test. St. Peter Sandstone cased.

[1] U.S. Geological Survey and the University of Wisconsin Geological and Natural History Survey.
[2] From Foley, Walton, and Drescher (1953, p. 74).
[3] From Suter, Bergstrom, Smith, Emrich, Walton, and Larson (1959, p. 49).

The coefficients of transmissibility of the sandstone aquifer in Racine and Kenosha Counties range from 13,000 to 23,000 gpd per ft (gallons per day per foot). The coefficient of storage is about 0.0004. Values of T and S from tests in the sandstone aquifer in and near the report area are summarized in table 2. The T and S values are useful in predicting the availability of water and the probable pumping lifts or drawdowns in any nearby wells.

The coefficients of transmissibility and storage may help determine proper well spacing, which would prevent two or more wells in the same area from competing for the available water supply because they are too close together. Figure 5 illustrates the effects of well spacing and pumping on water levels. The curves show the influence of a well pumping about 695 gpm (1 mgd) on water levels at ½, 1, 2, and 5 miles distant and, also, the effects on water levels after 30 days and after 1, 5, and 10 years of pumping. Because the drawdown is directly proportional to the pumping rate, Q, the curves can be used to estimate drawdowns for rates larger or smaller than those shown. For example, if the pumping rate is 0.5 mgd, the drawdown at each point on the curve would be one-half the value shown.

Pumping rates and drawdown are reliable indicators of the water-yielding characteristics of an aquifer. These rates, expressed as specific capacity, in gallons per minute per foot of drawdown, are given in table 3.

Specific capacities of wells in the sandstone aquifer range from 0.2 gpm per foot of drawdown (after 21 hours of pumping) in a well tapping the St. Peter Sandstone to 20.1 gpm per foot of drawdown (after 45 hours of pumping) in a well tapping the Galesville and Franconia Sandstones. The four wells having the highest specific capacities reportedly penetrated crevices in the Trempealeau Formation before tapping the Galesville and Franconia

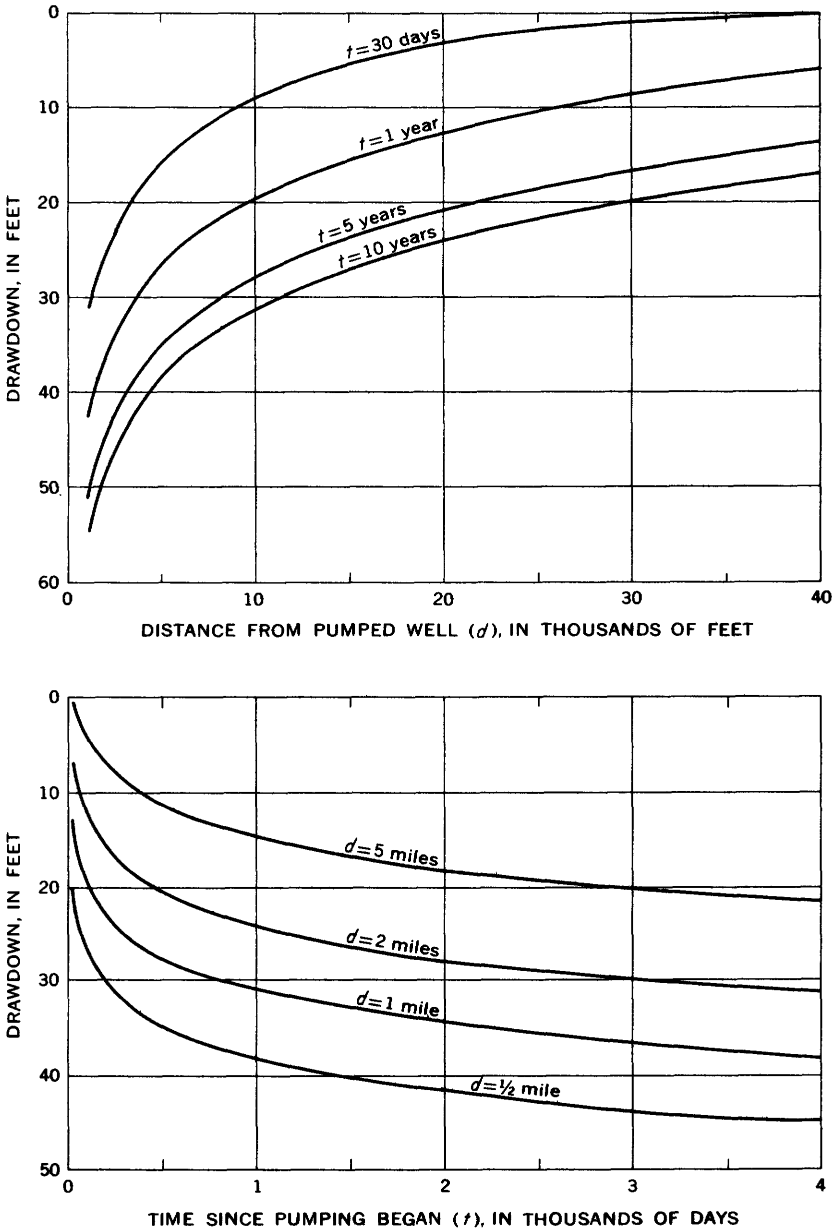


Figure 5.—Distance-drawdown and time-drawdown relationships for wells tapping the sandstone aquifer near Bong Air Force Base, Kenosha County, Wis. $Q=695$ gpm, $T=15{,}500$ gpd per ft, $S=0.0004$. Not adjusted for recharge boundary 22 miles to the west.

TABLE 3.—*Specific capacities of wells open to various parts of the sandstone aquifer, Racine and Kenosha Counties*

Well	Pumping rate (gpm)	Length of test (hr)	Hole diameter (in.)	Specific capacity (gpm per ft)	Remarks
Wells open through the St. Peter Sandstone					
Ke-2/20/15-26 [1]	10	21	5⅝	0.2	
Ra-3/20/34-28	80	....	8	.8	Open to Niagara aquifer.
Ra-4/23/27-49	70	....	6	.9	Do.
Wells open through the Galesville and Franconia Sandstones					
Ke-2/20/15-26	45	7	6	0.4	Well deepened.
Ra-2/19/5-325	752	12	12	18.8	Crevices in Trempealeau Formation.
Ra-3/19/22-21	250	10	8	2.4	
Ra-3/20/34-28	285	....	8	5.6	Well deepened.
Ra-3/21/30-57	1,450	48	12	20.1	Crevices in Trempealeau Formation.
Ra-3/22/21-17	40	....	8	.4	Open to Niagara aquifer.
Ra-4/22/29-53	372-412	7	10	4.6	Do.
Ra-4/23/21-60	299	8	10	1.4	Do.
Ra-4/23/8-47	455	24	10	2.5	Do.
Wells open through the Mount Simon Sandstone					
Ke-1/22/9-12	400	8	8	4.5	Open to Niagara aquifer.
Ke-2/20/15-24	1,001	23	15	5.8	
Ke-2/20/17-21	960	56	15	3.6	
Ra-2/19/6-339	1,300	24	15	11.5	Crevices in Trempealeau Formation.
Ra-3/19/32-27	1,356	24	12	9.7	Do.
Ra-3/19/32-37	525	....	10	6.6	After shooting.
Ra-3/20/25-15	249	....	8	2.5	Before shooting.
Ra-3/20/25-66	760	12	15	7.5	
Ra-4/21/21-341	158	8	8-6	1.5	
Ra-4/22/4-48	540	10	10	2.2	Open to Niagara aquifer.

[1] The well numbers indicate, in order, the county abbreviation, township, range, and section and the well's serial number within the county.

Sandstones. Otherwise, the specific capacities of wells in the sandstone aquifer appear to increase with depth, indicating that the highest yields are from wells tapping the greatest thickness of sandstone.

Discharge from the sandstone aquifer in Racine and Kenosha Counties is either underflow leaving the area or water withdrawn through wells. Withdrawn water is discussed in a later section on water use.

WATER-LEVEL CHANGES

Water-level changes caused by man generally are declines in response to withdrawals of water from the aquifer. Water-level declines in the sandstone aquifer of Racine and Kenosha Counties began when the first well penetrated the aquifer, probably a few years after the end of the Civil War. The early wells flowed (Chamberlin, 1877). Artesian head in wells at the cities of Racine and Kenosha was as much as 125 feet above land surface. The artesian head in a city well at Burlington was 30 feet above land surface when the well was drilled in 1890; however, the well flowed for only 4 years.

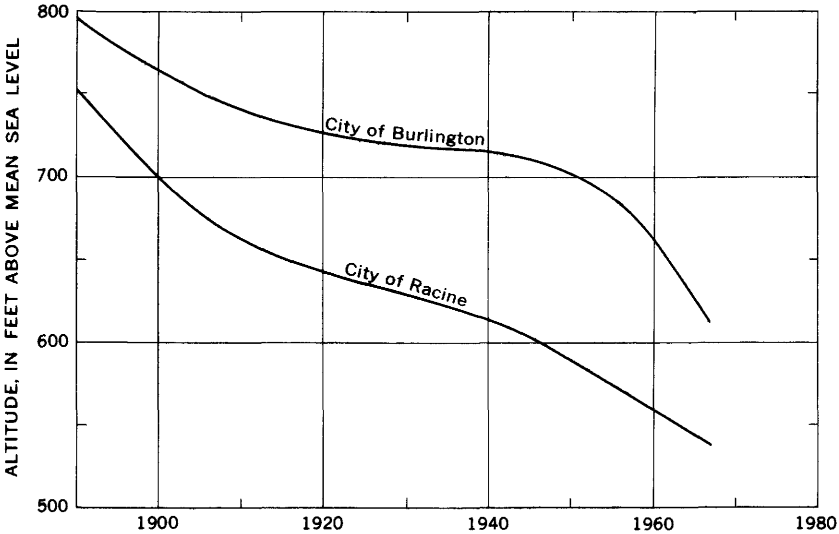


FIGURE 6.—Long-term water-level declines in the sandstone aquifer in Racine County.

Much of the early artesian flow was wasted because many of the wells were not restrained. The total water withdrawn as artesian flow from the aquifer was probably several millions of gallons per day, and water levels declined rapidly through 1910 (fig. 6).

The decreased rate of water-level declines after 1910 is associated with decreased artesian flow, which had stopped in nearly all the area by the early 1930's. The further decline of water levels resulted partly from the installation and use of pumps on these wells and partly from withdrawals at Milwaukee and Chicago.

The rate of pumping from the sandstone at Milwaukee was about 4 mgd between 1890 and 1925, whereas the withdrawal at Chicago increased from about 10 to about 60 mgd during the same period (fig. 7). Sharp increases in pumping rates at Milwaukee after the mid-1930's and at Chicago after the early 1940's, along with the continued pumping within the area, have produced marked effects on the water levels in Racine and Kenosha Counties. Contours of the piezometric surface (pl. 3) indicate that water in the sandstone aquifer is being diverted from Racine and Kenosha Counties toward centers of pumping at Chicago and Milwaukee.

Water-level changes in the sandstone aquifer primarily reflect the effects of long-term pumpage at Chicago and Milwaukee, rather than local pumpage. The similarity of declines in water levels in wells in Racine and Kenosha Counties (fig. 8) shows the regional

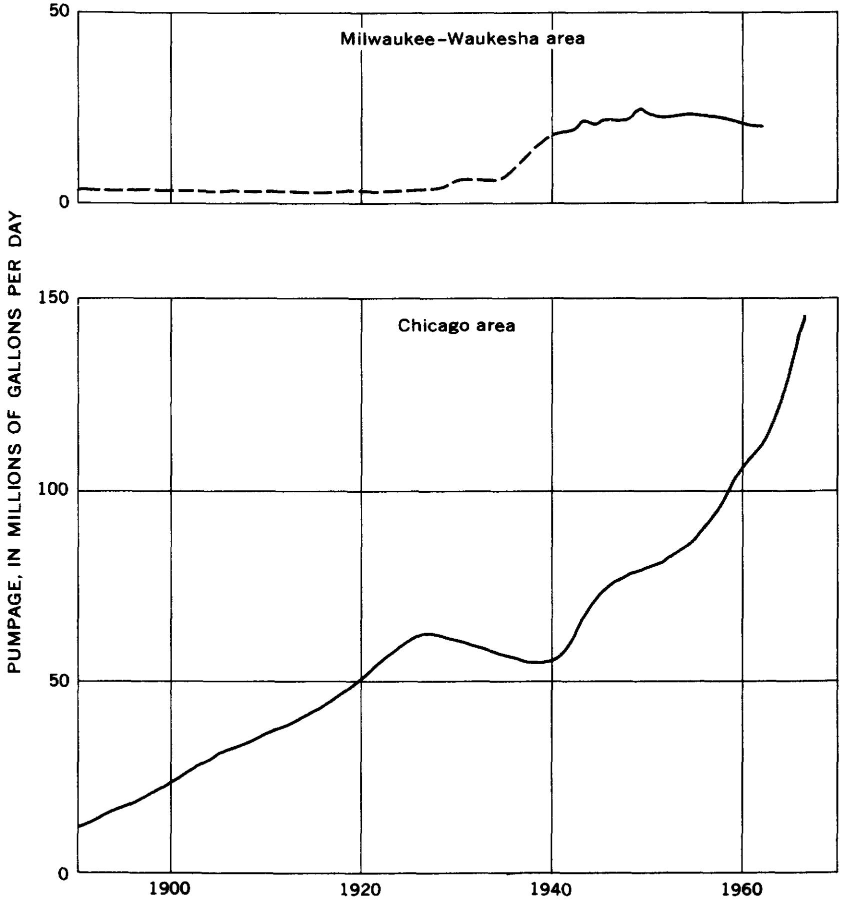


FIGURE 7.—Pumpage from deep wells in the Milwaukee-Waukesha area, Wisconsin, 1890–1961, and in the Chicago area, Illinois, 1890–1966. (From Green and Hutchinson, 1965; Sasman and others, 1967, fig. 2.)

decline even where little local use is made of the sandstone aquifer, such as at Bong Air Force Base (Ke–21) and near the city of Kenosha (Ke–6 and Ke–10).

The most heavily pumped part of the sandstone aquifer in the two-county area is at Burlington, where pumpage was about 1.1 mgd in 1967. The decline of water levels at Burlington (Ra–27) is greater than the regional trend because of this local pumping. The local effect of pumping is shown in figure 8 by the seasonal pattern of water-level highs in the winter and water-level lows in the summer.

Between 1958 and 1964 the water-level declines in the area ranged from about 3 feet per year at Bong Air Force Base to about 7 feet per year at Burlington. The rate of decline in the rest of the area was about 4 feet per year.

NIAGARA AQUIFER

The Niagara aquifer is the principal shallow aquifer overlying the Maquoketa Shale in Racine and Kenosha Counties. The Niagara aquifer, as used in this report, includes the dolomite near the top of the Maquoketa Shale and the dolomites of Silurian age. The aquifer extends over the entire area except for a few places where the Silurian rocks have been removed by erosion (pl. 1). Well yields are erratic and depend upon the size and number of crevices and solution cavities in the aquifer that are tapped by wells. Where impermeable glacial till overlies the dolomite, water in the aquifer may be under artesian pressure.

Throughout most of Racine and Kenosha Counties, the sand and gravel aquifer is connected hydrologically with the Niagara aquifer. Because water moves almost freely between the aquifers, they generally are considered to be a single hydrologic unit. Water-level designations shown on plates 2 and 4 are the levels of the combined aquifers. Local differences in drift lithology may cause water confinement and artesian pressure within the dolomite aquifer. Where this condition prevails, the sand and gravel deposits generally are absent or are not valued as aquifers. This report discusses the aquifers separately because of their differences in lithology and water-yielding characteristics.

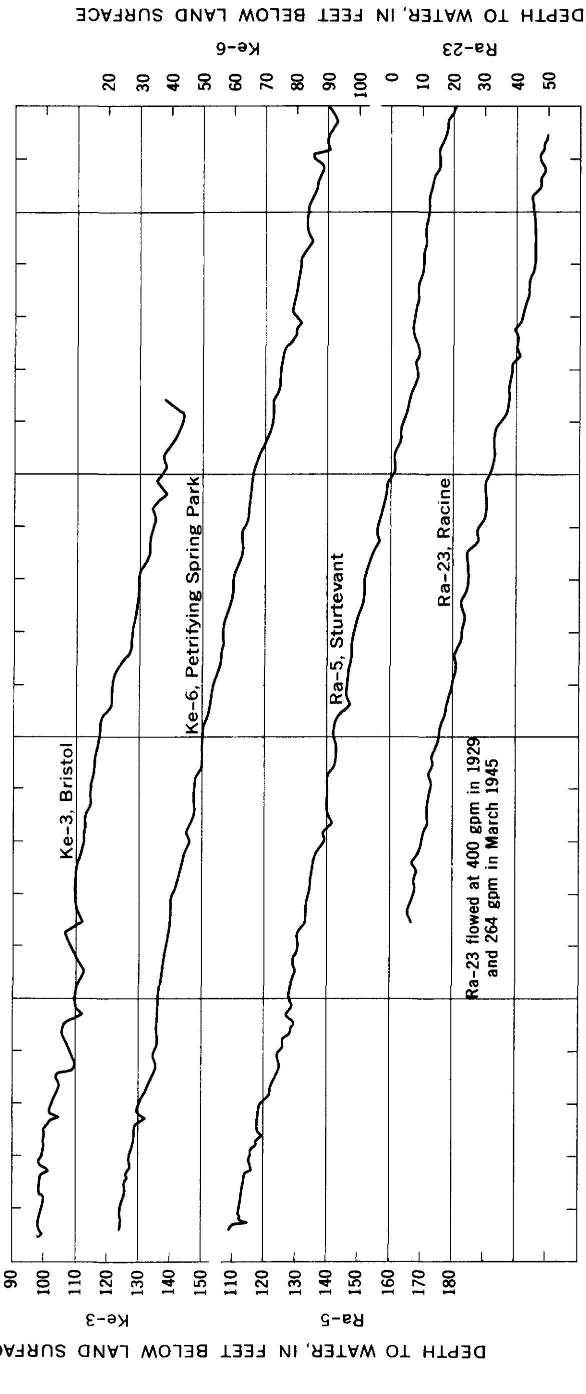
RECHARGE, WATER MOVEMENT, AND DISCHARGE

Recharge to the Niagara aquifer is from precipitation that falls on the two counties and seeps downward, although some water enters the area as underground flow. The downward seepage of water to the aquifer is through the glacial drift.

The permeability of the drift differs, and the rate of percolation through the drift to bedrock is not uniform (pl. 2). The most permeable surficial materials generally are in the western part of the area (pl. 2), where most of the recharge from downward seepage enters the Niagara aquifer. Thick drift materials of low permeability cover the rest of Racine and Kenosha Counties.

Some recharge is induced from Lake Michigan, where water levels in the aquifer near the lake are below the lake level.

The lateral movement of water through the Niagara aquifer generally is from west to east. The rate of water movement through the dolomite partly depends upon the interconnection of crevices and solution channels. In the western part of the area, thin beds of shale within the aquifer restrict the vertical move-


DEPTH TO WATER, IN FEET BELOW LAND SURFACE
Ke-6
Ra-23
Ke-3, Bristol
Ke-6, Petrifying Spring Park
Ra-5, Sturtevant
Ra-23, Racine
Ra-23 flowed at 400 gpm in 1929
and 264 gpm in March 1945
Ke-3
Ra-5
DEPTH TO WATER, IN FEET BELOW LAND SURFACE

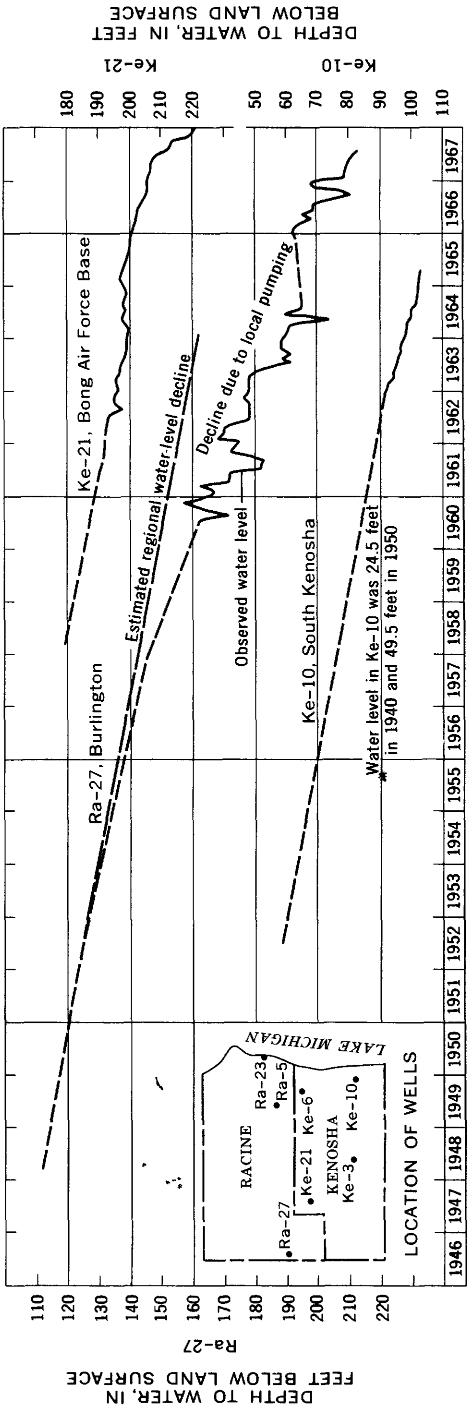


FIGURE 8.—Water levels in selected wells in the sandstone aquifer, 1946–67.

ment of water, and the water moves laterally in two zones. The upper zone is the top 40–50 feet of the aquifer, and the lower zone is the bottom 50 feet of the aquifer.

Differences in the movement of water in the Niagara aquifer are reflected in the range of specific capacities. The specific capacities (tables 4, 5), taken from drillers' reports, range from near 0 to 71 gpm per foot of drawdown, and yields are as much as 1,500 gpm, or 2 mgd. The median specific capacity of wells drilled into the Niagara Dolomite is about 1 gpm per foot of drawdown. The largest yields are from irrigation wells southeast of Wind Lake, Racine County; many of the smallest yields are from domestic wells near Lake Michigan.

The Niagara aquifer discharges water naturally into Lake Michigan, into some of the smaller lakes, and into rivers and streams. Other discharge is the withdrawal of water through wells.

WATER-LEVEL CHANGES

Water-level changes in the Niagara aquifer are caused by pumpage and by seasonal and long-term variations in recharge and natural discharge. Declines of water levels between the years 1900 and 1963 (fig. 9) were more than 40 feet near Union Grove and Wind Point, Racine County. (The year 1900 was one of nearly normal precipitation, which was preceded by a slightly dry period; 1963 was a year of slightly above average precipitation, which was preceded by a wet period.) The changes of water level shown in figure 9 are based on unpublished water-level data from a reconnaissance of ground-water conditions in 1899 and 1900 by the U.S. Geological Survey. Large drawdowns from pumping in a less permeable part of the aquifer, and probably leakage through wells into the underlying sandstone aquifer, caused the decline of water levels at Union Grove; water pumped from deep quarries and the pumping of many small wells probably caused the decline at Wind Point.

The piezometric surface of the Niagara aquifer (pl. 4) generally is stable, but local heavy pumping from the aquifer may cause localized water-level depressions. Heavy pumpage from the sandstone aquifer at Milwaukee and Chicago has not caused regional declines in the water levels of the Niagara aquifer (fig. 10).

SAND AND GRAVEL AQUIFER

Water-saturated sand and gravel deposits above the bedrock form a third source of ground water in Racine and Kenosha Counties. The sands and gravels are discussed as a single aquifer, although they are not hydraulically continuous throughout the

TABLE 4.—*Specific capacities of selected wells tapping the sand and gravel aquifer, Racine and Kenosha Counties*

Well	Pumping rate (gpm)	Length of test (hr)	Hole diameter (in.)	Aquifer penetration (ft)	Specific capacity (gpm per ft)	Screen length (ft)
Ke-1/20/ 2-23	560	8	12	26	11.2	108-136
2-25	245	8	6	35	8.0	117-141
11-15	50	......	8	7	2.0	143-150
2/20/16-249	60	5	5	27	4.0	95-105
18-19	10	3	5	42	.2	60-70
Ra-3/21/ 4-46	150	6	12	25	2.5	96-110
4-337	70	4	6	30	2.9	95-105

TABLE 5.—*Specific capacities of selected wells tapping the Niagara aquifer, Racine and Kenosha Counties*

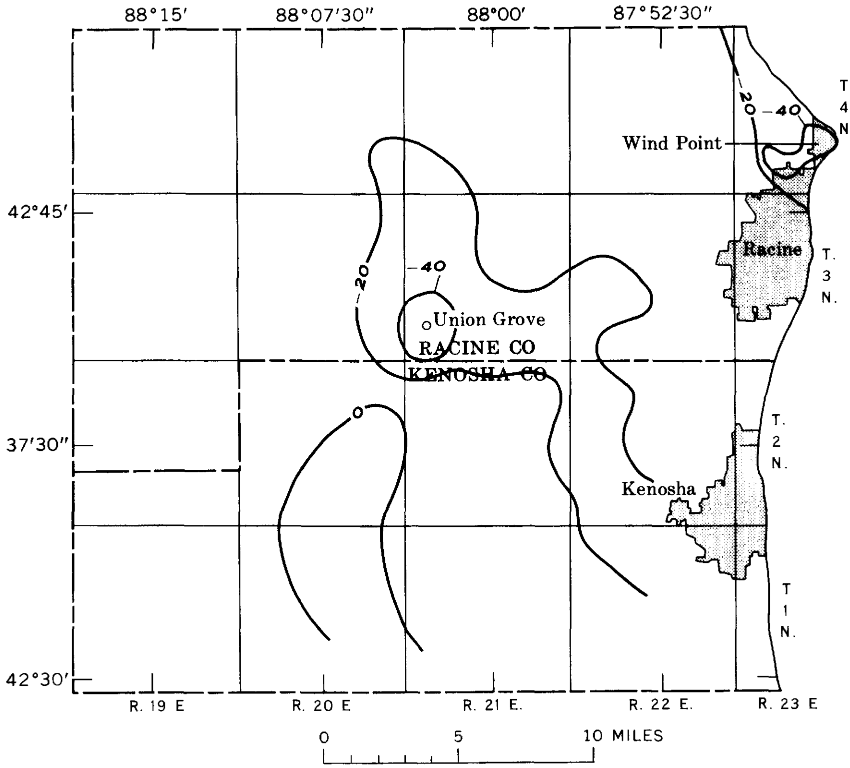
Well	Pumping rate (gpm)	Length of test (hr)	Hole diameter (in.)	Aquifer penetration (ft)	Specific capacity (gpm per ft)
Ke-1/20/ 2-20	35	9	6	79	0.2
30-57	70	......	8	15	5.0
1/22/13-29	80	2	10	200	.4
Ke-2/22/15-30	210	4	8	210	5.2
Ra-3/20/23-52	20	4	6	40	1.3
3/22/22-36	528	8	12	275	25.1
22-63	265	4	12	250	1.9
3/23/ 6-33	65	4	10	330	1.1
8-29	150	......	12	188	.9
4/19/36-340	175	8	6	102	12.5
4/20/15-32	1,150	72	12	19	55
15-292	1,500	8	15	175	71.4
16-342	1,050	10	12	132	21.9
21-31	280	5	8	39	11.7
23-345	450	8	12	165	3.7
14-55	600	15	10	50	9.5
24-58	100	12	10	55	.6
Ra-4/20/23-34	650	8	12	70	7.8
23-59	200	20	10	90	1.6
23-59	715	......	10	169	13.7
4/21/30-38	120	......	10	95	1.0
4/23/27-49	50	......	8	355	.4
27-56	192	6	8	350	4.8

area. The sand and gravel either is at land surface and extends down to bedrock or is interbedded within less permeable silt and clay deposits (pl. 2). The sand and gravel deposits may be fan shaped, spreading out and merging with adjacent fans, or they may be confined within long narrow valleys.

RECHARGE, WATER MOVEMENT, DISCHARGE, AND WATER-LEVEL CHANGES

Recharge to the sand and gravel aquifer is primarily from local downward seepage of precipitation. The rate of recharge is greatest in the western part of the two counties, where the sand and gravel is at or near land surface. The lowest rate of recharge occurs east of the Fox River, where the sand and gravel underlies impervious glacial till.

The lateral movement of water in the uppermost sands and gravels is locally toward streams and lakes (pl. 4). Where the sand and gravel deposits are near the surface, the aquifer probably



EXPLANATION

—20—
Line of approximate equal change of water level
Interval 20 feet

FIGURE 9.—Approximate water-level changes in the Niagara aquifer from 1900 to 1963.

is unconfined, and water movement reflects the topography; where the sand and gravel deposits are interbedded at depth in the silt and clay deposits, the lateral water movement in the aquifer may not be toward the nearest stream or lake. Where the sand and gravel deposits are deep and overlie the Niagara Dolomite, the two aquifers probably are connected hydraulically, and the lateral water movement within the two aquifers is similar.

The sand and gravel aquifer discharges to streams, inland lakes, land depressions intercepting the water table, underlying aquifers, Lake Michigan, and wells penetrating the aquifer. The aquifer also loses some water to vegetation where the roots reach the water table.

Water levels respond to seasonal changes in precipitation and to local pumpage. Long-term water-level changes are minor.

SURFACE WATER

The surface-water resources of Racine and Kenosha Counties in 1955 included Lake Michigan, 43 inland lakes, four rivers, and about 18,000 acres of wetlands (Wisconsin Conservation Department, 1960). Lake Michigan is the dominant water feature.

LAKE MICHIGAN

The importance of Lake Michigan to Racine and Kenosha Counties for water supply, transportation, economic development, and recreation is recognized; however, the hydrology of the lake is not within the scope of this report.

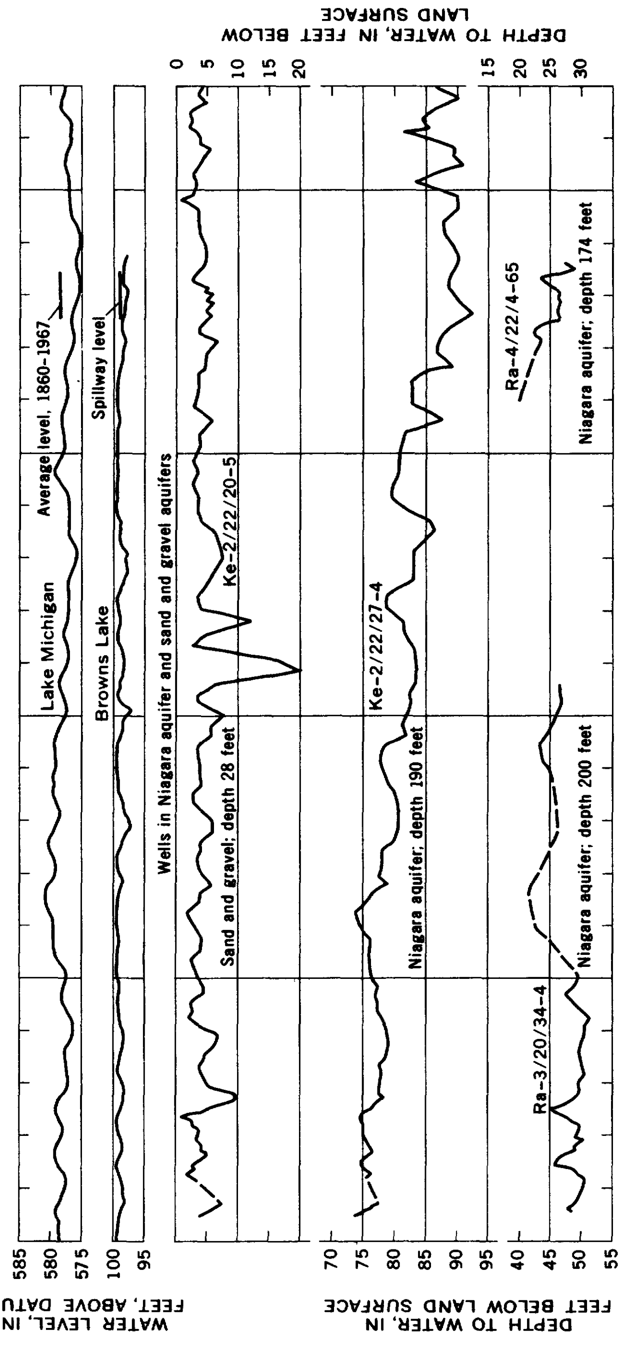
Discharge of water from Racine and Kenosha Counties into Lake Michigan is relatively low and has little effect on the level of the lake. The Root and Pike Rivers and a number of small streams drain about 220 square miles of Racine and Kenosha Counties and contribute a mean flow of about 125 cfs to Lake Michigan. Ground water, approximately 5 cfs, enters the lake as discharge from springs along the shore or from seeps and springs beneath the lake. Small amounts of water may move from the lake toward centers of pumping, where gradients (normally toward the lake) are reversed (pl. 4).

Lake Michigan's water level is largely determined by the difference between the amounts of precipitation and evaporation. The water level (fig. 10), monitored by the U.S. Army Corps of Engineers, Lake Survey Division, averaged 578.7 feet above mean sea level (International Great Lakes Datum) during the period 1860–1964. It ranged from 4.2 feet above to 3.4 feet below the average during this period (fig. 10). The water level during each month of 1964 was the monthly low for the period of record.

Relative to Racine and Kenosha Counties, Lake Michigan is virtually an inexhaustible source of water. Use of that resource, however, is limited to the Lake Michigan drainage basin and to the shoreline areas because of the legal aspects of diverting water from the basin (Southeastern Wisconsin Regional Planning Commission, 1966b) and because of the high cost of treating and distributing the water great distances from the lake.

STREAMS

Streams in Racine and Kenosha Counties are an important part of the water system, although they are not used for municipal or industrial supply, and only a small amount of water from them is


WATER LEVEL, IN FEET, ABOVE DATUM
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
Lake Michigan
Average level, 1860-1967
Browns Lake
Spillway level
Wells in Niagara aquifer and sand and gravel aquifers
Ke-2/22/20-5
Sand and gravel; depth 28 feet
Ke-2/22/27-4
Niagara aquifer; depth 190 feet
Ra-4/22/4-65
Niagara aquifer; depth 174 feet
Ra-3/20/34-4
Niagara aquifer; depth 200 feet
585
580
575
100
95
70
75
80
85
90
95
40
45
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0
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25
30

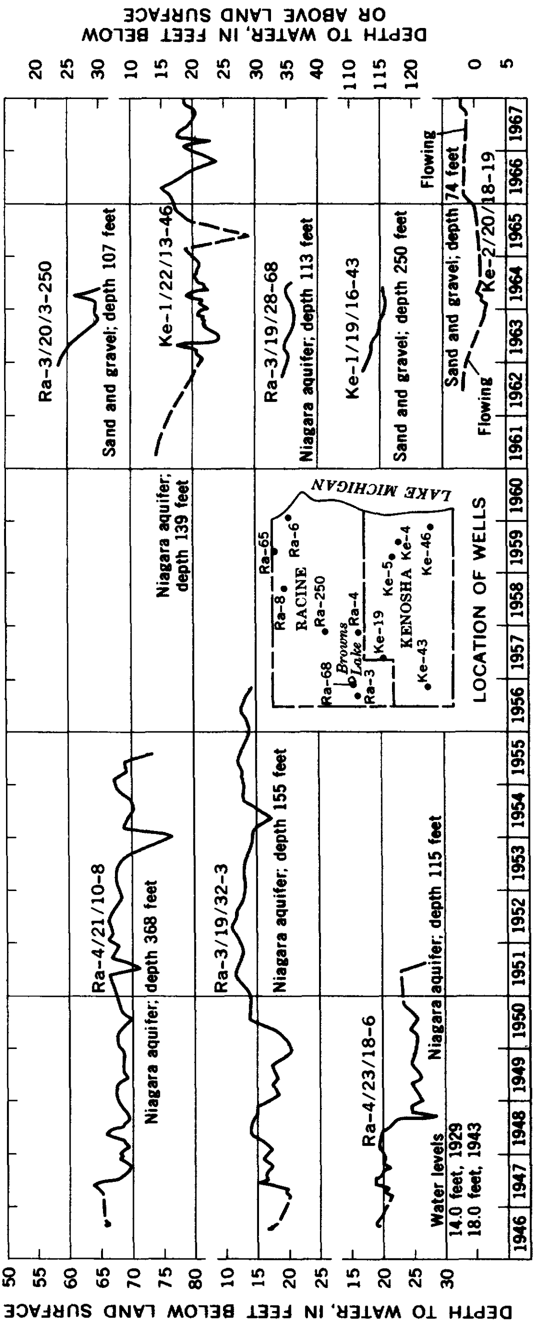

FIGURE 10.—Water levels in selected lakes and wells in the shallow aquifers, 1946–67.

used for agricultural purposes. The streams in the area mainly carry away local surface drainage, support fish and wildlife, provide water for recreation, and transport and dilute wastes. In contrast to the benefits they provide, the streams cause some damage during floods.

VARIATION OF STREAMFLOW

Streamflow is a combination of overland flow and ground-water runoff and varies with changes in the amount of precipitation and the route by which water reaches the stream. Overland flow causes most of the large variation in streamflow; it reaches the streams as runoff from rainstorms within the drainage basin or as delayed runoff from melting snow and ice. Ground-water runoff is a nearly steady contribution to streams and virtually is the low flow of streams.

The Fox River above Wilmot drains many areas of permeable sand and gravel deposits that provide a substantial amount of sustained streamflow (fig. 11). The discharge equaled or exceeded 100 cfs for 90 percent of the period 1940–67. Mill dams that were built many years ago at Waterford, Rochester, Burlington, and Wilmot are not used for their original purpose and are of little use in regulating the runoff of the Fox River during times of high or low flows.

The Des Plaines and Root Rivers drain areas of relatively impermeable silty clay that promotes rapid overland flow and provides little sustained ground-water flow (fig. 11).

In figure 11 the flow-duration curves show a comparison of the relative dependability of flow of the major streams in Racine and Kenosha Counties. Streams in sandy areas, such as the Fox River, have the flatter curves that indicate steadier, more dependable flow. Streams in clayey and silty areas, such as the Des Plaines and Root Rivers, have the steeper curves, indicating rapid runoff and lesser dependability.

LOW FLOWS

An evaluation of a stream's dependability must include an analysis of that stream's low-flow characteristics. The lowest flows are the limitations of available water during part of the year, and some water-use needs must be based on these limitations. Magnitudes and frequencies of low flows of the Fox River at Wilmot are shown by a set of curves in figure 12. The curves, based on 20 years of data, can be used to estimate future low flows.

Streamflows are lowest when ground-water contributions are least—in late summer and late winter and during droughts. Esti-

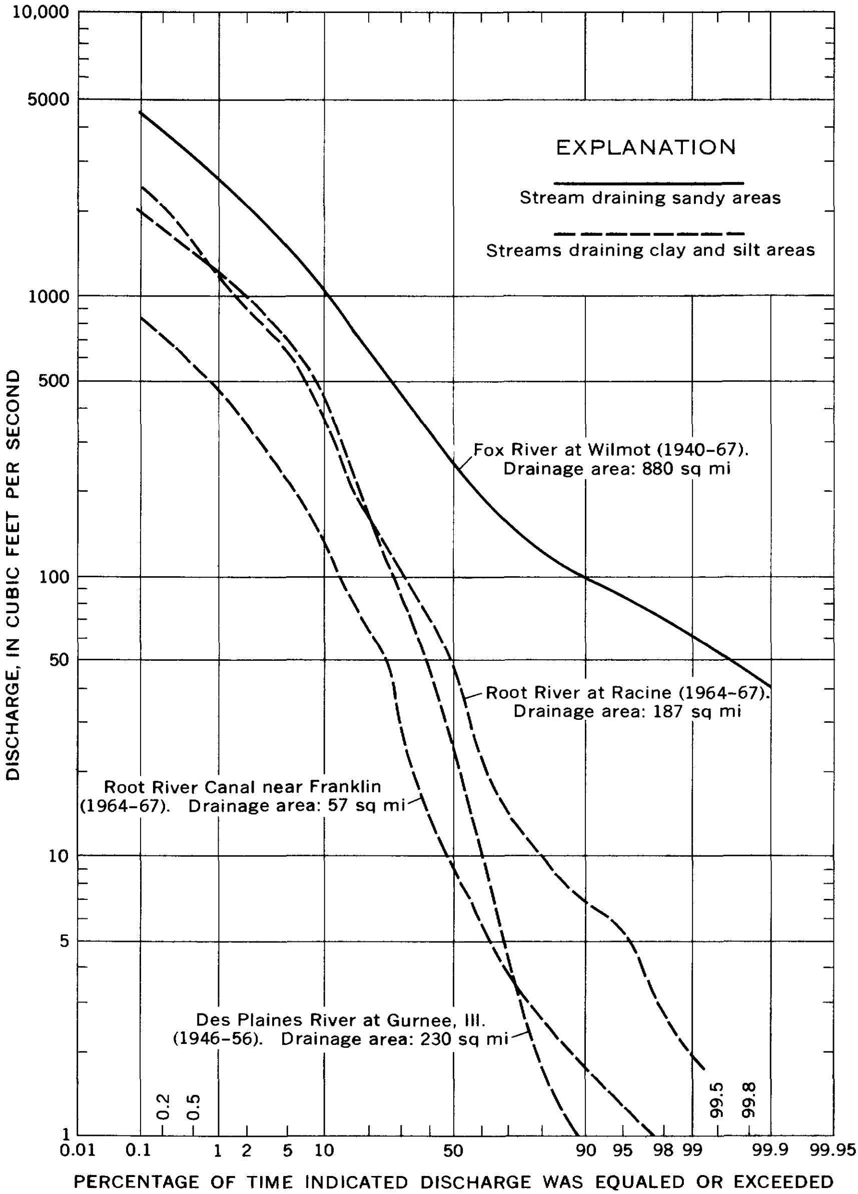

FIGURE 11.—Flow-duration curves for streams in sand and clay environments.

mates of streamflow during dry periods can be made from the curves in figure 13. For example, if a discharge of 0.114 cfs per sq mi, or 100 cfs, in the Fox River at Wilmot (point *A*) were measured on a summer day during a dry period, the estimated

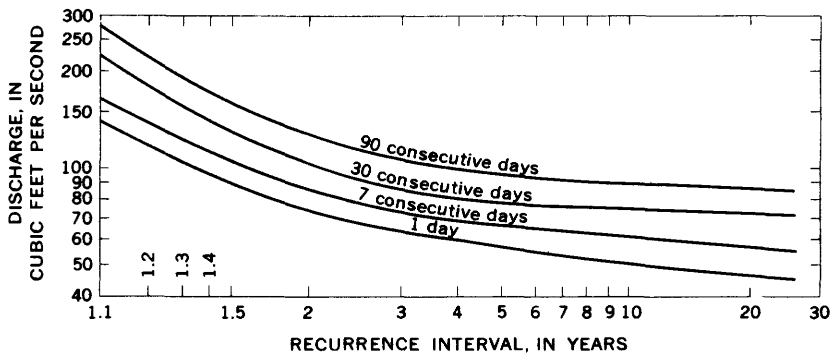

FIGURE 12.—Magnitude and frequency of low flow at Fox River at Wilmot, Wis., 1940–60 climatic years.

discharge after 10 additional days without rain would be about 0.100 cfs per sq mi, or 88 cfs (point *A'*). During that same 10-day period, the ground-water yield from the basin (*B–B'*) would be about 0.04 inch, or about 600 million gallons.

Sewage from municipal, industrial, and rural sources supplements the flow of many streams. Much of the sewage reaches and is transported by ground water that ordinarily would not reach the local streams by natural discharge. The sewage water sometimes accounts for all or most of the flow in the smaller streams. An apparent base flow of the Root River Canal in mid-November 1963 was mostly sewage-plant effluent and industrial-waste water. A series of low-flow measurements along the Root River Canal on November 14, 1963 (fig. 14), showed that waste water accounted for most gains in the flow. (Decreased flow along the lower part of the stream's reach indicated that water was seeping from the stream into the local ground-water reservoir.)

Further information on sewage contributions to streams in the study area is available in reports by the Wisconsin Department of Natural Resources (1967a, b, c).

The reported sewage effluent of about 1 cfs from treatment plants at Union Grove and Southern Wisconsin Colony and Training School was more than the total flow of the Root River Canal, as measured at Racine County Trunk C (fig. 14), 4–5 miles downstream from the treatment plants. The effluent was derived from water pumped from the sandstone aquifer. The increase in flow of 0.35 cfs between State Highway 20 and Twomile Road equaled the estimated pumpage of 150 gpm (0.33 cfs) from a sand and gravel aquifer at a large poultry-processing plant.

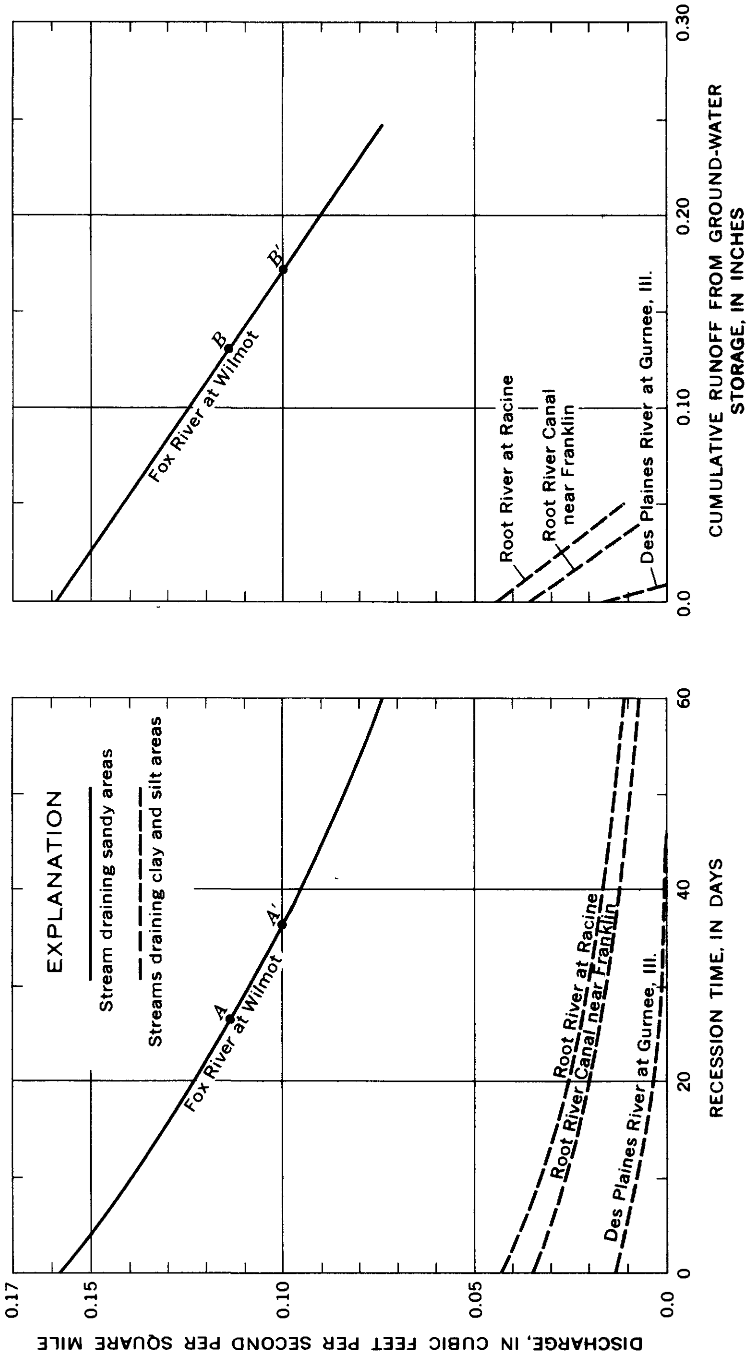

FIGURE 13.—Summer base-flow recession and ground-water yield for streams.

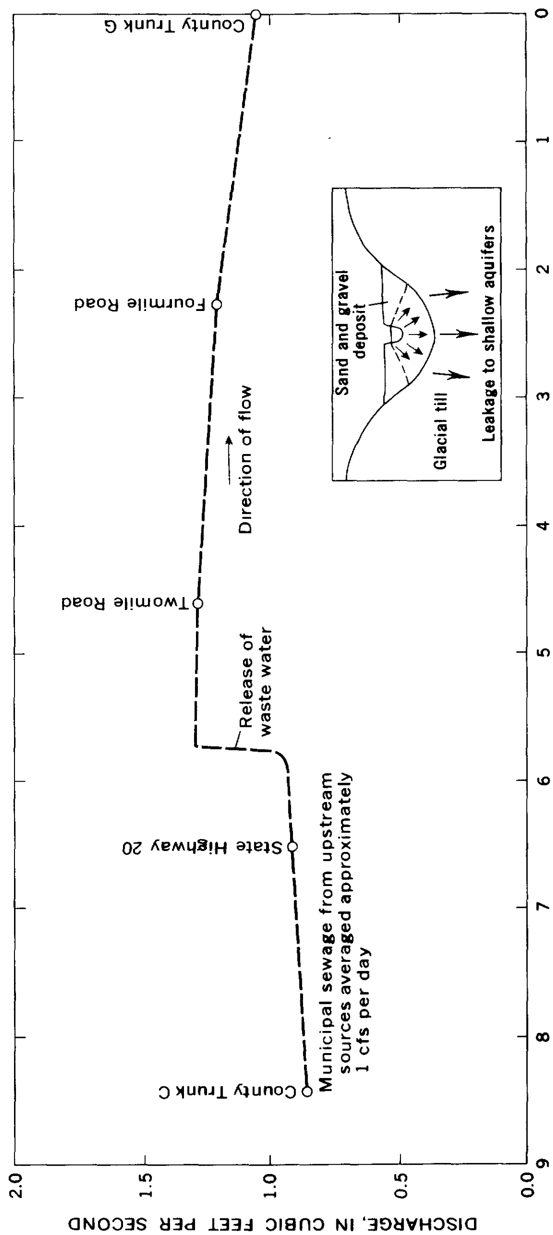

FIGURE 14.—Seepage from the Root River Canal to a ground-water reservoir, November 14, 1963. (Measurement sites are shown on pl. 4.)

Between Twomile Road and County Trunk G, the Root River Canal lost water to the ground-water reservoir. A net loss of streamflow in this 5-mile reach—about 150,000 gpd, or 30,000 gpd per mile—indicated that this reach of the river was a possible source of contamination to the local ground-water reservoir at that time (Nov. 14, 1963).

The low flow of the Fox River differs from that of other major streams in the area. In January 1964, for example, the flow of the Fox River at Wilmot was made up of about 72 percent ground-water discharge and about 10 percent sewage, whereas the flow of the Root River Canal at the gaging station at County Trunk G was about 0 percent ground water and about 70 percent sewage (the remainder of each low flow was made up of overland flow). Also, the sewage-plant effluent released to the Fox River in 1964 was about 5 percent of the total flow, whereas that released to the Root River Canal during the same time period was about 17 percent of the total flow.

FLOODS

Flooding in Racine and Kenosha Counties is a recurring problem along the occupied reaches of flood plains of many streams. In this area floods result from runoff of rainfall or snowmelt in late winter or early spring, when the ground is frozen or ice covered and the aquifers and surface-water bodies are unable to store additional water. Some floods, generally affecting small areas, are caused by ice jams. Floods resulting from high-intensity rainfalls in small areas generally occur during the summer and fall.

In the Fox River basin within Wisconsin, urban flood-damage surveys by the U.S. Army Corps of Engineers indicated that flood damage in the spring of 1960 amounted to about $357,000, and in the spring of 1962, about $43,000 (Southeastern Wisconsin Regional Planning Commission, 1963c, p. 89). Most damage from both floods was sustained near the village of Silver Lake, Kenosha County, where buildings occupy the flood plain, including areas within the meander loops of the river.

Floods equal in magnitude to the 1960 flood of the Fox River at Wilmot (about 7,500 cfs) have a recurrence interval of 60 years, based on annual maximum streamflow data (Ericson, 1961). Such a flood has less than a 2-percent chance of occurring in any year (fig. 15).

During the period 1940–64, floods on the Root River were relatively frequent, minor, and local; however, a major flood occurred in 1960. Damages incurred from the 1960 flood were about $372,000 (Southeastern Wisconsin Regional Planning Commission, 1966c,

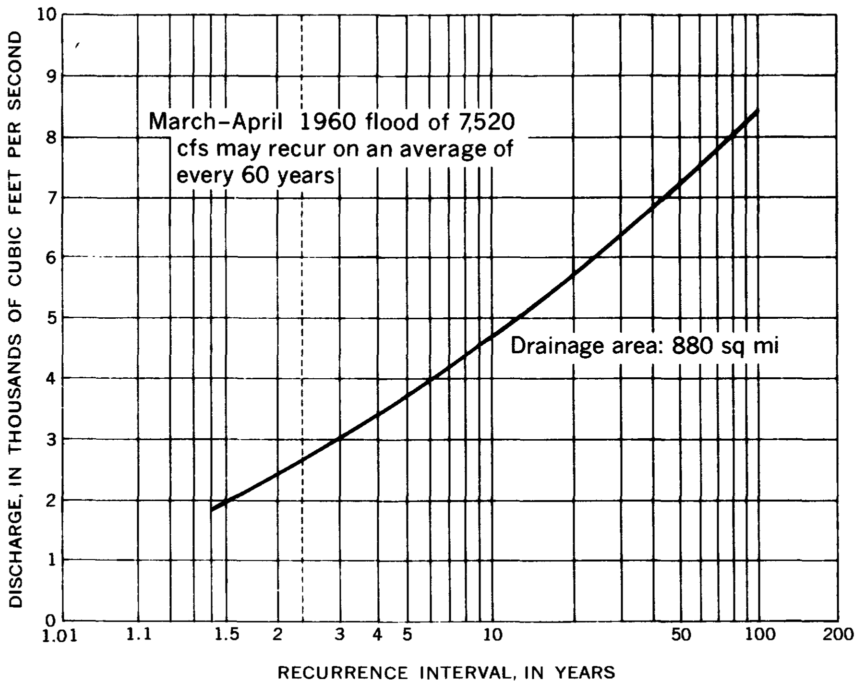

FIGURE 15.—Magnitude and frequency of annual maximum streamflow at Fox River at Wilmot, Wis.

p. 10), most of which occurred in Racine. The probability of occurrence of a flood comparable in magnitude to that of 1960 on the Root River is 1 percent, or an average of once in 100 years (Southeastern Wisconsin Regional Planning Commission, 1966c, p. 51).

Information concerning floods on the Des Plaines River at the Wisconsin and Illinois boundary is available from the analyses by Noehre (1964) and by the U.S. Army Corps of Engineers (1966).

INLAND LAKES AND WETLANDS

Inland lakes, the chief recreational attraction in the western half of Racine and Kenosha Counties, are an important part of the water resources of the area. Of the 43 named lakes in the area, 28 are kettle lakes, which occupy depressions formed by melting ice masses that were trapped in glacial deposits; several other lakes were formed where glacial moraines dammed the drainage systems. More than 30 of the 43 named lakes in the area drain through natural channels; of these lakes, 20 have artificial control structures across their outlets. Of the 43 lakes, 33 are in the Fox River basin, nine are in the headwaters of the Des Plaines River, and one is in the Lake Michigan basin (Poff and Threinen, 1961a, b). Twenty-four of the lakes are less than 100 acres in area, and 18 of those are less than 20 feet deep. Wind Lake, covering 821 acres, is the largest inland lake in the two counties; Waubeesee Lake, 73 feet deep, is the deepest lake.

WATER-LEVEL CHANGES

Lake surfaces in about 35 of the lakes in Racine and Kenosha Counties are the visible parts of the water table; consequently, their stages fluctuate with changes in ground-water levels (pl. 4).

Browns Lake is an example of a water-table lake. The periods of seasonal high and low stages of Browns Lake (pl. 4; fig. 10) coincide generally with the periods of high and low water levels in well Ra-3/19/28-68. Browns Lake apparently gains water from the sand and gravel deposits along the east side of the lake and loses water through the gravel deposits and till on the west side (pl. 2, section *D-D'*), where the movement of ground water is toward the Fox River.

The rest of the lakes have a partial seal between the lake bottom and the ground-water body and are perched lakes that fluctuate independently of the local changes in ground-water levels. Paddock, Shangrila, Benet, and Eagle Lakes are examples of perched lakes. In November 1963 the levels of these lakes were 15-63 feet higher than the local water levels in the shallow aquifers. Each of these lakes is underlain by relatively impervious glacial clay till (pl. 2), and the lake stage is probably related to the level of a perched water table in the glacial drift above the major shallow aquifers.

WETLANDS

Wetlands are flat lowlands that are covered with water or that are susceptible to frequent flooding and slow drainage; they generally contain organic matter. Most of the wetlands in Racine and Kenosha Counties are ground-water-discharge areas along streams or along the margins of lakes; some of the marshes are remnants of shallow lakes that have filled with peat, clay, and vegetation.

Wetland areas change seasonally and decrease as drainage ditches are built. Between the time of the wetland survey made in 1934 and the wetland survey in 1954-55, about 50 percent of the 35,546 acres of wetlands within the two counties were drained. Most of the land was drained for agricultural use (Wisconsin Conservation Department, 1960). Between 1955 and 1967 the greatest loss of wetlands was near Wind Lake, where the wetlands were drained and replaced by sod farms. About 9,000 of the remaining 17,898 acres (in 1954-55) are considered to be drainable.

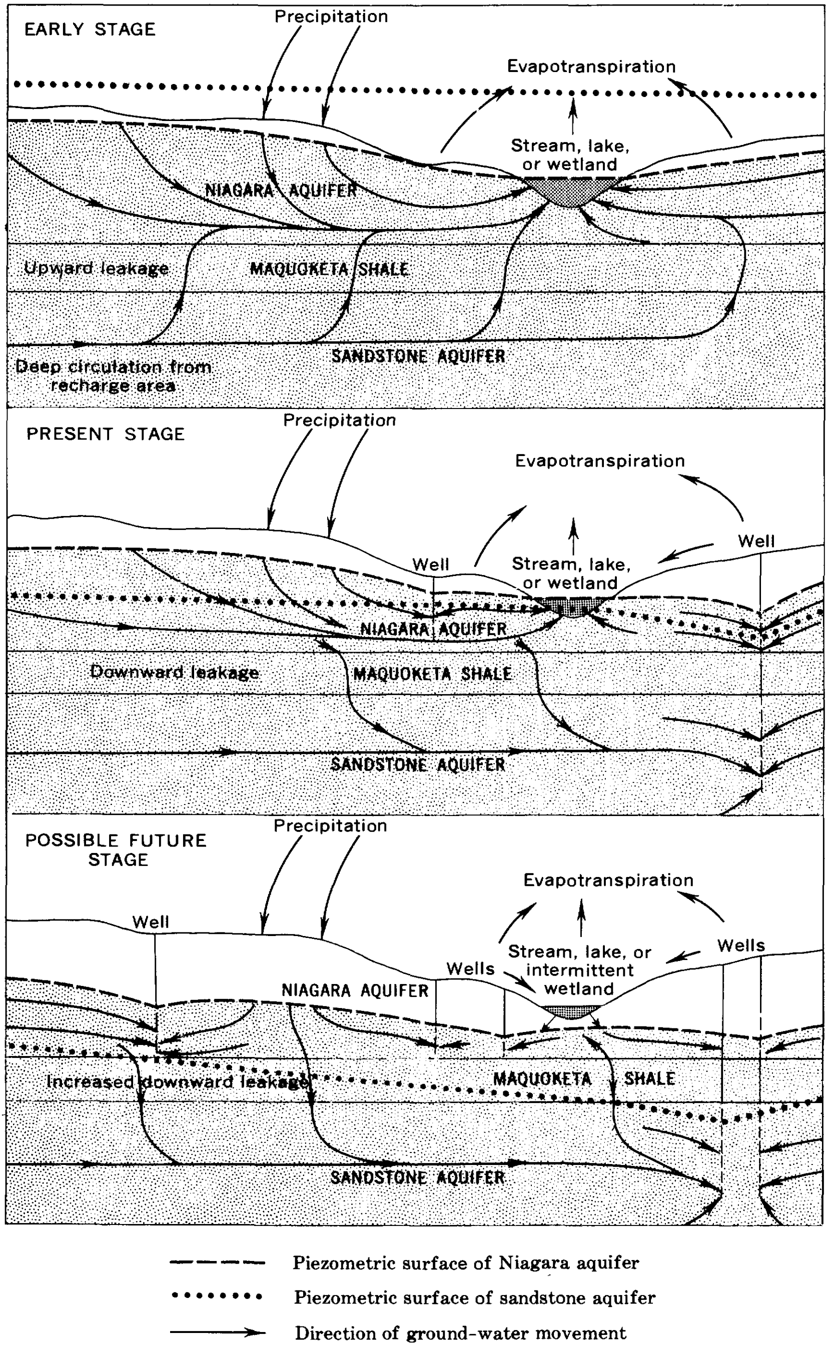

FIGURE 16.—General relationships between the deep and shallow aquifers and surface-water bodies during early, present, and possible future stages of development.

Wetlands, the habitat of wildlife, are important to sportsmen and to conservationists and are significant in the recreational use of the local water resources.

RELATIONSHIP BETWEEN SURFACE WATER AND AQUIFERS

The interchange of water between surface-water bodies and ground-water aquifers and the movement of water between aquifers characterize the unified water system in Racine and Kenosha Counties. Water movement within this system varies in response to changes in precipitation, evapotranspiration, drainage, and man's activities.

Generally, during the winter months the land surface is frozen and covered with snow, water seeps from ground-water reservoirs into streams and lakes, streamflow is small, and ground-water levels are low. Precipitation during that time runs off quickly or accumulates as snow or ice.

During the early spring, water from melting snow and ice either seeps into the ground or runs off to the streams and lakes, the runoff rate is high, and the ground-water levels generally rise.

During the growing season the water system loses water by evapotranspiration, which minimizes recharge to the shallow ground-water reservoir. Withdrawal of water for nearly all uses is maximum at this time of year; streamflows decrease (fig. 13); and ground-water levels decline to the minimum.

After the first killing frost in the fall, evapotranspiration diminishes greatly, and soil moisture increases. Between the first frost and the winter freeze, runoff increases, and conditions are good for ground-water recharge. When the ground freezes in early winter, ground-water recharge ceases, streamflow consists only of ground-water discharge, and ground-water levels decline.

The increasing pumpage of ground water is altering some of the relationships between aquifers and surface water.

Prior to 1900, when ground-water withdrawal was small, ground water moved laterally through the Niagara aquifer and discharged to streams, lakes, and wetlands. Ground water from the sandstone aquifer contributed to this movement by leaking upward, through the Maquoketa Shale, into the Niagara aquifer (fig. 16).

At the present time pumpage from the Niagara aquifer is small and local, and ground water continues to move laterally to surface-water bodies. However, regional pumpage from the sandstone aquifer has lowered artesian pressure in this aquifer below that in the Niagara aquifer and has induced downward leakage of water from the Niagara aquifer (fig. 16). This diversion of ground water downward and toward areas of pumpage has slightly reduced the ground-water inflow to streams, but much of the local pumpage from wells returns to the streams as sewage effluent.

In the future, if pumpage of water from all aquifers should increase greatly, water levels in the shallow aquifers may decline below the beds of streams, lakes, and wetlands (fig. 16). This perching of streams and lakes would induce downward leakage and recharge the shallow aquifers. The wetlands would either be intermittent or disappear. Local pumpage of water from wells would continue to be returned to the streams.

WATER BUDGET

A generalized water budget of Racine and Kenosha Counties indicates the amount of water in various environments within the hydrologic cycle. During the period 1931–60, the mean annual precipitation in the two counties was 32.3 inches, and the average annual runoff was 6.9 inches. The difference between precipitation

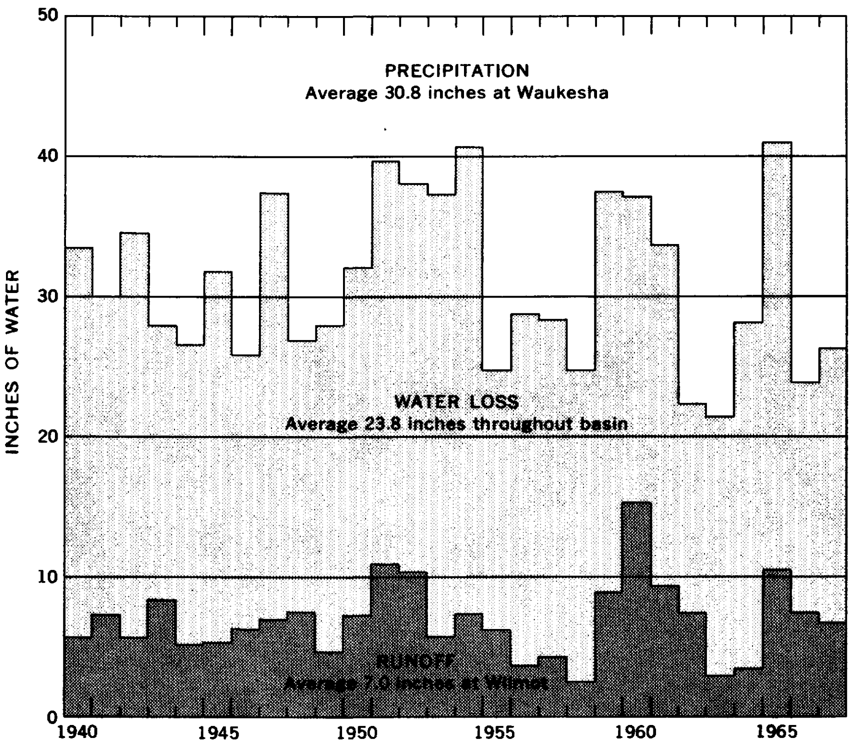

FIGURE 17.—Summary of annual runoff, precipitation, and water losses in the Fox River basin, Wisconsin, 1940–67. (Precipitation data from U.S. Weather Bureau.)

and runoff, 25.4 inches, returned to the atmosphere as evapotranspiration. Runoff, measured as streamflow, is approximately equal to the total water yield of the area because the quantity of groundwater underflow and the consumption of water during beneficial use are estimated to be less than 0.2 inch.

For the Lake Michigan basin part of Racine and Kenosha Counties (220 sq mi), the difference between the mean annual precipitation of 32.5 inches at Racine, 1931–60, and the average annual runoff of 6.9 inches gives an estimated annual evapotranspiration rate of 25.6 inches.

The average annual runoff of 7.0 inches in the Fox River basin for the period 1940–67 (fig. 17) is believed to approximate the long-term average of the western part of the two counties (390 sq mi).

Water inflow and outflow in the sandstone aquifer is not balanced. The declining water levels in this aquifer (fig. 8) indicate that water is not replaced as fast as it is withdrawn—that is, stored ground water is being removed. In the study area, depletion amounts to about one-half million gallons per day. Ground-water movement is predominantly northeast toward Milwaukee and southeast toward Chicago (pl. 3). Table 6 itemizes the inflow, outflow, and storage changes in the sandstone aquifer in 1963. The aquifer, however, is not being dewatered, nor are water levels declining in the recharge area.

QUALITY OF WATER

Water in its natural surroundings is never pure; it contains dissolved and suspended mineral matter. Precipitation is more nearly pure but contains gasses and solids dissolved from the air. After reaching the ground, water dissolves additional chemicals

TABLE 6.—*Estimated 1963 water budget of the sandstone aquifer, Racine and Kenosha Counties, Wis.*

[Values are in millions of gallons per day]

Inflow and outflow	Areas of pumpage influence	
	Milwaukee area	Chicago area
Recharge		
Inflow from principal recharge area	3.0	0.5
Leakage from overlying rocks	.8	.2
Total recharge	+3.8	+0.7
Discharge		
Deep-well pumpage	2.5	0.0
Outflow	1.7	.8
Total discharge	−4.2	−0.8
Approximate storage loss	−0.4	−0.1

TABLE 7.—*Representative chemical analyses of water from wells in the sandstone aquifer, Racine and Kenosha Counties*

[Chemical constituents are in milligrams per liter. Source of analysis: G, U.S. Geological Survey; W, Wisconsin State Laboratory of Hygiene; P, private (commercial) laboratories. Values calculated by the author are in italics.]

Well	Owner or place	Year of analysis	Source of analysis	Depth of well (ft)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Cations: Calcium (Ca)	Cations: Magnesium (Mg)	Cations: Sodium (Na)	Cations: Potassium (K)	Anions: Bicarbonate (HCO_3)	Anions: Carbonate (CO_3)	Anions: Sulfate (SO_4)	Anions: Chloride (Cl)	Dissolved solids [1]	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Remarks
Ke-1/22/ 9-268	Chicago and Northwestern Railway Co.	1906	P	1,639	....	19.3	....	107.3	33.9	35.3		*346*	....	183.4	6.2	558	*407*	*123*	....	....	May contain water from Niagara aquifer.
10-8	Larry Maurer	1962	G	773	12	....	0.22	5.2	3.2	....	....	210	19	183	12	503	26	0	798	8.8	
Ke-2/20/15-26	Brighton School	1962	G	750	14	....	2.5	63	14	....	....	332	*0*	39	7.5	350	215	0	579	6.4	Do.
17-21	Bong Air Force Base	1958	W	1,903	15	....	.5	75.6	20.0	9		*310*	*0*	41.4	3.5	330	266	*12*	....	7.4	Sample collected after pumping.
Ke-2/22/11-6	Petrifying Springs Park	1963	G	1,751	14	....	.36	....	210	....	....	290	0	304	45	796	170	0	1,220	7.8	
Ke-2/23/30-11	Pennoyer Sanitarium	1890	P	1,280	11	*7.7*	*.7*	*94*	*26*	*36*	trace	*305*	....	*136*	*9*	*455*	*350*	*100*	....	....	Strong flow; may contain Niagara aquifer water. St. Catherine's Hospital.
31-269	Park City Water Co	1891	P	1,650	....	8.2	....	111.9	20.0	38.2		*342*	....	128.1	8.0	494	*361*	*81*	....	....	Private water utility.
Ke-2/23/32-270	City of Kenosha	....	P	1,365	....	7.7	.4	93.8	22.8	36.1		*309*	....	136.0	8.9	458	*407*	*154*	....	....	May contain Niagara aquifer water.
Ra-3/19/22-21	St. Francis Monastery	1962	G	1,271	14	....	.37	65	26	....	....	262	0	70	5.5	333	269	54	528	7.8	
30-2	Burlington	1891	P	1,008	....	6.6	1.5	63.4	25.2	9.0	4.1	*283*	....	47.1	4.7	300	*261*	*29*	....	....	City well 3.
6-339	do	1966	W	1,474	....	....	.15	62	24.5	*6.3*	....	*295*	*0*	28	2.7	284	257	*15*	....	7.3	City well 8.
Ra-3/20/25-66	Southern Wisconsin Colony	1964	W	1,650	....	....	.25	80.8	15.5	11.0	....	*310*	*0*	44.5	2.0	334	266	*8*	....	7.7	Well 3.

Ra-3/21/29-318	Union Grove	1888	P	2,005	...	...	...	117.2	16.4	8.8		*318*	...	112.5	6.2	420	*360*	*100*	...	...	Private utility well. Probably open in Niagara aquifer.
30-11	do	1935	W	665	...	...	0	...	...	...	...	*308*	...	41	5	356	330	78	...	...	City well 1.
	do	1947	G	665	13	5.8	.17	62	18	42	7.7	322	0	50	5.5	353	228	0	459	7.3	Do.
30-57	do	1966	W	1,136	...	...	.24	65	18.4	19	...	*254*	*0*	60	4.0	314	239	*31*	...	7.6	City well 3.
30-349	do	1966	W	1,343	...	...	.28	74	16.1	12	...	290	*0*	30	1.9	294	252	*14*	...	7.4	City well 4.
Ra-3/22/21-19	St. Bonaventure School	1962	G	1,160	13	...	1.2	45	19	...	...	142	0	300	11	570	190	74	836	7.6	
21-320	C. M. & St. P. RR	1903	P	1,500	...	...	...	108.5	22.5	31.6		*321*	...	151.6	7.6	480	*363*	*100*	...	...	Probably open in Niagara aquifer, flowed until 1899.
Ra-3/22/21-17	Sturtevant	1960	W	1,625	...	...	.05	127	16.5	35	...	*320*	*0*	197	6.5	578	380	*118*	...	7.8	City well, open in Niagara aquifer.
Ra-3/23/ 8-22	Horlick Malted Milk Co	1967	G	1,962	18	11	1.7	352	29	30	14	266	0	742	38	1,460	998	780	1,630	7.3	
9-313	Racine Well Co	...	P	1,600	...	13.8	...	80.3	15.0	43.9		*238*	...	*151.8*	*4.5*	*428*	*263*	*68*	...	...	Strong flow; private utility well. Probably open in Niagara aquifer.
9-23	Wisconsin Gas and Electric Co	1930	P	1,730	16	*12.0*	...	*189*	*21.2*	*40.4*		*289*	...	*417*	*28*	*760*	*564*	*327*	...	...	Open in Niagara aquifer.
	do	1939	P	1,730	16	*9.2*	...	*237*	*21*	*31.7*		*266*	...	*473*	*25*	*935*	*681*	*463*	...	7.6	Do.
9-26	Eisendrath Tanning Co	1962	G	1,628	16	...	1.3	227	26	...	...	276	0	477	36	1,020	674	448	1,270	7.1	
Ra-3/23/20-310	Chicago & Northwestern Railway Co	1891	P	1,400	...	19.3	...	111.0	25.7	43.8		*324*	...	177.7	28.9	567	*382*	*116*	...	...	Probably open in Niagara aquifer.
Ra-4/19/35-351	Waterford	1966	W	1,520	...	...	.27	68	18.5	5.6	...	*268*	...	44	3.3	294	247	*27*	...	7.4	
Ra-4/22/ 4-48	Caddy Vista subdivision	1967	G	1,625	16	9.5	1.6	110	24	17	5.6	298	0	142	12	467	373	129	725	7.6	
31-14	Golf Bowl	1962	G	1,025	16	...	1.5	54	20	...	...	286	0	154	8.5	475	217	0	721	7.8	
Ra-4/23/ 7-47	Crestview subdivision	1966	W	1,200	...	...	0.33	82	20.4	53	...	*259*	*0*	150	23	508	292	*80*	...	7.4	Open to Niagara aquifer.
Median values						9.2	0.4	82	20.4	18	5.6	292	0	142	7.5	467	292	78	762	7.6	

[1] U.S. Geological Survey determines dissolved solids by weighing residue on evaporation at 180°C. Some analyses are for residue weight after evaporation at somewhat different temperatures, but no serious error is believed to be involved.

TABLE 8.—*Representative chemical analyses of water from the Niagara aquifer and the sand and gravel aquifer, Racine and Kenosha Counties*

[Chemical constituents are in milligrams per liter. Source of analysis: G, U.S. Geological Survey; W, Wisconsin Laboratory of Hygiene; P, private (commercial) laboratories. Values calculated by the author are in italics]

Well	Owner or place	Year of analysis	Source of analysis	Depth of well (ft)	Temperature (°C)	Silica (SiO_2)	Iron (Fe)	Cations: Calcium (Ca)	Cations: Magnesium (Mg)	Cations: Sodium (Na)	Cations: Potassium (K)	Anions: Bicarbonate (HCO_3)	Anions: Carbonate (CO_3)	Anions: Sulfate (SO_4)	Anions: Chloride (Cl)	Dissolved solids [1]	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Remarks
Ke-1/19/14-271	C. M. & St. P. RR	1900	P	224	....	8.9	....	3.0	1.3	149.7		*398*	....	8.9	2.1	369	*13*	*0*	....	....	Probably in Maquoketa Shale.
16-169	Randall School	1959	P	203	....	17	0.9	....	....	....	....	*342*	....	37	10	361	320	*40*	....	7.6	
17-268	Lake Knolls subdivision	1966	W	135	....	....	<.4	91	41.6	4.9	....	*407*	*0*	45	9.5	450	401	*66*	....	7.2	In sand and gravel.
28-276	Twin Lakes	1935	W	224	....	....	.4	....	....	....	....	*288*	....	....	5	......	208	*0*	....	....	
Ke-1/20/11-15	Central High School	1962	G	150	11	....	1.4	73	42	....	....	448	0	21	2.0	389	355	0	668	7.4	In sand and gravel.
30-57	Wilmot High School	1963	G	185	10	....	.79	....	....	8.4	....	418	0	12	2.0	343	333	0	627	7.3	
Ke-1/21/16-242	Bristol Soda Spring	....	P	......	....	13.7	2.6	18.4	9.1	87.3		*219*	....	89.5	4.5	333	*83*	*0*	....	....	Analysis before 1915.
23-108	Charles Gillmore	1963	G	220	11	....	.24	....	....	78	....	202	0	57	8.0	275	67	0	468	7.5	H_2S odor.
36-266	Phillip O. Kromm	1942	W	104	....	30.0	2.0	37.5	63.5	....	....	*420*	....	45.2	5.0	404	320	*0*	....	8.2	In sand and gravel.
Ke-1/22/ 5-28	Leon Dodge	1962	G	174	....	....	.28	31	17	....	....	100	0	260	14	488	148	66	722	7.9	
9-272	C. M. & St. P. RR	1890	P	45	....	....	....	46.3	31.4	48.0		*299*	....	97.2	1.8	374	*245*	*0*	....	....	
Ke-1/22/ 9-274	Bain Station	1905	P	130	....	14.5	....	16.5	11.7	70.2		*283*	....	.7	6.7	261	*89*	*0*	....	....	
26-94	Prairie Lane School	1963	G	250	....	....	.83	....	....	72	....	196	0	42	14	251	64	0	442	7.3	H_2S odor.
35-24	Pleasant Homes	1966	W	180	....	....	.29	37	30.4	44	....	252	0	100	2.0	350	219	*12*	....	8.0	
35-267	John Gould	1935		240	....	16.0	.2	22.8	22.5	37.3	....	*232*	....	31.9	4.0	251	149	*0*	....	....	Analysis by State of Illinois.

Ke-1/23/19-31	Frank Zoller	1962	G	105	11	....	.11	7.5	2.2	....	....	158	0	4.4	8.5	167	28	0	267	8.0	H_2S odor.
Ra-2/19/ 5-64	Lavelle Rubber Co	1962	G	143	11	....	.31	45	27	....	....	364	0	40	5.0	347	223	0	599	7.4	
6-330	C. M. & St. P. RR	1891	P	12	....	....	....	77.5	33.1	9.9		*354*	....	54.0	2.7	354	*329*	*39*	....	....	In sand and gravel.
Ke-2/20/16-249	Bong Air Force Base	1957	P	107	....	27	.21	58	43	28		412	*0*	34	5	*398*	320	0	....	7.7	
18-19	do	1957	P	74	....	14	.8	88	41	2		433	*0*	33	4	*396*	356	34	....	7.9	
....	do	1962	G	74	11	....	....	89	42	....	....	460	0	31	3.5	408	395	18	....	7.3	Flowing.
Ke-2/21/20-100	Ed Aker	1963	G	40	10	....	.60	....	....	50		264	0	152	2.0	446	268	51	675	7.5	Do.
Ke-2/22/11-236	Petrifying Springs Park	1963	G	150	9	....	.31	....	....	113	....	123	0	256	12	507	144	43	796	7.1	Do.
23-279	Hillcrest School	1958	W	260	....	....	.2	....	....	....	....	*168*	*7*	....	....	......	95	*0*	....	8.45	
25-254	Sparkling Springs Water Co	1963	G	208	11	....	.18	....	....	106	....	92	0	262	11	490	134	58	758	7.3	Bottled.
Ra-3/19/32-333	McCona and Fraser	....	P	130	....	6.7	.4	63.5	25.2	9.0	4.2	*283*	....	47.4	4.7	300	*262*	*30*	....	....	Analysis before 1915.
Ra-3/20/28-330	Eagle Lake Manor	1966	W	115	....	....	.32	37	34.4	35.0	....	*331*	*0*	33	3.0	298	236	*0*	....	7.7	In sand and gravel.
Ra-3/20/34-4	Pure Milk Assoc	1963	G	200	10	....	.25	....	....	44	....	276	0	67	3.0	322	202	0	555	7.4	
Ra-3/21/ 4-337	Cooper Dixon	1963	G	110	11	....	.48	....	....	65	....	130	0	188	4.0	396	164	58	600	7.4	In sand and gravel.
30-335	C. M. & St. P. RR	1891	P	180	....	7.8	....	125.0	35.0	73.6		*323*	....	300.7	26.3	728	356	*91*	....	....	
Ra-3/22/ 4-283	John Petersen	1963	G	130	11	....	.51	....	....	60	....	141	0	148	2.0	336	134	18	542	7.5	
21-263	Wisconsin Engineering Co	1908	P	300	....	....	....	59.5	27.9	99.4		*92*	....	373.3	10.1	615	*262*	*186*	....	....	
Ra-4/19/27-333	Waterford Woods	1966	W	184	....	....	.36	66	33.1	4.6	....	*334*	....	41	2.0	338	308	....	....	7.5	
Ra-4/19/35-150	Waterford	1963	G	104	10	....	.10	....	....	6.0	....	376	0	54	12	400	368	60	679	7.4	
Ra-4/19/35-151	do	1946	W	108	....	....	.1	74.4	36.5	....	....	*366*	*0*	48	12.5	376	340	*40*	....	7.2	
Ra-4/20/23-59	Wind Lake Produce	1962	G	225	11	....	.15	28	25	....	....	262	0	10	2.0	231	173	0	406	8.0	
Ra-4/21/10-8	Harold Wollmer	1963	G	368	11	....	.44	....	....	74	....	108	0	163	6.0	345	104	16	553	7.4	
Ra-4/21/30-30	North Cape	1966	W	300	....	....	.09	16	11.3	59	....	*162*	0	65	3.2	246	87	*0*	....	8.0	
Median values						14.2	0.32	45.8	30.9	46	....	283	0	47.3	4.7	358	221	0	600	7.5	

[1] U.S. Geological Survey determines dissolved solids by weighing residue on evaporation at 180°C. Some analyses are for residue weight after exaporation at somewhat different temperatures, but no serious error is believed to be involved.

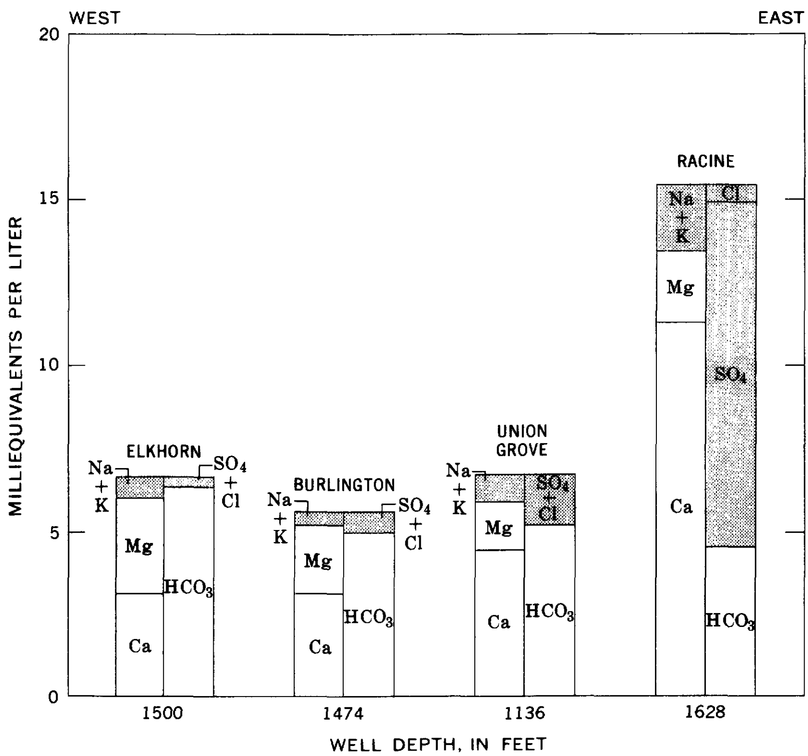

FIGURE 18.—Analyses of water from the sandstone aquifer, showing changes in chemical character from west to east.

from the soil and rocks. In general, the amounts of dissolved constituents depend upon the dissolving strength of the water, the solubility of the earth materials, and the time available for solution.

In Racine and Kenosha Counties, ground water is generally of good quality but is hard. The quality of base flow in streams is similar to that of ground water, but the addition of overland runoff dilutes the chemical content of stream water.

GROUND WATER

SANDSTONE AQUIFER

Water in the sandstone aquifer within Racine and Kenosha Counties is primarily a calcium magnesium bicarbonate type, although in eastern Racine and eastern Kenosha Counties, water in the lower part of the aquifer is a calcium sulfate type (fig. 18). The total dissolved solids generally increase from west to east and from the upper to the lower parts of the aquifer. The dissolved solids range from 282 mg/1 (milligrams per liter) in water from a well at Burlington to 1,420 mg/1 in water from a well at Racine; the median is about 460 mg/1. Water in the sandstone aquifer is very hard and contains excessive (over 0.3 mg/1) concentrations of iron in about 50 percent of the wells sampled.

The chemical analyses of water from wells tapping the sandstone aquifer in Racine and Kenosha Counties, as tabulated in table 7, are both new and old. Most of the old wells were open to both the sandstone and the Niagara aquifers, but the oldest analyses probably represent water from only the sandstone aquifer because of the strong artesian flow at the time. The newest analyses may represent water from both aquifers.

Water in the sandstone aquifer near Racine is the hardest and most mineralized of all water sampled in Racine and Kenosha Counties. Water from several deep wells in that vicinity contains dissolved solids of more than 1,000 mg/1 and has high concentrations of sulfate. The distribution of saline water in the bedrock aquifers of eastern Wisconsin was described by Ryling (1961).

The temperature of water in the sandstone aquifer is virtually constant in time, but it increases almost 0.6°C (1°F) with each 100 feet of depth. The temperature of water in the recharge area is about 10°C (50°F), nearly the mean annual air temperature. The average water temperature in deep wells at Burlington is about 13°C (56°F), and that in deep wells near Lake Michigan is about 16°C (61°F) and may be as high as 18°C (64°F).

Water from the sandstone aquifer is used for most purposes with little or no treatment. Communities do not soften their water, but individual users commonly do. The water may be aerated or chlorinated, especially for public and industrial supplies.

NIAGARA AND SAND AND GRAVEL AQUIFERS

Water in the Niagara and the sand and gravel aquifers also is primarily a calcium magnesium bicarbonate type. However, in southeastern Kenosha County, water in these aquifers may be either a sodium bicarbonate or a sodium sulfate type. The median concentration of dissolved solids in water from the shallow aquifers is about 370 mg/l, or about 100 mg/l less than concentrations from the sandstone aquifer. The water is very hard, having a median hardness about the same as water in the sandstone aquifer, although the range in hardness is much less (13 to 394 mg/l).

The iron content of water in the Niagara and sand and gravel aquifers varied and was excessive (more than 0.3 mg/l) in 56

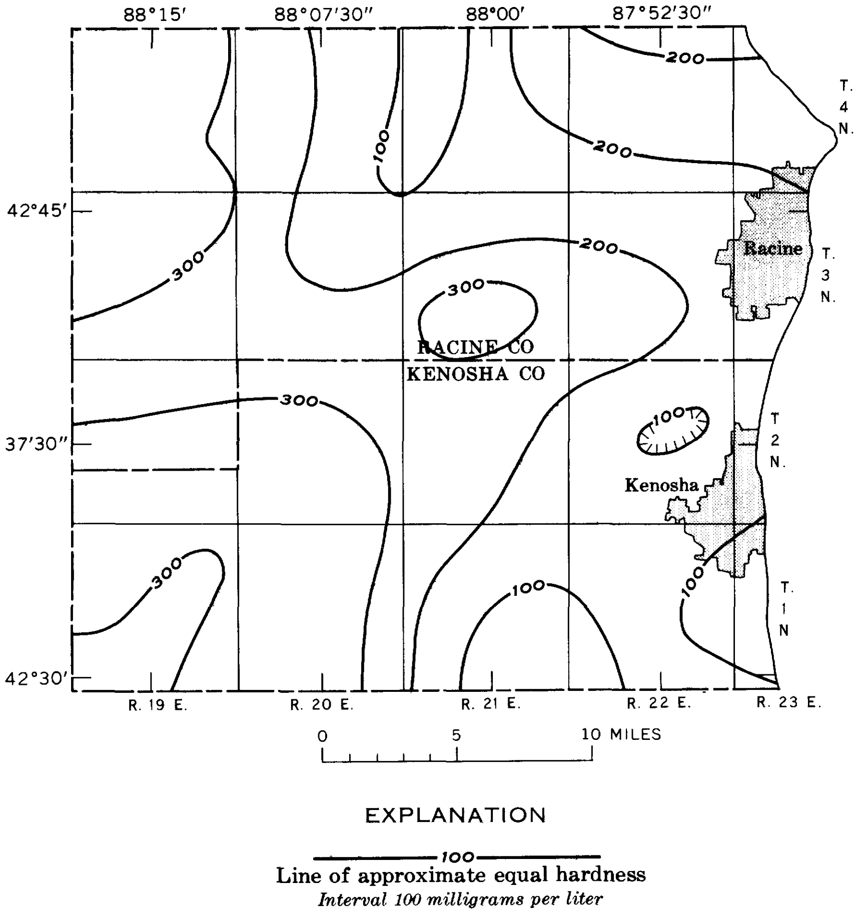

FIGURE 19.—General distribution of water hardness in the combined Niagara aquifer and sand and gravel aquifer.

percent of the wells sampled. Iron appears to be more prevalent in the sand and gravel aquifer than in the Niagara aquifer. Chemical analyses of water from the Niagara and the sand and gravel aquifers are shown in table 8.

Water in the Niagara and the sand and gravel aquifers is generally hardest in the central and western parts of the study area (fig. 19). In Union Grove the hardness is as much as 395 mg/l. (See table 8.) In contrast, the water is relatively soft (less than 120 mg/l) in both eastern Kenosha County and north-central Racine County, where the water is a sodium sulfate type. Natural softening may occur in the water by the exchange of calcium and magnesium ions for sodium and potassium ions in the shale beds of the Niagara Dolomite.

Hydrogen sulfide occurs in ground water in some wells in southeastern Kenosha County and produces an offensive "rotten-egg" odor.

The temperature of water in the Niagara and sand and gravel aquifers averages about 11°C (51°F) below depths of about 50 feet. Above 50 feet the water temperature fluctuates somewhat in response to seasonal changes in air temperature.

Water pumped from the Niagara aquifer and the sand and gravel aquifer in the area, like water from the sandstone aquifer, is used for most purposes with little treatment, except for softening by the user. Water with dissolved hydrogen sulfide sometimes is chilled before drinking to prevent the escape of the offensive-smelling gas. Where the iron content of the water is particularly troublesome, water aeration and filtration can be used to remove most of the iron before use.

SURFACE WATER

Water in streams and lakes in Racine and Kenosha Counties generally is a calcium magnesium bicarbonate type and contains additional substances not normally present in ground water. The water is very hard, although softer than ground water, and is low in iron; the median hardness of surface water in the area is 219 mg/l, and the median content of iron is 0.07 mg/l. The quality of the water in many streams in the area is altered by storm runoff, by sewage effluent, and by industrial-waste waters.

The quality of water in the streams varies during the year in response to changes in streamflow. Dissolved solids are greatest during times of low flows, when the surface water is chemically similar to the ground water. Generally, the concentration of organic substances is greatest and the concentration of dissolved solids is least during times of high flow and rapid runoff.

The quality of stream water differs at Fox River at Wilmot, Root River at Racine, and Des Plaines River at County Trunk C (table 9). The maximum concentration of dissolved solids, 1,366 mg/l, and of chlorides, 265 mg/l, in the Root River are significant because they reflect the effects of sewage effluent released when the dilution potential of the stream is low. During dry periods, sewage effluent may constitute the major part of the flow of some streams.

At least 4 mg/l of dissolved oxygen is needed in streams to sustain most native fish life. Data from monthly sampling (Apr.

TABLE 9.—*Range of selected water-quality parameters for three streams in Racine and Kenosha Counties, April 1961–December 1964*

[Data based on monthly sampling by Wisconsin Committee on Water Pollution (now Dept. of Natural Resources); values are in milligrams per liter, except pH]

	Bicarbonate (HCO_3)	Chlorides (Cl)	Nitrates (NO_3)	Phosphorus (P)	Dissolved oxygen (O_2)	Hardness (total)	Solids: Total	Solids: Dissolved	pH (field)
Fox River at Wilmot									
Maximum	436	37	3.12	0.73	21.5	424	652	499	9.0
Minimum	188	8.5	<.08	.06	1.65	214	312	272	7.4
Root River at Racine [1]									
Maximum	715	265	3.76	8.7	15.6	680	1,380	1,366	8.8
Minimum	315	9	.04	.07	.8	160	200	181	7.4
Des Plaines River at County Trunk C									
Maximum	467	147	5.28	0.18	15.25	608	1,100	995	8.5
Minimum	90	9	.06	.03	1.05	158	300	267	7.4

[1] Samples were collected at the State Street and State Highway 38 bridges through 1962, and were collected at the Marquette Street bridge thereafter.

1961–Dec. 1964) by the Wisconsin Committee on Water Pollution (1965) show that dissolved oxygen was less than 4 mg/l in about 4 percent of the water samples from the Fox River, 11 percent of the samples from the Root River, and nearly 18 percent of the samples from the Des Plaines River. The results of a detailed study of the area by Southeastern Wisconsin Regional Planning Commission (1966c) provide further information on the quality of water in streams in the area and forecast quality for the year 1990.

Water in Browns, Eagle, Elizabeth, and Silver Lakes is chemically similar to water in both the Niagara aquifer and the sand and gravel aquifer near the lakes, although lake waters are less mineralized and softer than the local ground water. (Samples from the lakes were collected during a period of high runoff.) Water from all three sources is a calcium magnesium bicarbonate type. The hardness of the water in the four lakes ranged from 185 to 202 mg/l, and the dissolved solids contained in the water ranged from 196 to 222 mg/l. The concentration of dissolved solids ranged from 190 to 440 mg/l in water in 20 other inland lakes in the area, as indicated by the specific conductances determined in 1960 (Poff and Threinen, 1961a, b).

Water in Lake Michigan, similar to most of the water within the two counties, is a calcium magnesium bicarbonate type. It is softer than most ground water and water in the inland lakes, but it still needs softening for most domestic uses. The quality of water in Lake Michigan (table 10) is more constant than the changing quality of water in the inland lakes and streams.

TABLE 10.—*Chemical analyses of treated and untreated Lake Michigan water used by the cities of Kenosha and Racine*

[Chemical constituents are in milligrams per liter. Analyses by Wisconsin State Laboratory of Hygiene.]

Chemical Constituent	Kenosha July 27, 1966 Untreated	Kenosha July 27, 1966 Treated	Racine August 2, 1966 Untreated	Racine August 2, 1966 Treated
Iron (Fe)	<0.04	<0.04	0.51	<0.04
Manganese (Mn)	<0.04	<0.04	<0.04	<0.04
Calcium (Ca)	36	34	39	35
Magnesium (Mg)	10.6	10.8	7.8	11.2
Sodium (Na)	3.9	3.9	4.3	4.3
Bicarbonate (HCO_3)	134	123	132	122
Carbonate (CO_3)	0	0	0	0
Sulfate (SO_4)	20	23	20	25
Chloride (Cl)	4.7	6.0	6.5	8.0
Fluoride (F)	0.1	....	0.3	....
Nitrate (NO_3)	<2.0	<2.0	<2.0	<2.0
Dissolved solids	140	144	160	160
Hardness as $CaCO_3$	134	130	130	134
Noncarbonate hardness as $CaCO_3$	0	0	0	0
Alkalinity as $CaCO_3$	110	101	108	100
Hydrogen sulfide (H_2S)	0	0	0	0
pH (field, in standard units)	8.0	7.2	8.0	7.6

WATER USE

Withdrawal and use of water within the two counties in 1967 was 43.0 mgd (table 11), which was equivalent to a per capita use of about 160 gpd. Public supplies accounted for nearly 80 percent of the total withdrawal in 1967.

About 32.6 mgd, or 76 percent of the total withdrawal in 1967, came from Lake Michigan for municipal supplies at Racine and Kenosha. Prior to 1942 the average daily pumpage for these two cities increased annually at a rate of about 0.2 mgd (fig. 20). Since 1942 the average daily pumpage has increased about 0.8 mgd annually.

Less than 1 percent of the total withdrawal in 1967 came from streams and inland lakes; this water was used only for livestock and irrigation.

About 6.8 mgd, or 16 percent of the total withdrawal in 1967, came from the shallow aquifers, mostly through domestic wells in the Niagara Dolomite. This water supplies about 65,000 persons. The Niagara aquifer and the sand and gravel aquifer also furnish water for livestock, for irrigation near Wind Lake, and for some small industries.

About 3.3 mgd, or less than 8 percent of the total withdrawal in 1967, was from the sandstone aquifer. One-third of the pumpage from this aquifer was for the city of Burlington; the rest was used for smaller public, industrial, and domestic supplies (pl. 3).

TABLE 11.—*Summary of 1967 water pumpage in Racine and Kenosha Counties*

Water source	Pumpage (mgd)	Percent of pumpage
Surface Water		
Lake Michigan:		
City of Racine	19.6	
City of Kenosha	13.0	
Inland lakes and streams:		
Stock and irrigation	.3	
Total	32.9	76.5
Ground Water		
Niagara and sand and gravel aquifers:		
Small utilities and private	5.1	
Stock and irrigation	.9	
Self-supplied industries and commerce	.8	
Total	6.8	15.8
Sandstone aquifer: [1]		
City of Burlington	1.1	
Village of Union Grove	.4	
Village of Waterford	.2	
Institutions	.5	
Self-supplied industries and commerce	.9	
Small utilities and domestic	.2	
Total	3.3	7.7
Grand total	43.0	100.0

[1] In wells that are open in both the sandstone and the Niagara aquifers, it is not possible to determine the amount of water pumped from each. For these wells, all production is attributed to the sandstone aquifer.

The nonwithdrawal use of water in the study area is primarily for recreation, for fish and wildlife, and for the dilution and transportation of sewage and industrial-waste water. In addition to these uses, Lake Michigan is used for commercial transportation and for fishing. Because of its great volume, the lake has the potential for receiving warm water from power-generation plants. Other than Lake Michigan, the chief recreational waters of Racine and Kenosha Counties are the Fox River and the inland lakes in the western part of the area (Southeastern Wisconsin Regional Planning Commission, 1965b).

ADEQUACY OF WATER RESOURCES FOR PRESENT AND FUTURE NEEDS

Lake Michigan, the three aquifers, the streams and the small lakes assure Racine and Kenosha Counties of adequate and dependable water resources. Lake Michigan supplies water for most uses in the urbanized eastern part of the area. The shallow aquifers, particularly the Niagara aquifer, generally yield enough water for domestic and various minor uses. The sandstone aquifer

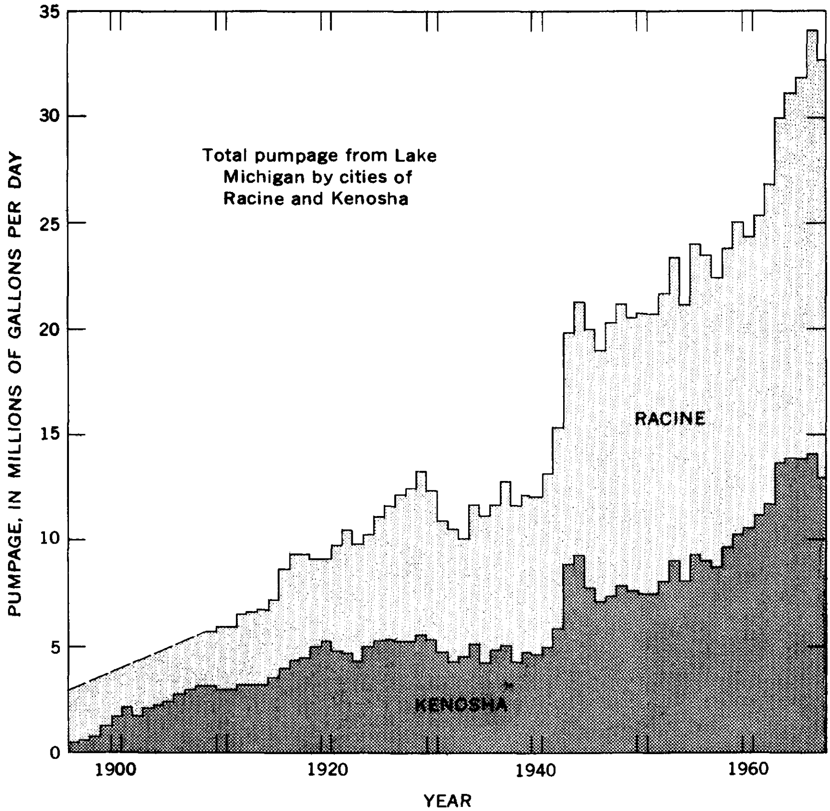

FIGURE 20.—Municipal pumpage from Lake Michigan, 1896–1967.

supplies adequate amounts of water for most uses anywhere within Racine and Kenosha Counties.

The Fox River effectively dilutes and transports sewage and industrial-waste water. In contrast, other streams in the urbanized parts of the two counties, particularly the Root River, have so little water during low flows that they cannot dilute waste waters sufficiently. As a result, the dissolved oxygen in those streams is sometimes at a critical low for sustaining fish life. Consideration of other pollution problems that would affect the usefulness of streams and lakes within the area is beyond the scope of this report.

The quality of water in Racine and Kenosha Counties generally is good for most purposes. Water from Lake Michigan, the most important source, is the least mineralized water available to the area and is suitable for domestic and most industrial uses after common methods of treatment.

Ground water is harder and more mineralized and contains more iron than surface water, but it contains little if any organic substances. The even, low temperature of the ground water makes it desirable for industrial cooling. Water in the sandstone aquifer is generally of good quality; however, it is very hard, and some ground water near Racine is saline. Softening and, in places, aeration for the reduction of iron or hydrogen sulfide make the water suitable for domestic and most industrial uses.

The surface- and ground-water resources will be adequate to supply the future demands for water in Racine and Kenosha Counties. Increased demands will result from the needs of an increasing population and expanding industrialization (projection by Southeastern Wisconsin Regional Planning Commission, 1963b, p. 60, 66). Total pumpage and use of water may be about 80 mgd by 1990, or nearly double the pumpage of 1967.

Lake Michigan will continue to be the principal source of water. The water utilities at Racine and Kenosha may pump as much as 52 mgd from Lake Michigan in 1990 to meet the needs of the urban area in the eastern part of the two counties.

Ground-water pumpage in the area in 1990 may be as much as 28 mgd, or nearly triple the ground-water pumpage of 1967. An increasing number of wells in the Niagara and sand and gravel aquifers will be pumped for domestic and small public supplies where service from the large municipal supplies is not available. Pumping from the Niagara and sand and gravel aquifers for domestic use in 1990 may be concentrated along both sides of Interstate Highway 94 and near the inland lakes in the western part of Kenosha County; for irrigation purposes, pumpage may be concentrated near Wind Lake and at truck farms near Lake Michigan.

Increasing pumpage from the sandstone aquifer in the area through 1990 is anticipated because of increasing needs for a plentiful supply of good-quality water. Increasing use of the sandstone aquifer in the Milwaukee-Waukesha area has been forecast by Green and Hutchinson (1965) and in the Chicago region by Walton (1964).

Lake Michigan, the Fox River, and the inland lakes will continue to provide recreational waters for the present population and for the anticipated influx of new residents and visitors to the area. These waters and the remaining wetlands will continue to be used for fish and wildlife.

Future changes in the water system resulting from increasing withdrawals will be similar to, but greater than, the changes being produced now. By 1990 the continued increase in regional pumping may lower water levels by as much as 100 feet, and increased amounts of water will be taken from storage. The rate of decline caused by local pumping probably will increase because of well interference, especially at Burlington. Pumping levels in closely grouped wells may fall below the top of the Platteville-Galena unit and may possibly drop to the St. Peter Sandstone. As differences between water levels in the sandstone and in the shallow aquifers increase, downward leakage through the Maquoketa Shale to the sandstone aquifer will increase slightly.

Water levels in the Niagara and the sand and gravel aquifers will decline as the rates of pumping from these aquifers increase. As a result, the seepage of ground water into the streams and lakes will decrease and in some places may stop. However, most of the water withdrawn from the ground, including water from the sandstone aquifer, will be released into the streams as treated waste water.

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☆ U.S. GOVERNMENT PRINTING OFFICE: 1970 O—387-860