Geology and Water Resources of Winnebago County, Wisconsin

By PERRY G. OLCOTT

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By Perry G. Olcott

ABSTRACT

Sources of water in Winnebago County include surface water from the Fox and Wolf Rivers and their associated lakes, and ground water from sandstone, dolomite, and sand and gravel deposits. Surface water is hard and generally requires treatment, but is then suitable for municipal and most industrial uses. Pollution is only a local problem in the lakes and rivers, but algae are present in most of the lakes. Ground water in Winnebago County is hard to very hard, and dissolved iron is a problem in a large area of the county. A saline-water zone borders the eastern edge of the county and underlies the areas of concentrated pumpage at Neenah-Menasha and Oshkosh.

A thick, southeastward-dipping sandstone aquifer, yielding as much as 1,000 gallons per minute to municipal and industrial wells, underlies Winnebago County. A dolomite aquifer in the eastern and southern part of the county yields as much as 50 gallons per minute to wells. Sand and gravel layers and lenses in preglacial bedrock channels, in northwestern Winnebago County and in the upper Fox River valley, yield as much as 50 gallons per minute to wells.

Present water problems in the county include algae and local pollution in the Lake Winnebago Pool, iron in water from the sandstone aquifer, and saline ground water in the eastern part of the county. Potential problems include rapid decline of water levels because of interference between closely spaced wells, migration of saline ground water toward areas of pumping, surface-water pollution from inadequate sewage and industrial-waste processing plants, and ground-water pollution in dolomite formations.

Development of the water resources of the county should follow a comprehensive plan which takes into consideration all aspects of water use. Dispersal of wells, especially extending toward the west from the heavily pumped Neenah-Menasha and Oshkosh areas, is recommended to reduce water-level declines and to avoid saline water. Supplemental use of ground water is recommended for municipal expansion of water facilities and to reduce the algae treatment problem of water from the Lake Winnebago Pool.

INTRODUCTION

PURPOSE AND SCOPE

Winnebago County has an abundance of generally good-quality surface and ground water which is far in excess of the present use. However, expansion of population and industry will place much greater demands on the water resources of the county in the future.

Unless orderly procedures in water management are followed, serious problems may result, such as overpumping of the aquifers or the impairment of the suitability of water for some purposes.

The purposes of this study are (1) to describe all sources capable of yielding water of suitable quality and quantity to fulfill long-term demands, (2) to provide information on the availability and use of water, (3) to point out present and anticipated water problems, and (4) to suggest possible methods for the development of the water resources of the county.

The report contains information on the geologic framework through which water moves; the source, movement, quantity, and quality of ground water; and the relationship of surface and ground water. The information is adequate for the broad aspects of planning water-resource development and for the management of existing water supplies. However, individual problems may arise that require more specific information than that given in the report.

This study is part of a planned investigation of the geology and water resources of the rapidly developing Fox River valley industrial complex and municipal region extending from Green Bay to Fond du Lac. The related studies in this region cover Fond du Lac County (Newport, 1962), Outagamie County (LeRoux, 1957), Brown County (Drescher, 1953), the Green Bay area (Knowles and others, 1964; Knowles, 1964), Waupaca County (Berkstresser, 1964), and Waushara County (Summers, 1965).

LOCATION, EXTENT, AND POPULATION

Winnebago County is in east-central Wisconsin adjacent to and including part of Lake Winnebago (fig. 1). The county has an area of about 454 square miles exclusive of that part covered by Lake Winnebago.

The total population of Winnebago County in 1960 was 107,928, of which 72.1 percent lived in urbanized areas. Between 1950 and 1960, the total population increased 18.5 percent (U.S. Dept. Commerce, 1960). The population of the major cities in 1960 was as follows: Oshkosh, 45,110; Neenah, 18,057; and Menasha, 14,647.

GEOGRAPHY

The land-surface altitudes of Winnebago County range from about 750 to 950 feet. In general, topographic features in the county are controlled by the bedrock surface. Hills and ridges on the bedrock surface are covered by only a thin veneer of glacial material and form similar features on the land surface. The valleys cut in the bedrock surface are filled with glacial deposits and generally are flat, often marshy, areas.

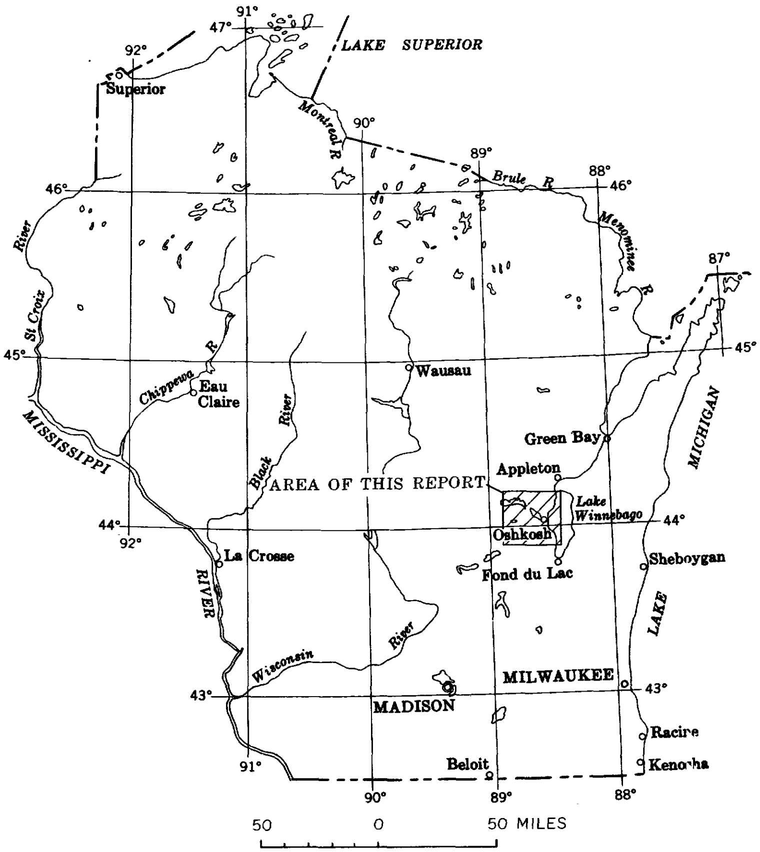

FIGURE 1.—Location of Winnebago County, Wis.

Two parallel escarpments, formed by the dissected edges of two resistant bedrock formations, trend northeastward across the county and dominate the topography. The most prominent of these escarpments extends from the western edge, just south of the Fox River, to the northern edge of the county in sec. 3, T. 20 N., R. 16 E. (pl. 1). The second ridge is relatively subdued and extends from the southern edge, in sec. 36, T. 17 N., R. 14 E., to the northern edge of the county, in sec. 2 T. 20 N., R. 16 E. (pl. 1).

The land surface in the northwestern part of the county, west of the two ridges, is underlain by low areas on the bedrock surface and is flat and poorly drained. In the area east of the two ridges, the land surface dips gently to the southeast, roughly conforming to the dip of the underlying bedrock. This eastern area is characterized by low hills and ridges and is well drained. The Rush Lake area lies between the two ridges, and the land surface is flat and marshy.

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CLIMATE

The climate of Winnebago County is characterized by mild, humid summers and rather long, severe winters. The average annual temperature at Oshkosh is 45.9°F, on the basis of 74 years of record by the U.S. Weather Bureau. Average monthly temperatures range from 18.6°F in January to 72.3°F in July. Generally, about 5 months of the year are free from freezing temperatures.

Average annual precipitation in the county, including snowfall, is about 28 inches, on the basis of 74 years' record. Average monthly precipitation ranges from about 1.2 inches in February to about 3.9 inches in June. The precipitation generally is distributed evenly throughout the county, and about 58 percent of the total annual precipitation falls during the growing season from May through September.

PREVIOUS INVESTIGATIONS

Previous investigations in Winnebago County include a summary of the water resources by Weidman and Schultz (1915), a map of the bedrock geology by Bean (1949), and studies of the Pleistocene geology by Thwaites (1943) and by Alden (1918). Other pertinent studies are noted in the text.

COOPERATION AND ACKNOWLEDGMENTS

This investigation is part of an overall statewide cooperative program of the U.S. Geological Survey and the University of Wisconsin Geological and Natural History Survey; it was planned and conducted under the supervision of C. L. R. Holt, Jr., district geologist, U.S. Geological Survey, in cooperation with George F. Hanson, State Geologist.

The data used for this report were collected from many industrial and municipal water managers, private well owners, well drillers, and the University of Wisconsin Geological and Natural History Survey, whose cooperation is gratefully acknowledged.

The author is especially indebted to Mr. Karl Knudson of the Winnebago State Hospital and Mr. Walter Grandis of the Winnebago County Hospital who contributed much to the success of an aquifer test conducted at the hospitals.

Acknowledgment is made to the State Laboratory of Hygiene for water analyses and to Mr. Hanson for his review of this report.

WELL-NUMBERING SYSTEM

The numbers assigned to wells used in this study are composed of three parts and indicate the locations of the wells (fig. 2). The first part of the well number is an abbreviation for Winnebago County.

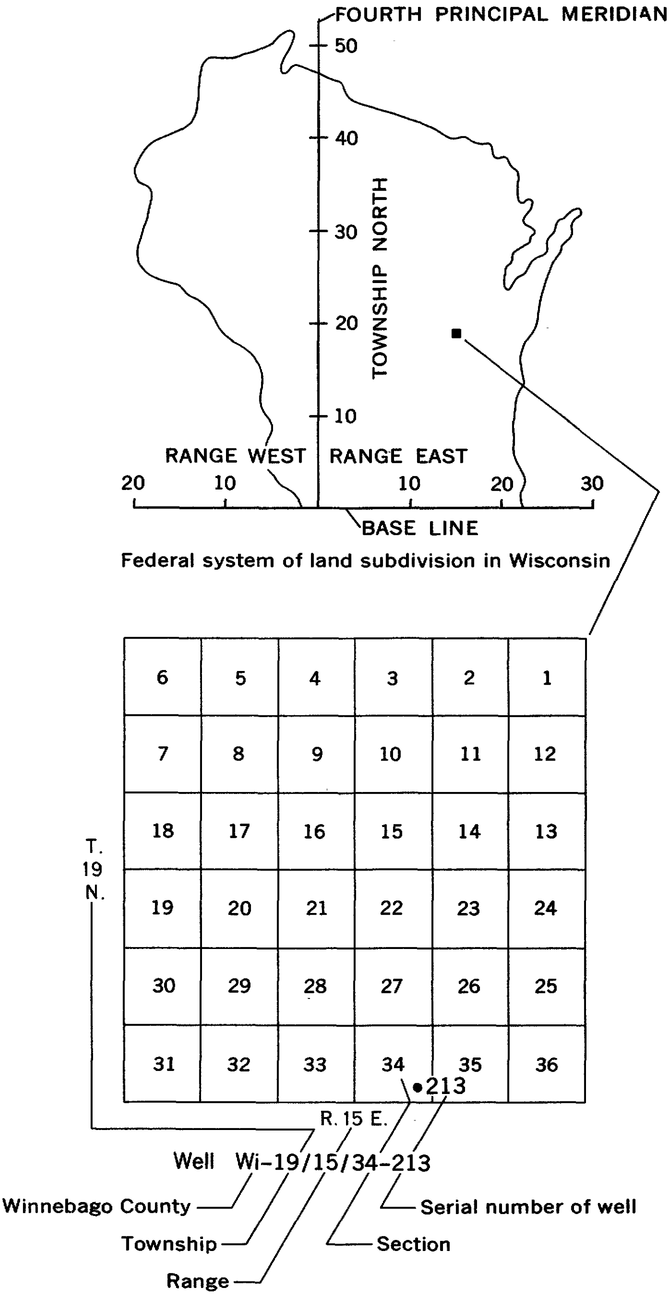


FIGURE 2.—Well-numbering system in Wisconsin.

The second part of the well number, based on the Federal system of land subdivision, lists the township north of the Wisconsin base line, the range east of the fourth principal meridian, and the section number of the well location. The third part of the well number is the serial number that is generally assigned in the order that the well was scheduled in the field. Numbers assigned to rock outcrops are similar but have an "R" preceding the serial number.

Because of space limitations, only the serial numbers of wells and outcrops are shown on the maps in this report.

GEOLOGIC SETTING AND HYDROLOGIC CHARACTERISTICS OF ROCK UNITS

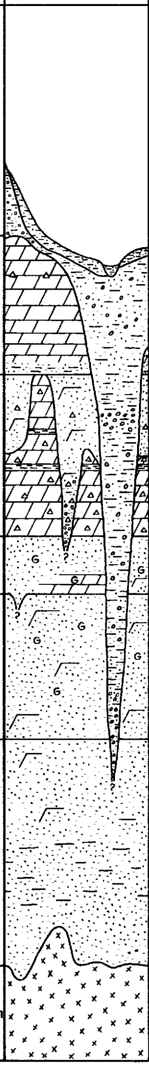
Sedimentary rocks underlying Winnebago County form the reservoirs, or acquifers, that supply water to industrial, municipal, farm, and domestic wells and contribute the base flow of streams. The movement of ground water is controlled by the physical framework of the rock units. A knowledge of the geologic setting and hydrologic characteristics of these rock units is necessary to an understanding of the hydrology of the county. The lithology and water-yielding characteristics of the rock units in Winnebago County are summarized in figure 3.

The bedrock geology and the topography of the bedrock surface were mapped from well-log and outcrop information, and are shown on plate 1. Ordovician rocks generally are more extensive and have a slightly different configuration than shown by Bean (1949). Contours on the bedrock surface in the southern part of the county generally agree with those shown by Alden (1918, pl. 2).

The subsurface geology of Winnebago County, as determined from well logs, is shown by a fence diagram (pl. 2). The diagram is an isometric projection of a series of intersecting cross sections, based on information from wells shown in the index map (pl. 2). It shows the attitude, thickness, and relationship of the geologic units underlying the county and the relationship of the bedrock, land, and piezometric surfaces.

PRECAMBRIAN ROCKS

The lower boundary of the ground-water reservoir in Winnebago County is the surface of the crystalline rocks of Precambrian age. These rocks are composed principally of granite, as reported for the wells that reach the Precambrian surface, but other igneous and metamorphic rock types probably exist in the county. Precambrian rocks prevent the downward movement of ground water from the overlying sedimentary rocks. They are devoid of water except for a limited amount that may be found in fractures.



SYSTEM	ROCK UNIT	RANGE IN THICKNESS (feet)	GENERALIZED GEOLOGIC SECTION	LITHOLOGY	WATER-YIELDING CHARACTERISTICS
QUATERNARY	Pleistocene and Recent deposits	0–320		Upper part, clay, silt, and sand, red and pink, stratified to unstratified, sorted to unsorted; lower part, clay, silt, sand, and gravel, gray and brown, stratified to unstratified, sorted to unsorted	Yield 50 gpm or less from sand and gravel layers and lenses depending on thickness and extent. Recent alluvium not considered an aquifer
	UNCONFORMITY				
ORDOVICIAN	Platteville, Decorah, and Galena Formations undifferentiated	0–170		Dolomite, gray to brown, massive, fossiliferous; sandstone at base, coarse- to fine-grained, gray, shaly, dolomitic, chert (△)	Yield small quantities of water from joints, bedding planes, and solution channels
ORDOVICIAN	St. Peter Sandstone	0–200 (0–200 combined with Prairie du Chien Group)		Sandstone, very fine to coarse-grained, white, gray, and pink, dolomitic; shale, conglomerate, and siltstone in basal part, sandy, dolomitic; some chert (△)	Yields small to large quantities of water depending on thickness
	UNCONFORMITY				
ORDOVICIAN	Prairie du Chien Group	0–200		Dolomite, gray to brown, some sand and shale layers; some chert, white, oolitic (△)	Yields small quantities of water from joints, bedding planes, and solution channels
CAMBRIAN	Trempealeau Formation	0–120		Sandstone in upper part, very fine to medium-grained; siltstone and (or) dolomite in lower part, gray and red, glauconitic (G)	Yield medium to large quantities of water depending on permeability and thickness
CAMBRIAN	Franconia Sandstone	0–120		Sandstone, coarse- to fine-grained; some siltstone and dolomite layers, red and gray, dolomitic, glauconitic (G)	
CAMBRIAN	Dresbach Group	50–350		Sandstone, coarse- to medium-grained, some fine to very fine grained, some silt and shale layers especially in middle part; white to light gray, some pink and pale red	
	UNCONFORMITY				
PRE-CAMBRIAN	Crystalline rock	Unknown		Predominantly granite	Not an aquifer

Figure 3.—Rock units and their water-yielding characteristics in Winnebago County.

The configuration of the Precambrian surface in Winnebago County and surrounding area is shown on the structure-contour map (pl. 3), which was modified from Thwaites (1957). The Precambrian surface in Winnebago County dips southeastward at about 20 feet per mile (pls. 2, 3), and existing data indicate that the surface is fairly smooth.

However, ridges and knobs rising several hundred feet above the general Precambrian surface have been found in surrounding areas (pl. 3), and may exist undetected in Winnebago County. The knob shown in T. 20 N., Rs. 13 and 14 E., was mapped by Bean (1949). Any ridges and knobs rising above the general level of the Precambrian surface may impede the movement of ground water through the overlying sedimentary rocks. The ridges and knobs not only would form a barrier to horizontal flow of water in sedimentary rocks below the top of these highs, but also would reduce the thickness of overlying sedimentary rocks.

CAMBRIAN AND ORDOVICIAN ROCKS—THE SANDSTONE AQUIFER

Cambrian and Ordovician rocks comprise all consolidated sedimentary strata above the Precambrian surface in Winnebago County. These rocks are predominately sandstone, but dolomite is also present (fig. 3). Although Cambrian and Ordovician rocks do not have the same lithology and permeability, all the units below the upper dolomite unit in Winnebago County are interconnected hydraulically and form a single aquifer, which in this report is called the sandstone aquifer. Water levels in wells in the upper dolomite unit (Platteville, Decorah, and Galena Formations undifferentiated) (fig. 3) and in the underlying rocks indicate, at least locally, a poor hydraulic connection. Therefore, the dolomite unit is not included in the sandstone aquifer.

Cambrian and Ordovician rocks range in thickness from 0 feet in the northwest corner of the county, in the area of a Precambrian mound, to about 700 feet along the margin of Lake Winnebago (pl. 2). Thickness of these rocks at any location can be determined by subtracting the altitude of the Precambrian surface (pl. 3) from the altitude of the bedrock surface (pl. 1). The dip of the rocks, which generally conforms to the dip of the underlying Precambrian surface (pl. 2), is southeastward and ranges from 20 to 25 feet per mile, in the northern part of the county, to 10 to 15 feet per mile, in the southern part.

CAMBRIAN SYSTEM

The Dresbach Group, one of the most productive water-yielding units of the sandstone aquifer, is a thick sandstone unit, present throughout Winnebago County. It is composed predominantly of coarse- and medium-grained dolomitic sandstone but contains some fine-grained to very fine grained sandstone. Silt and shale layers are present, especially in the middle and lower parts, and range in thickness from a few inches to several feet. The Dresbach ranges in thickness from 250 to 300 feet, except in areas of Precambrian mounds or preglacial valleys; it does not crop out in the county.

The Dresbach Group rests unconformably on the Precambrian surface. In Wisconsin, the Dresbach can be subdivided into the Mount Simon, Eau Claire, and Galesville Sandstones in ascending order, but for the purposes of this report it is not differentiated. The Mount Simon has not been reported in well logs and apparently is missing in Winnebago County.

Rocks of the Dresbach Group are thoroughly consolidated and do not cave into wells. Layers that are cemented with silica are hard and may cause difficulty in drilling.

The Dresbach Group yields medium to large quantities of water to wells. The upper part probably produces the most water because silt and shale in the middle and lower parts reduce permeability and inhibit the movement of water.

The Franconia Sandstone, a productive water-yielding unit of the sandstone aquifer, is present over most of Winnebago County except in the northwestern corner where it has been removed by erosion (pl. 2). The Franconia is mostly a coarse- to fine-grained sandstone, but may contain siltstone and dolomite layers as thick as 10 feet. The Franconia has a maximum thickness of about 120 feet in the county. It is easy to drill and does not cave into wells. The Franconia yields moderate to large amounts of water to wells, depending on the occurrence of siltstone and dolomite layers.

The Trempealeau Formation, a relatively unproductive water-yielding unit of the sandstone aquifer, is present over most of the county except in the northwestern corner where it has been removed by erosion (pl. 2). It consists of medium-grained to very fine grained dolomitic sandstone in its upper part and dolomitic siltstone and sandy dolomite in its lower part. Glauconite is common in the formation. The Trempealeau has a maximum thickness of about 150 feet in the county. It may be thin where it is overlain by the St. Peter Sandstone because of an ancient erosional surface on the upper contact. The thick section of Trempealeau in the area of well Wi–17/15/29–33 (pl. 2) is attributed to the presence of an ancient channel which cut into the Franconia Sandstone and which was subsequently filled by the upper sandstone unit of the Trempealeau (M. E. Ostrom, Wisconsin Univ. Geol. and Nat. History Survey, oral commun., 1963). The lower dolomite unit of the Trempealeau (pl. 1) crops out north and west of Winchester in secs. 11 and 16, T. 20, N., R. 15 E. (Wi–20/15/11–R52, Wi–20/15/11–R 53, and Wi–20/15/16–R39).

The upper part of the Trempealeau Formation probably yields only small quantities of water to wells because of interbedded siltstone and very fine grained sandstone. Small quantities of water may be contributed to wells tapping joints, fractures, and bedding planes in the dolomite found in the lower part.

ORDOVICIAN SYSTEM

The combined Prairie du Chien Group and St. Peter Sandstone are about 200 feet thick and are present over about half of the county. The contact between the Prairie du Chien and St. Peter is an ancient erosional surface having a relief equal to, or greater than, the total thickness of the two units. Consequently, both of these units range in thickness from 0 to 200 feet, either unit locally filling the entire interval to the exclusion of the other (fig. 3, pl. 2).

The Prairie du Chien Group, a relatively unproductive water-yielding unit of the sandstone aquifer, is present in a discontinuous belt extending diagonally across the county in a northeast-southwest direction (pl. 1) and in several areas in the southeastern half of the county. The Prairie du Chien is composed of hard algal dolomite and has irregular and discontinuous beds, which generally range in thickness from half an inch to 2 feet. Thin sand and green shale layers are common, and the unit contains white oolitic chert which is unique to the Prairie du Chien Group.

Water occurs in limited quantities in solutionally enlarged joints, fractures, and bedding planes in the dolomite of the Prairie du Chien Group, and generally only small quantities are contributed to wells tapping these openings. Thin shale layers restrict the vertical movement of water through the dolomite. Because the Prairie du Chien Group has a lower permeability than that of the underlying sandstone of Cambrian age, it retards the vertical movement of water and thus produces artesian conditions in the underlying sandstones.

The St. Peter Sandstone, a productive water-yielding unit in the sandstone aquifer, is present over most of the southeastern half of the county (pls. 1, 2). Locally, it is thin or missing in this area where the Prairie du Chien Group is present. The St. Peter is a very fine grained to coarse-grained dolomitic sandstone; however, in areas where it is thick, the lower part generally contains dolomitic shale and silt, conglomerate, and fragments of chert. Generally, the St. Peter is poorly cemented and easily drilled. It does not cave into wells except in the basal shale, silt, and conglomerate zone. The St. Peter is exposed at the land surface in two small quarries southeast of Eureka (Wi–17/14/3–R14 and Wi–17/14/3–R15) and crops out southwest of the village of Rush Lake (Wi–17/14/32–R70).

The St. Peter Sandstone yields small to large amounts of water to wells, depending on the unit's thickness and on the content of fine-grained sandstone and shale.

The Platteville, Decorah, and Galena Formations are not differentiated in Winnebago County for the purposes of this report. The three formations will be considered as one unit and referred to as the Platteville-Galena unit.

The Platteville-Galena unit, a relatively unproductive water-yielding unit, is present in the eastern and southern part of the county (pls. 1, 2). The unit is predominantly a massive to thin-bedded fossiliferous dolomite, but 5 to 10 feet of course- to fine-grained shaly dolomitic sandstone is present at its base. It contains dolomitic shale layers, which mostly are very thin but may be as thick as 10 feet. Chert is present in the upper part of the unit. The Platteville-Galena unit ranges in thickness from 0 to about 170 feet in the county. Because it is the uppermost bedrock unit where it is present, and has been subject to erosion, the full stratigraphic thickness is not present in the county. The unit crops out at the land surface in many places along the low escarpment that it forms, especially in the northeastern part of the county.

The Platteville-Galena unit generally yields small quantities of water to wells. As in the Prairie du Chien Group, water moves through joints, fractures, and bedding planes in the rock which may locally be enlarged by solution. Low permeability of the Platteville-Galena unit probably produces artesian conditions in the underlying, more permeable sandstone aquifer.

DEVELOPMENT OF WATER FROM THE BEDROCK AQUIFER

High-capacity wells in Winnebago County, including industrial and municipal or public supply wells, tap the sandstone aquifer. The upper part of the Dresbach Group, the Franconia Sandstone, and the St. Peter Sandstone are the most productive formations, but small to moderate amounts of water are obtained from the Prairie du Chien Group, the Trempealeau Formation, and the middle and lower part of the Dresbach Group. The Platteville-Galena unit generally contributes only small quantities of water to wells.

Generally, domestic and farm wells tap the Platteville-Galena unit or the upper part of the sandstone aquifer except in areas where the bedrock surface is deeply buried by unconsolidated deposits of Quaternary age. All bedrock units generally yield enough water for domestic and farm use.

AQUIFER CHARACTERISTICS

Aquifer characteristics express the capacity of an aquifer to transmit and store water and are a function of the geologic characteristics of the aquifer. A knowledge of aquifer characteristics is necessary for predicting the effects of pumpage on water levels and for determining

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the volume and velocity of water moving through the aquifer—hence for determining the availability of water.

Aquifer characteristics are expressed quantitatively as the coefficients of transmissibility and storage. The coefficient of transmissibility is defined as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer, under a hydraulic gradient of 1 foot per foot. The coefficient of storage is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Aquifer characteristics may be determined by measuring the rate of drawdown of water level in a pumped well and in nearby observation wells as water is withdrawn from the aquifer at a uniform rate. These data are analyzed by the Theis (1935) nonequilibrium formula to determine the coefficients of transmissibility and storage for the aquifer. The nonequilibrium formula assumes that the aquifer is (1) infinite in areal extent, (2) homogeneous and transmits water in all directions with equal ease, and (3) confined between impermeable beds. It also assumes that (4) the coefficients of transmissibility and storage are constant, (5) the discharging well penetrates the entire thickness of the aquifer, and (6) the discharged water is released from storage instantaneously with decline in head. Because these conditions are not fully met in nature, considerable judgment must be used in establishing the validity of the results.

An aquifer test of the sandstones of Cambrian age was conducted at the Winnebago State Hospital and the Winnebago County Hospital, well Wi–19/17/31–39 being the discharge well and wells Wi–19/17/31–37, Wi–19/16/36–61, and Wi–19/16/36–32 being observation wells. These wells are open only in the sandstones of Cambrian age and tap all or most of the aquifer.

Water-level measurements were made in the four wells while well Wi–19/17/31–39 was pumped at an average rate of 290 gpm (gallons per minute) for a period of about 27.5 hours and during a recovery period of about 12 hours. It was determined that 20,000 gpd per ft (gallons per day per foot) and 0.0002 are reliable values for the coefficients of transmissibility and storage, respectively, for the sandstones of Cambrian age in the vicinity of the test area.

The coefficient of transmissibility of an aquifer is dependent on the permeability and thickness of the aquifer. An examination of logs of wells located throughout Winnebago County indicates that the permeability of the sandstone aquifer is relatively uniform. However, the thickness of the aquifer is highly variable and, in general, decreases from east to west (pl. 2). The coefficient of transmissibility of the sandstone aquifer probably decreases from a maximum of about 20,000 gpd per ft along the eastern edge of the county, where the aquifer has its maximum thickness (pl. 2), to very low values in the northwestern part of the county, where preglacial channels have reduced the aquifer thickness to a minimum (pls. 1, 2).

Specific capacity expresses the general relationship of the discharge from a pumping well to the resultant drawdown of water level in the well and is generally expressed in gallons per minute per foot of drawdown. Although specific capacity is affected by the construction and development of the well and the rate and length of time of pumping, it depends on the coefficients of transmissibility and storage of the aquifer, and it may be used to determine very roughly the productivity of the aquifer.

The specific capacities of 140 wells in Winnebago County, open in either the Platteville-Galena unit, the St. Peter Sandstone, the Prairie du Chien Group, or the sandstones of Cambrian age, were determined from data on drawdowns and discharges reported by well drillers. The average and range in specific capacities for wells tapping each rock unit and the number of wells used in the analyses are shown in table 1.

It is impossible to predict accurately the specific capacity of a well drilled at any particular location because of the differences of the physical characteristics of the rock units and the differences in well construction and development.

TABLE 1.—*Average specific capacities of wells open in units of the sandstone aquifer in Winnebago County*

Rock unit	Number of wells	Average specific capacity, in gpm per ft of drawdown	Range in specific capacities
Platteville-Galena unit	60	6.3	0.1–44.0
St. Peter Sandstone	18	5.7	.2–20.0
Prairie du Chien Group	12	4.2	.7–12.5
Sandstones of Cambrian age	50	6.3	.8–22.5

BEDROCK SURFACE

The topography of the bedrock surface is important in Winnebago County because this surface forms the upper boundary of the bedrock aquifers as well as the lower surface of the overlying drift aquifer. The topography of the bedrock surface is often closely related to the surficial topography, and thus has an indirect control on the drainage pattern in the county. The thickness of glacial drift, which can be determined by subtracting the bedrock-surface altitude from the land-surface altitude (pl. 1), is useful for indicating the depth to which a bedrock well should be cased, the thickness of the drift aquifer, and areas of thin drift where pollution may be a problem.

The bedrock surface in Winnebago County has been dissected by preglacial and glacial erosion and has a considerable amount of relief (pls. 1, 2). Altitudes on this surface generally range from 450 feet in the northwestern part of the county to about 900 feet in the southwestern part. In general, the lowland areas in the bedrock surface are underlain by rather easily eroded sandstone of Cambrian age and St. Peter Sandstone of Ordovician age. The highland areas are formed by the dolomite of the Prairie du Chien Group and of the Platteville-Galena unit (pls. 1, 2).

The Platteville-Galena unit, covering most of the eastern and southern part of the county (pl. 1), forms a broad, flat, southeastward-sloping plain on the bedrock surface. The slope of this plain ranges from an average of about 25 feet per mile in the northeastern part of the county to an average of about 15 feet per mile in the southern part. The plain terminates in a northwestward-facing escarpment formed by the edge of the dolomite and an adjacent lowland underlain by the St. Peter Sandstone. The lowland formed on the St. Peter probably underlies most of the marshy Rush Lake area in southwestern Winnebago County (pls. 1, 2).

The Prairie du Chien Group is exposed at the bedrock surface in a broad discontinuous belt extending from the southwestern corner of the county to the northern border, roughly parallel to the Platteville-Galena escarpment (pl. 1). The Prairie du Chien has been deeply dissected and forms a series of hills and ridges, but the unit as a whole dips to the southeast at about the same slope as the Platteville-Galena unit. The Prairie du Chien forms a prominent discontinuous northwestward-facing escarpment.

Sandstones of Cambrian age form the bedrock surface in the northwestern part of the county and in the Fox and Wolf River valleys. The deep valley cut in sandstones of Cambrian age in the northwestern part of the county (pls. 1, 2) is part of a preglacial valley extending from Waupaca County (Berkstresser, 1964), through Winnebago County under the Wolf River and Lake Poygan, and into Waushara County (Summers, 1965). The valley trends southward in Waushara County, parallel to the Winnebago County border, and probably connects with a preglacial channel just west of Berlin (pl. 3; Alden, 1918, pl. 2) which may represent the course of the ancient Wolf River.

The buried valley underlying the present Fox River (pl. 1) from the western border of the county to Lake Butte Des Morts probably represents the course of the ancient Fox River. The bedrock valley underlying Little Lake Butte Des Morts and extending southward to Lake Butte Des Morts (pl. 1) also may have been part of the ancient Fox River valley. If this is true, altitudes on the floor of the valley indicate that the ancient Fox River flowed southwestward and emptied into the Wolf River in the vicinity of Berlin. The buried valley underlying Rush Lake is an extension of the ancient channel now occupied by Green Lake in Green Lake County as shown by Alden (1918, pl. 2).

QUATERNARY DEPOSITS—THE DRIFT AQUIFER

Quaternary deposits include all glacial and alluvial deposits between the bedrock surface and the land surface in Winnebago County. These unconsolidated deposits consist of clay, silt, sand, gravel, boulders, peat, and marl and are sorted to unsorted and stratified to unstratified. Quaternary deposits in the northern part of the county have been mapped by Thwaites (1943) and in the southern part of the county by Alden (1918). These maps are adequate for the purposes of this report.

Glacial deposits were laid down during the Cary and Valders Stades of the Wisconsin Glaciation (Thwaites, 1943, p. 121). The deposits of Cary age cover the county and fill the buried valleys in the bedrock surface. Deposits of Cary age are gray to brown and consist of morainal, glaciolacustrine, and some outwash and ice-contact deposits. Drillers' logs indicate that there is a high percentage of clay and silt in the deposits of Cary age in Winnebago County. Deposits of Valders age overlie the Cary and consist predominantly of reddish-brown clay and silt in the form of ground moraine and glaciolacustrine deposits. They generally are very thin and cover most of the county except the southwestern corner (Alden, 1918, pl. 3; Thwaites, 1943).

Alluvium includes Recent deposits of unconsolidated material laid down along stream channels, and peat and marl formed in marshes and lakes. Sand dunes in the northwestern part of the county probably formed in Recent times (Thwaites, 1943, p. 141).

Quaternary deposits in Winnebago County range in thickness from 0 feet at rock outcrops to a maximum known thickness of 315 feet in the northwestern corner of the county (well Wi–20/14/16–136). Figure 4 is a generalized map showing the approximate thickness of Quaternary deposits in the county. These deposits are thickest where deep valleys are cut in the bedrock surface and thinnest where the bedrock surface is high (pl. 2). The thickness of Quaternary deposits at any particular site can be determined by subtracting the bedrock-surface altitude from the land-surface altitude shown on plate 1.

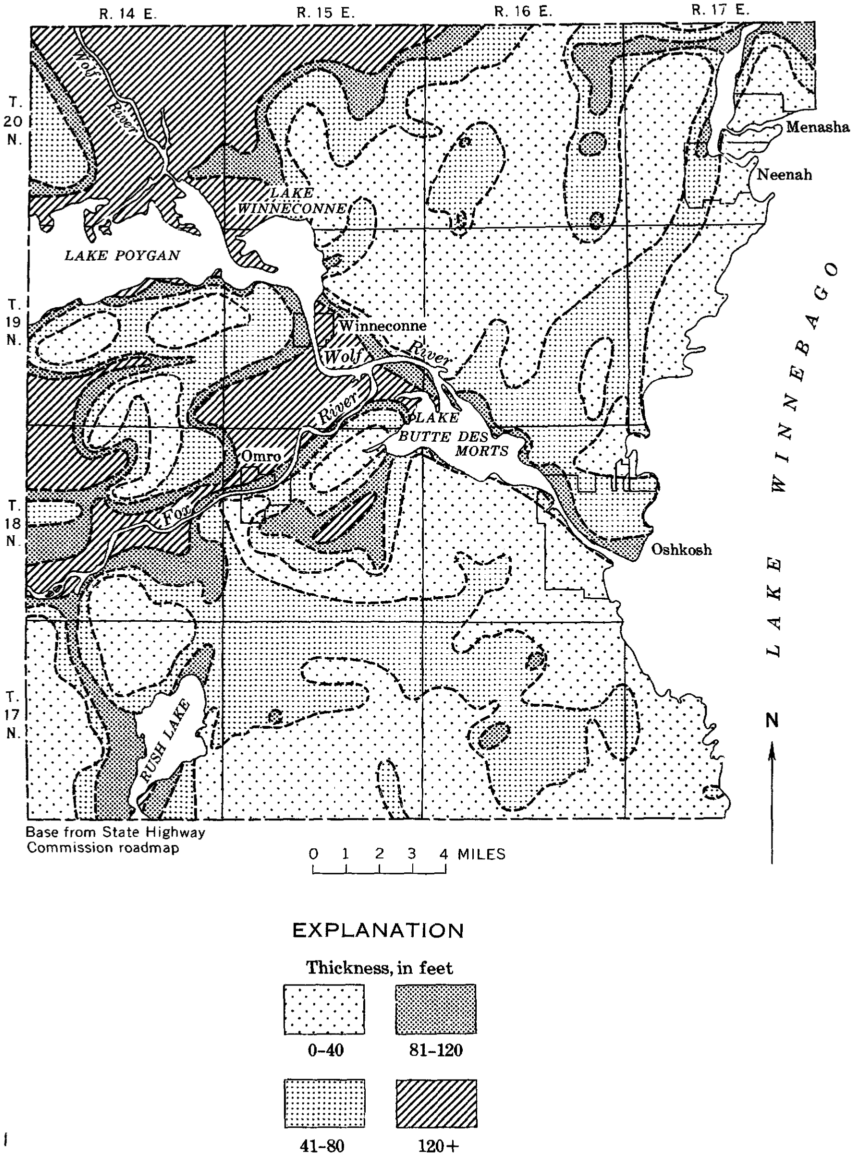

Figure 4.—Approximate thickness of Quaternary deposits in Winnebago County.

Drillers' logs indicate a nearly continuous layer of sand and gravel along the floor of the buried preglacial valleys, especially in the valleys underlying the Wolf and upper Fox Rivers (pl. 1). This layer attains a maximum thickness of about 100 feet in a few places but generally is less than 20 or 30 feet. Yields of wells penetrating the sand and gravel generally are small, probably because of a high clay and silt content. There are probably no sand and gravel deposits in the county that are extensive enough to yield large quantities of water to wells. Water in the sand and gravel layer is under artesian pressure and is confined by overlying silt and clay; most of the wells penetrating the sand and gravel flow at the land surface. Water levels in wells indicate that a good hydraulic connection exists between this unit and the underlying sandstones of Cambrian age.

Glacial deposits overlying the basal sand and gravel layer in the buried valleys and throughout the remainder of the county are principally clay, but isolated sand and gravel lenses are present, especially in the areas of the buried valleys. These sand and gravel lenses are under artesian pressure. Small water supplies may be obtained from these lenses. However, the location and extent of the deposits cannot be determined from available data.

In areas of the county not underlain by preglacial valleys, the limited thickness and extent of sand and gravel layers and the high clay content of the glacial till make the glacial deposits a poor source for water. However, the glacial drift acts as a confining layer for the underlying sandstone aquifer.

The limited thickness and extent of recent alluvial deposits make these deposits a poor source of water. It has been reported that some sand dunes in the northwestern part of the county have provided enough water to wells for domestic use. However, the sand dunes normally are not a dependable or extensive source of water in Winnebago County.

SOURCES OF WATER

The source of all surface and ground water in Winnebago County is precipitation. Water from rainfall and snowmelt either returns to the atmosphere by direct evaporation or by transpiration by plants, remains in the soil zone above the water table as soil moisture, runs over the land surface to streams and lakes as runoff, or percolates downward to the zone of saturation as recharge and becomes ground water. Ground water moves through the aquifer and is discharged to streams and lakes.

SURFACE WATER

FOX AND WOLF RIVERS

Winnebago County is in the Lake Michigan drainage area and lies within the drainage basin of the Fox River and its principal tributary, the Wolf River. Streams and lakes in the county either are tributaries to, or are part of, these two rivers which flow into Lake Butte des Morts (pl. 1) in the central part of the county.

The Fox River rises in Columbia County in south-central Wisconsin where it flows within about 1 mile of the Wisconsin River at the city of Portage. There it is connected to the Wisconsin River by a canal. The river enters Winnebago County near Eureka, flows northeastward through Lake Butte des Morts and Lake Winnebago, and leaves the county north of Menasha. It then flows northeastward to Green Bay where it empties into Lake Michigan.

Lake Winnebago divides the river into two distinct sections, the upper and lower Fox River. The upper Fox River flows through a fairly flat, poorly drained area underlain by sandstones of Cambrian age and drops only about 35 feet in the 107 miles between Portage and Lake Winnebago (Smith, 1908, p. 26). This section of the river is characterized by low banks and frequent flooding. The low gradient of the upper Fox River provides little opportunity for producing power.

The lower Fox River, underlain by dolomite of the Plattesville-Galena unit, drops about 167 feet in the 35 miles between Menasha and Green Bay (Smith, 1908, p. 29), and provides waterpower for several hydroelectric plants built along this part of the river. The storage and regulated release of water at dams make the flow of the lower Fox River very uniform. Navigation is maintained on the lower Fox by means of 19 locks operated by the U.S. Army Corps of Engineers.

The Wolf River rises in Forest County near the Wisconsin-Michigan border. In the upper half of its course, north of the city of Shawano, the river is underlain by crystalline rocks of Precambrian age and has high banks, a steep gradient, and many falls and rapids. The river drops 775 feet in the 80 miles between Lenox and Shawano (Smith, 1908, p. 96). The lower half of the Wolf River, below Shawano, is underlain by sandstones of Cambrian age and is characterized by a low gradient, low banks, and frequent flooding. The river drops only about 42 feet in the 80 miles between Shawano and Winneconne in Winnebago County (Smith, 1908, p. 96). The low gradient and broad flood plains of the lower Wolf River make it unsuitable for dam construction, but private interests have made several waterpower developments on the upper Wolf River.

The Little Wolf River empties into the Wolf River and the Lake Winnebago Pool near New London (pl. 3). It drains an area underlain by Precambrian crystalline rocks which are covered chiefly by till.

The Waupaca River empties into the Wolf River and the Lake Winnebago Pool a few miles north of the Winnebago County line. The river drains an area overlain principally by thick outwash deposits of sand and gravel resting on Precambrian crystalline rocks.

Flow characteristics of the upper Fox River and the Wolf River and its tributaries, which contribute water to the Lake Winnebago Pool, are dependent chiefly on the geology of their respective basins. Stream gages on these rivers are listed in table 2 along with drainage area and average discharge. Flow-duration curves for these gaging stations, show that, during 80 to 85 percent of the time, the flow of the upper Fox, Wolf, and Little Wolf Rivers is principally ground water. In the Waupaca River, the flow is principally ground water during about 90 percent of the time. The Little Wolf River, draining an area of ground moraine and crystalline rocks, has the greatest amount of rapid surface runoff. The Waupaca River, draining an area of outwash sand and gravel, has the least amount of rapid surface runoff. Runoff from the upper Fox and Wolf Rivers, draining areas of outwash, moraine, crystalline rocks, and sandstones, falls between these two extremes.

In general, drainage in Winnebago County is controlled by the topography of the bedrock surface. The prominent features of the bedrock surface are expressed in the surficial topography of the county which directly controls the drainage pattern. Parts of the Fox River and most of the small streams flow parallel to the escarpments of the Platteville-Galena unit and Prairie du Chien Group, and to the strike of the bedrock formations; they thus drain the valleys underlain by St. Peter Sandstone and sandstone of Cambrian age (pl. 1). The Wolf River, including Lakes Winneconne and Butte des Morts, and the Fox River at Oshkosh have cut through the dolomite escarpments, their flow being at right angles to the other streams and down the dip of the bedrock formations (pl. 1).

LAKES, MINOR STREAMS, AND WETLAND AREAS

Rush Lake, in the southwestern corner of the county, has an area of about 4.8 square miles and is very shallow, probably averaging less than 5 feet in depth. The lake is at an altitude of 821 feet and empties into the Fox River through Rush Creek (pl. 1).

Rush Creek drains Rush Lake and the large wetland area in the southwestern part of the county (pl. 1). Eightmile Creek has been partly dredged to connect with Rush Creek to drain the wetland area. Rush Creek has an average fall of about 11 feet per mile in the 6 miles between Rush Lake and the Fox River.

The Rat and Arrowhead Rivers also have been partly dredged to drain wetlands. These rivers drain the lowland areas in the north-central part of the county and have gradients of only a few inches per mile.

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In general, wetlands are concentrated in the low-lying areas in the western and northwestern parts of the county, especially in the Wolf and upper Fox River valleys and in the Rush Lake area. Drainage has reduced the total wetlands area from about 47,360 acres in 1938 to about 32,550 acres in 1961 (Wisconsin Conserv. Dept., 1962).

Little Lake Butte des Morts in the northeastern part of the county is below the Menasha Dam and is part of the lower Fox River. The lake surface is at an altitude of 738 feet and has an area within the county of about 2 square miles.

Other streams in the county (pl. 1) are intermittent, generally flowing only in the spring and early summer and after heavy rainstorms.

RESERVOIRS—THE LAKE WINNEBAGO POOL

The Lake Winnebago Pool is the slack-water area behind the Menasha and Neenah Dams on the two outlets of Lake Winnebago (pl. 1). The pool has a surface area of about 265 square miles at the elevation of the crest of the dam (Knowles and others, 1964, p. 22). It includes Lakes Winnebago, Butte des Morts, Winneconne, and Poygan, the Fox River upstream to about Eureka in Winnebago County, and the Wolf River upstream nearly to New London in Waupaca County. The pool, excluding Lake Winnebago, covers about 7 percent of the total area of the county.

The Corps of Engineers regulates the release of water from the Lake Winnebago Pool for navigation and waterpower development on the lower Fox River. The limits of regulation are from 21¼ inches above the crest down to the crest of the Menasha Dam during the navigation season (generally from the first part of May to the end of October), and down to 18 inches below the crest during the remainder of the year (U.S. Army Corps of Engineers, 1922, p. 91). True lake level is determined by a staff gage at the mouth of the upper Fox River at Oshkosh which has a datum of 745.05 above mean sea level. The usable capacity of the pool within the limits of regulation is 25 billion cubic feet or about 190 billion gallons (Knowles and others, 1964, p. 19).

Changes in inflow from the Fox and Wolf Rivers and their tributaries for the 1959 water year affected the storage and outflow of water of the Lake Winnebago Pool (fig. 5). The inflow, computed from records of the daily discharge at four gaging stations above the pool, is shown in table 2. The drainage area upstream from these gaging stations is about 75 percent of the drainage above Menasha Dam.

The effect of changes in storage in the pool on the flow of the lower Fox River also is shown in figure 5. The outflow was computed from records of daily discharge of Rapide Croche Dam (table 2), at which the drainage area is only about 2 percent larger than at Menasha Dam.

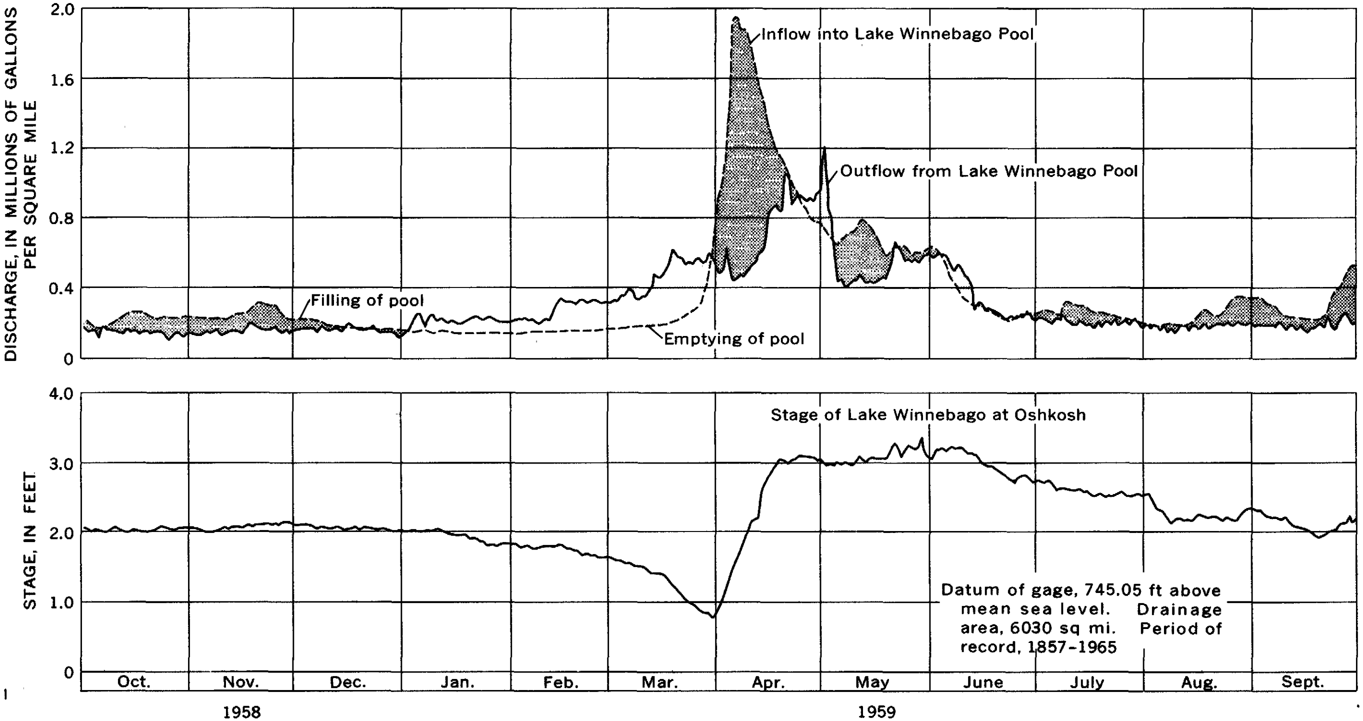

FIGURE 5.—Inflow, outflow, and stage of the Lake Winnebago Pool for 1959 water year. Modified from Knowles, Dreher, and Whetstone (1964).

Water was stored in the Lake Winnebago Pool in the late fall, and then released steadily through the winter to supplement the naturally decreasing flow in the lower Fox River and to lower the pool in anticipation of high spring runoff. Much of the spring runoff from the upper part of the basin was then stored in the Lake Winnebago Pool. The stage of the pool rose about 2 feet from March 30 to April 18. The flow at Rapide Croche Dam was kept fairly uniform throughout the summer as the level of Lake Winnebago fluctuated with the runoff from the upper part of the basin.

TABLE 2.—*Average discharge of streams flowing into and out of the Lake Winnebago Pool*

Gaging station	Drainage area (sq mi)	Average discharge for period of record (cfs)	Period of record
Above Lake Winnebago Pool:			
Fox River at Berlin	1,430	1,101	1898–1962
Wolf River at New London	2,240	1,713	1896–1962
Little Wolf River at Royalton	514	399	1914– 62
Waupaca River at Waupaca	272	237	1916– 62
Below Lake Winnebago Pool:			
Fox River at Rapide Croche Dam	6,150	4,194	1896–1962

QUALITY OF SURFACE WATER

Surface water in Winnebago County is hard, has a considerable annual range in temperature, is locally polluted, and has a serious algae problem in the summer months. However, after treatment of the water, its quality generally is suitable for municipal and most industrial purposes. The water generally requires softening before it is used in high-pressure boilers and also may require treatment to reduce turbidity, iron, and manganese. Some industrial uses may require additional treatment.

The average quality of surface water has probably remained nearly constant over a long period of time. Analysis of water taken from several places on the Fox River and Lake Winnebago over the period 1896 to 1963 (table 3) show fairly consistent concentrations of dissolved mineral constituents. The variation that does occur probably is related both to the time of year that the samples were taken and to the location of the sampling sites.

The quality of surface water fluctuates because of the variable ratio of ground-water discharge and surface runoff contributed to streams throughout the year. During periods of base flow, approximately 85 percent of the time, the streamflow is derived almost entirely from ground water, and the chemical quality is nearly constant. Ground water generally is more highly mineralized than surface runoff. The total hardness of water from the Fox River at Omro, sampled monthly, is shown in figure 6. Total hardness was greatest during the winter

TABLE 3.—*Chemical analyses of water from selected sites on the Fox River and Lake Winnebago in Winnebago County and from Lake Michigan*

[Results, except for pH, in parts per million. Agency making analysis: Prentiss, G. N. Prentiss, Chicago, Milwaukee and St. Paul Railroad; WSLH, Wisconsin State Laboratory of Hygiene; Davidson, G. M. Davidson, Chicago and Northwestern Railway; DDCC, Dearborn Drug and Chemical Co., Chicago, Ill.]

Location	Source of water	Date of collection	Agency making analysis	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Total solids	Hardness (as $CaCO_3$)	pH
Menasha [1]	Fox River	2- 6-1909	Prentiss			34	19.1		6.6	5.1		186		
Do	Lake Winnebago	5-31-45	WSLH	0.1	0.0	33.8	16.5	161	14.5	6.5	0.3	186	146	8.4
Do	do	9-25-46	WSLH	.2	.0	21.3	18.5	280	15.0	5.5	.5	210	155	8.0
Do	do	8-11-58	WSLH	.0	.0	33.8	16.5	134	40.0	9.0	1.2		180	
Neenah	do	5-31-45	WSLH	.1	.0	33.8	17.0	166	17.0	6.0	.4	188	168	8.4
Do	do	3-15-60	WSLH	.2	.3	38.8	21.9	194	16.0	4.0	.4	236	180	7.7
Do	do	3-14-62	WSLH	.7	.66	41.2	22.6	213	10	5.0		416	196	7.6
Oshkosh [1]	do	6-23-1896	Davidson			33.4	19.0		29.2	6.4		192		
Do.[1]	do	1-17-1911	DDCC			35.4	20.4		13.9	5.3		196		
Do.[1]	Fox River	4-28-13	Prentiss			26.2	12.4		10.9	6.2		129		
Do	Lake Winnebago	5-31-45	WSLH	.4	.0	35.6	17.3	173	13.0	5.0	.4	216	142	8.1
Do	do	2-28-57	WSLH	<.05	.0	41.3	21.0	217	10.5	5.5	.35	222	197	8.35
Omro	Fox River	4-10-61	WSLH					149		0		240	155	7.4
Do	do	4-19-62	WSLH					149		0		176	138	7.8
Do	do	4-22-63	WSLH					173		1.5		252	163	8.2
Average				.2	.1	34.0	18.5	183	16.4	4.7	.5	218	165	8.0
Cudahy	Lake Michigan	5- 4-1964	WSLH	.06	>.05	34	11.4	110	17	6.5	.05	168	132	8.05

[1] From Weidman and Schultz (1915, p. 635).

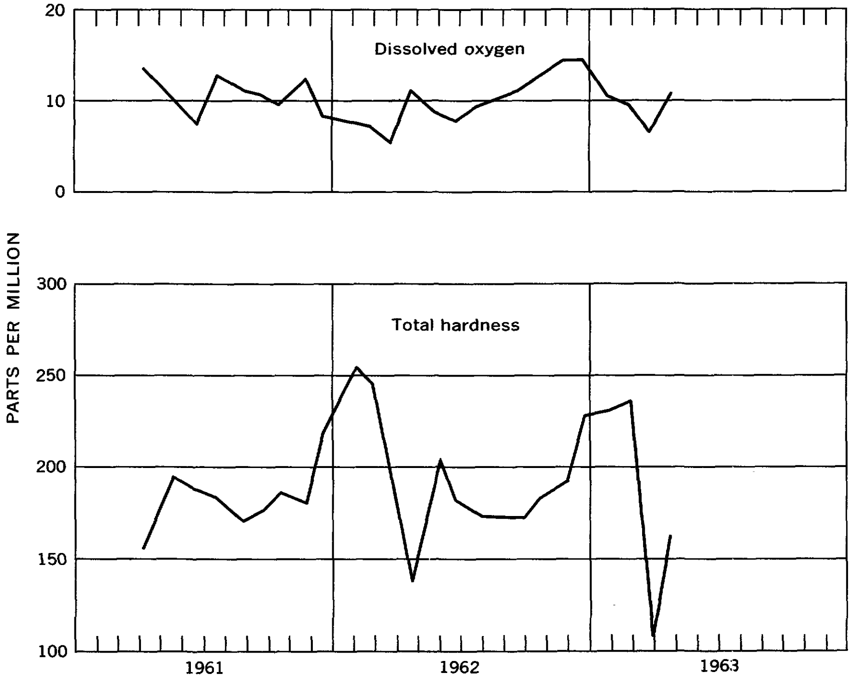

FIGURE 6.—Total hardness and dissolved-oxygen concentrations in water from the Fox River at Omro, April 1961–April 1963.

months when streamflow was principally derived from ground-water discharge, and was least in the spring when streamflow was diluted by runoff from snowmelt and spring rains.

Much of the suspended sediment in water of the upper Fox and Wolf Rivers is entrapped in the Lake Winnebago Pool. Suspended-sediment concentration of the Fox River at Omro measured monthly by the Wisconsin Committee on Water Pollution for the period April 1961 to April 1963 ranged from 5 to 261 ppm (parts per million) and averaged about 39 ppm. Similar data for the Wolf River were not available. The concentration of suspended sediments of water entering the lower Fox River at Neenah generally is less than 15 ppm (Wisconsin Comm. on Water Pollution, 1956).

Presently, the Lake Winnebago Pool is fairly free of pollutants; however, treated municipal sewage is discharged into the pool from Oshkosh, Fond du Lac, and small cities and villages on the Wolf and upper Fox Rivers. This treated municipal sewage and any industrial pollutants that enter the pool generally are only a minor problem because they are sufficiently treated before discharge and are diluted by the large volume of water in the pool (Theodore Wisniewski, Wisconsin Comm. on Water Pollution, oral commun., 1964). However, minor pollution problems do occur locally, especially in the areas of discharge pipes for sewage or industrial wastes.

The growth of algae in the pool during the summer months is a major treatment and aesthetic problem in the county. Algal growth is supported by natural nutrients in the lake and by some manmade nutrients that enter the lake. High water temperature, caused by the shallowness of the pool and the slow circulation of water through the pool, also encourages the growth of algae.

Dissolved oxygen concentrations in most parts of the Winnebago Pool generally are sufficient to support biologic activity at all levels, though possibly not in the shallower parts of the pool. Dissolved oxygen in water is depleted principally by organic decomposition and biologic activity. Oxygen is replaced by dissolution from the atmosphere at the water surface and especially by algae and other water plants which release oxygen to the water as a byproduct of photosynthesis (Birge and Juday, 1911, p. 51). In the winter months when the lake surface is frozen, little oxygen is dissolved in the water and organic decomposition is still in progress, reducing dissolved oxygen concentration. Dissolved oxygen concentration of the Fox River at Omro, tested monthly for the period April 1961 to April 1963, is shown in figure 6. The concentration generally declined during the winter months and rose in the spring when the water was free of ice. Although information is not available for the Wolf River and Lake Winnebago during this period, four measurements of dissolved oxygen concentration of the Fox River at Neenah in 1955 ranged from 8.7 to 13.3 ppm and averaged 10.7 ppm (Wisconsin Comm. on Water Pollution, 1956).

Water from the Lake Winnebago Pool generally is usable for cooling purposes at all times during the year. The water temperature of Lake Winnebago at Oshkosh ranges from about 32°F in the winter months to about 80°F in the summer months and averages about 53°F. Although industries prefer water having a maximum temperature of 60°F for cooling purposes, some industries can utilize water having a maximum temperature of 85°F.

GROUND WATER

OCCURRENCE

Aquifers in Winnebago County occur under either water-table or artesian conditions, or often under a combination of the two. Under water-table conditions the aquifer is unconfined and generally is exposed at or near the land surface. The water level in a well penetrating this aquifer is coincident with the water table. Fluctuations in the height of the water table cause unsaturated parts of the aquifer to become saturated as the water table rises and cause saturated parts of the aquifer to become dewatered as the water table declines.

Under artesian conditions, the aquifer is confined between relatively impermeable beds and is supplied water from areas at higher altitudes. The ground water is under pressure and will rise in a well penetrating the unit above the lower surface of the upper confining bed and to a height equal to the hydraulic head on the aquifer. If this pressure or piezometric surface is higher than the land surface, the well will flow. When the piezometric surface is lowered by pumping or free flow from a well, the aquifer is not dewatered; water removed from the aquifer is derived from compaction of the aquifer and associated beds and from the expansion of the water itself. This compaction of the aquifer and expansion of the water constitute the storage factor of an artesian aquifer.

Under natural conditions, an aquifer often is under water-table conditions at or near its recharge area where the formation is near the land surface, but may be under artesian conditions where the formation is more deeply buried, down dip from the recharge area.

Throughout most of Winnebago County, the sandstone aquifer is under artesian pressure. Water in the sandstone aquifer is confined by the less permeable Platteville-Galena unit where it is present, and by glacial drift throughout the county. The Prairie du Chien Group is less permeable than the overlying and underlying sandstones and probably retards the vertical movement of water between the sandstone units. In its area of outcrop (pl. 1), the upper part of the Prairie du Chien Group is probably under water-table conditions, the water occurring in fractures, solution channels, and bedding planes. The unit confines water in the underlying sandstones in this outcrop area.

Water occurs in solutionally enlarged fractures, joints, and bedding planes in the Platteville-Galena unit. Generally the unit occurs under water-table conditions in areas where the overlying glacial drift is thin. Water levels in wells indicate a general hydraulic connection between the Platteville-Galena unit and the underlying sandstone aquifer; however, locally these units are hydraulically separated.

Quaternary deposits in Winnebago County generally are saturated, but because of the high silt and clay content of most of the unconsolidated material, these deposits yield only small quantities of water to wells. In the buried bedrock valleys, where the drift is thick, small artesian wells may be developed from lenses or layers of sand and gravel confined between layers of silt and clay.

RECHARGE, DISCHARGE, AND MOVEMENT

Ground water moves through an aquifer from areas of recharge to areas of discharge. The direction of movement is down the hydraulic gradient of the aquifer, from points of higher altitude to points of lower altitude on the piezometric surface. Because the piezometric surface of the aquifer roughly conforms to the topography in Winnebago County, ground-water movement is, in general, from highland areas to lowland areas. The velocity of ground-water movement depends on the slope of the hydraulic gradient and the permeability of the aquifer, and in the county the velocity generally is only a few inches to a few feet per day. In dolomite, water may travel at much higher rates through fractures and solution channels.

The configuration of the piezometric surface in Winnebago County for the period July 29 through August 4, 1963, is shown on plate 4. Because all the formations in the county in general are hydraulically connected, the map was constructed from water levels in 304 wells penetrating various geologic units.

The formations in Winnebago County that contain water under water-table conditions receive recharge by direct percolation of water from the land surface to the zone of saturation. These formations include glacial drift that has permeable materials at the land surface, the Platteville-Galena unit where it is overlain by only a thin layer of drift, and the Prairie du Chien Group in its area of outcrop.

The formations that contain water under artesian conditions receive recharge by water moving from areas of outcrop into more deeply buried parts of the same formation, through overlying glacial material, or through overlying consolidated units. These formations include (1) the permeable layers in the glacial material that are overlain by material of lower permeability, (2) the St. Peter Sandstone, (3) the Prairie du Chien Group where it is deeply buried, and (4) the sandstones of Cambrian age. Recharge can also take place by leakage between two formations. For example, if the hydrostatic head in the St. Peter Sandstone is lowered sufficiently by a pumping well penetrating that unit, water would move upward into the St. Peter Sandstone from the underlying Prairie du Chien Group and sandstones of Cambrian age, and downward into the St. Peter Sandstone from the overlying Platteville-Galena unit and glacial drift.

Ground water is discharged naturally from an aquifer by seepage into streams and lakes, by evapotranspiration, and by springs, and is discharged artificially by pumping and flowing wells. All streams and lakes in Winnebago County are areas of discharge, ground water generally making up their flow during 85 to 90 percent of the time.

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A large quantity of water is discharged from the aquifer by pumping and flowing wells. Evapotranspiration is a quantitatively important means of discharge in wetland areas where the water table is at or near the land surface. Little or no evapotranspiration takes place from the deep water-table and artesian aquifers. Springs are not common in Winnebago County and they are not a large source of discharge.

Winnebago County is subdivided by topographic and ground-water divides that separate the movement of water toward the Fox River, the Wolf River, or segments of the two rivers. In Winnebago County, three ground-water drainage areas, associated with the upper Fox River, the Wolf River, and Lake Winnebago, are separated by the two ground-water divides shown on plate 4. These ground-water divides conform closely to the topographic divides, and for the most part follow the escarpments of the Platteville-Galena unit and the Prairie du Chien Group (pl. 1). The divides are drawn across Lakes Butte des Morts and Winneconne on plate 4 only for discussion purposes. The lakes are a common discharge point for adjacent ground-water basins, and actual ground-water movement under the lakes is not affected by divides.

LAKE WINNEBAGO GROUND-WATER DRAINAGE AREA

The Lake Winnebago ground-water drainage area in Winnebago County includes the eastern one-third of the county east of the north-south trending ground-water divide (pl. 4). Dolomite of the Platteville-Galena unit forms the bedrock surface over most of the area (pl. 1) and the dolomite is overlain by a fairly thin layer of glacial drift (fig. 4). Recharge to the sandstone aquifer in this area percolates through semipermeable glacial drift and the Platteville-Galena unit. The ground water then moves roughly perpendicular to the contours on the piezometric surface (pl. 4) from the ground-water divide toward Lake Winnebago and part of Lake Butte des Morts, except in the areas affected by pumping, and is discharged into these surface-water bodies.

Because the water table in this area is fairly deep and only a small percentage of the area is in wetlands (Wisconsin Conserv. Dept., 1962, p. 5), evapotranspiration is not a large factor of ground-water discharge.

The depressions in the piezometric surface surrounding Neenah-Menasha, Oshkosh, and the Winnebago State and County Hospitals north of Oshkosh (pl. 4) are the result of concentrated pumping. Because discharge of ground water by pumping has been more rapid than movement of water toward these areas, water has been removed from storage, and the piezometric head has been lowered. A steep hydraulic gradient has been established toward the center of the cones of depression. This steepening of the hydraulic gradient has increased the rate of movement of water toward the centers of pumping, and some of the water that would have been discharged to Lake Winnebago under natural conditions now moves toward the cones and becomes available to wells. This intercepted ground-water discharge reduces streamflow somewhat in the area of the cone of depression. However, about 90 percent of the ground water pumped is not removed from the area but is returned to the stream. About 10 percent of the water pumped is used consumptively. In the Neenah-Menasha area, intercepted ground-water discharge that might have entered the Lake Winnebago Pool is pumped from wells and is discharged to Little Lake Butte des Morts.

Recharge to the Neenah-Menasha area is derived over an area of only about 43 square miles (pl. 4). The recharge area is bounded approximately by the major ground-water divide about 4 miles west of the center of pumping, a minor divide about 6 miles south of the pumping center, a minor divide about 2 miles east of the center, and a minor divide about 2 miles north of the center. Ground water moves down the hydraulic gradient, established by the lowered piezometric surface under the cities, from the divides toward the center of pumping. Because the area of recharge and the hydraulic gradient are greatest west of the cities, this area is contributing the greatest amount of recharge to the area of pumping. Transmissibility is assumed to be uniform in the area. The cone of depression, therefore, is most evident south of the area of pumpage, where the hydraulic gradient toward the cities is very flat (pl. 4). If pumpage were increased in the Neenah-Menasha area to the extent that the area affected by pumpage would expand to the ground-water divides, the divides would move outward and actually increase the size of the recharge area. Induced recharge or leakage from Lake Winnebago and Little Lake Butte des Morts probably prevents rapid expansion of the cone of depression to the north and east.

If average annual recharge is about 3 inches (probably a conservative estimate), recharge to the Neenah-Menasha area is about 2.3 billion gallons per year. Total pumpage in the area in 1962 was estimated at about 1.4 billion gallons per year, or 3.8 mgd (million gallons per day). Because most of the ground water moves toward the center of pumping, there is little ground-water discharge to streams in the Neenah-Menasha area.

Recharge to the Oshkosh area, including the Winnebago State and County Hospitals, is derived from an area of about 49 square miles (pl. 4). The area is bounded approximately by the major ground-water divide about 5 miles west of the center of pumping, a minor divide about 5 miles north of the pumping center, a divide about 2 miles east of the pumping center and underlying Lake Winnebago, and a divide about 3 miles south of the center of pumping. If annual recharge to the aquifer is 3 inches over this area, the recharge amounts to about 2.6 billion gallons per year. Annual pumpage in the area is estimated at about 0.5 billion gallons (1.4 mgd).

The depression in the piezometric surface at Oshkosh is much shallower than in the Neenah-Menasha area because pumpage in Oshkosh is much less than that in the Neenah-Menasha area. Because the area of recharge and the hydraulic gradient are greatest west and southwest of Oshkosh (pl. 4), this area is contributing the greatest amount of recharge to the area of pumping. Some induced recharge from Lake Winnebago and the Fox River also probably reaches the aquifer in the Oshkosh area. This induced recharge reduces streamflow in the Oshkosh area; however, the amount is small compared to the flow of the Fox River and probably is not measureable.

FOX RIVER GROUND-WATER DRAINAGE AREA

The Fox River ground-water drainage area, lying between the two major ground-water divides, covers the central and southwestern part of Winnebago County (pl. 4). The sandstones of Cambrian age, the Prairie du Chien Group, the St. Peter Sandstone, and the Platteville-Galena unit all are exposed at the bedrock surface in this area (pl. 1). Generally, the two dolomite units are under water-table conditions. The bedrock is overlain by glacial material that generally ranges in thickness from 20 feet in the highland areas to 120 feet in the lowland areas (pl. 2). Artesian conditions prevail in the thick section of the drift aquifer along the upper Fox River and surrounding Lake Butte des Morts. Many of the wells in these areas are flowing, the artesian head being maintained by recharge from the highlands adjacent to the river and Lake Butte des Morts.

Minor divides separate the movement of ground water toward several streams, Rush Lake, the upper Fox River, and Lake Butte des Morts; however, the general pattern of movement is from the major ground-water divides toward the upper Fox River and Lake Butte des Morts. Ground water from Fond du Lac and Green Lake Counties enters the southwestern part of Winnebago County and contributes to the ground-water runoff to the upper Fox River and Rush Lake. This ground-water movement is greatest in areas where the gradient is steep, such as in the extreme southwestern corner of the county, and is least where the gradient is flat, such as in the Rush Lake and upper Fox River areas.

Ground water is discharged artificially from the Fox River ground-water drainage area by municipal pumpage at Omro and Winneconne, by domestic pumpage from private wells, and by flowing wells along the Fox River and Lake Butte des Morts. Discharge from wells is very small compared to ground-water discharge to the streams.

Natural ground-water discharge from the basin is to the Fox River, Lake Butte des Morts, Rush Lake, and the several small streams in the area. The discharge of ground water by evapotranspiration is quantitatively important in the extensive wetlands where the water table is at or very near the land surface.

Wetlands may be either recharge or discharge areas for ground water. In the spring, when the water table is at or very near the land surface, ground water is discharged to streams from the wetlands, and recharge is rejected because of the saturated soil conditions. Ground water is rapidly discharged from the wetlands by evapotranspiration during the warm summer months. The water table declines during this period and, because the soil is no longer saturated at the land surface, recharge can take place.

WOLF RIVER GROUND-WATER DRAINAGE AREA

The Wolf River ground-water drainage area in Winnebago County extends from the northern and western borders of the county to the major ground-water divide (pl. 4). The sandstones of Cambrian age are exposed at the bedrock surface over most of the area but the Prairie du Chien Group, St. Peter Sandstone, and Platteville-Galena unit form the bedrock along the divide (pl. 1). The bedrock is overlain by glacial deposits generally ranging from 20 feet at the divide (fig. 4) to 300 feet along the Wolf River and Lake Poygan (Wi-20/14/16–136).

The sandstones of Cambrian age receive recharge through the dolomite units, which are generally under water-table conditions along the ground-water divide. Recharge also probably occurs by leakage through the thick section of glacial material in the area. However, about 15 to 20 percent of the land surface is covered by wetlands (estimate from Wisconsin Conserv. Dept., 1962) where recharge is rejected for at least part of the year.

Ground water is entering the county as underflow along the northern and western border of the county. Ground water is moving toward the Wolf River and Lake Poygan from near the western edge of Waushara County (Summers, 1965, fig. 8) and from 3 to 4 miles north of the Winnebago-Outagamie-Waupaca Counties line (Berkstresser, 1964, fig. 9; LeRoux, 1957, pl. 5). This underflow moves into the county along the western border between Pumpkinseed Creek and the Waupaca County line (pl. 4) and along the northern border between the Wolf River and the Rat River. The rate of underflow was estimated by the use of Darcy's law (Ferris and others, 1962, p. 71) to be 2 to 3 mgd. However, the complexity of the geology and the scarcity of data in the area make this figure very approximate.

Ground water in the Wolf River basin moves from the recharge areas toward the Wolf, Arrowhead, and Rat Rivers and Lakes Poygan and Winneconne, which are the discharge areas of the basin. Evapotranspiration is a quantitatively important means of ground-water discharge because of the extensive wetland areas adjacent to the lakes and rivers.

The only pumpage in the basin is for domestic and farm use. However, numerous uncapped flowing wells throughout most of the area greatly increase the artificial discharge.

WATER-LEVEL FLUCTUATIONS AND THEIR SIGNIFICANCE

Water-level fluctuations in wells in Winnebago County indicate changes in storage in the ground-water reservoir. The ground-water reservoir is similar to a large tank or surface reservoir in that water levels fluctuate in response to changes in recharge to and discharge from the reservoir. When recharge exceeds discharge, storage increases and water levels rise. When discharge exceeds recharge, storage decreases and water levels fall. However, unlike the water level of a surface reservoir, ground-water levels may rise in one part as they fall in another part of the same reservoir.

Variations in the amount of recharge to the aquifer in Winnebago County are the result of areal and short- and long-term changes in rainfall, of variable evapotranspiration rates during the year and from year to year because of changes in air temperature and plant growth, and of changes in soil conditions including frost in the ground and moisture content of the soil. Artificial changes, caused by pumping of wells and draining of wetlands, also may affect recharge.

Major changes in the amount of discharge from the aquifer are generally the result of pumping, but natural discharge also varies in direct relation to the amount of recharge that enters the aquifer.

Seasonal changes in recharge generally cause an annual cycle of water-level fluctuations. Water levels rise in the spring because low evapotranspiration rates and saturated soil allow a high percentage of water from spring rains and snowmelt to soak into the ground and recharge the aquifer. Water levels decline through the summer because most of the rain water is returned to the atmosphere by evaporation and transpiration or is retained in the soil zone and is not available for recharge. Water levels may rise slightly in the fall because of reduced evapotranspiration after the first frost kills plant life.

Water levels decline through the winter because frost in the ground prevents recharge. Annual water-level fluctuations in four wells in Winnebago County (Wi–20/15/19–129, Wi–19/16/19–168, Wi–18/14/28–235, and Wi–17/16/25–287), unaffected by pumping are shown in figure 7. The amplitude of the water-level fluctuations was not the same in the four wells because wells Wi–19/16/19–168 and Wi–18/14/28–235 (having the greatest fluctuations) are near local ground-water divides, whereas wells Wi–20/15/19–129 and Wi–17/16/25–287 (having the least fluctuations) are near discharge areas. Water levels were higher in 1962 than in 1963 because rainfall was greater in 1962. However, each of the four wells shows an annual cycle of fluctuations.

Long-term changes in water levels, resulting from changes in rainfall and effects of pumping, are shown by the hydrograph of Wi–20/17/20–1 from 1946 to 1962 (fig. 8). Total pumpage in the Neenah-Menasha area and cumulative departure from normal precipitation at Oshkosh from 1888 to 1962 for the same period also are shown. Cumulative departure from normal precipitation is the algebraic sum of the differences between average monthly precipitation determined for the total period of record and the actual monthly precipitation. The trend of the water level in well Wi–20/17/20–1 approximates that of precipitation, both declining from 1946 to 1950 and from 1955 to 1959, rising or leveling off from 1959 to 1962, and declining in 1963. However, water levels rose or leveled off in the period 1950 to 1955 while precipitation continued to decline. This rise in water levels may have been caused by a decrease in pumping. Pumping effects can be seen in the period 1956 to 1963, when water levels generally declined during periods of increased pumping and rose during periods of decreased pumping.

Water levels in the Neenah-Menasha and Oshkosh areas have been lowered by a concentration of industrial pumping (pl. 4). Water levels in the Neenah-Menasha area in 1915 were reported to be at or near the land surface (Weidman and Schultz, 1915, p. 683), but by 1963 they were 110 to 120 feet below the land surface. Pumping has lowered water levels in the Oshkosh area 25 to 30 feet below the 1915 level. This lowering of water levels by pumping is caused by a reduction of the artesian pressure in the area, not by a dewatering of the aquifer. Inasmuch as the sandstone aquifer is still saturated with water, present drawdowns are not excessive, and abundant supplies of water are still available from the 600-foot-thick aquifer.

The hydrograph of well Wi–20/17/15–17 (fig. 7) shows the effects of pumping in the Neenah-Menasha area during 1962–63. Because a large percentage of the ground water is used for industrial cooling,

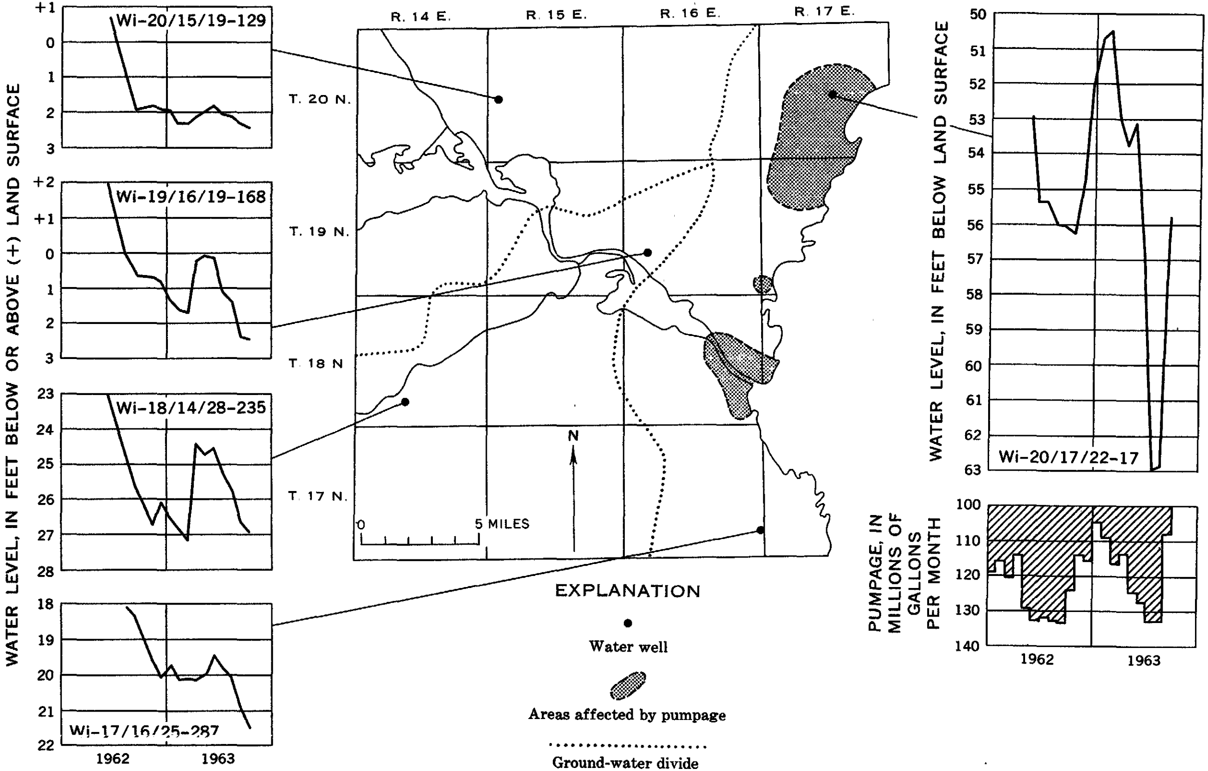

FIGURE 7.—Wells in Winnebago County showing water-level fluctuations in areas unaffected by pumpage, and water-level fluctuations and pumpage in the Neenah-Menasha area, 1962–63.

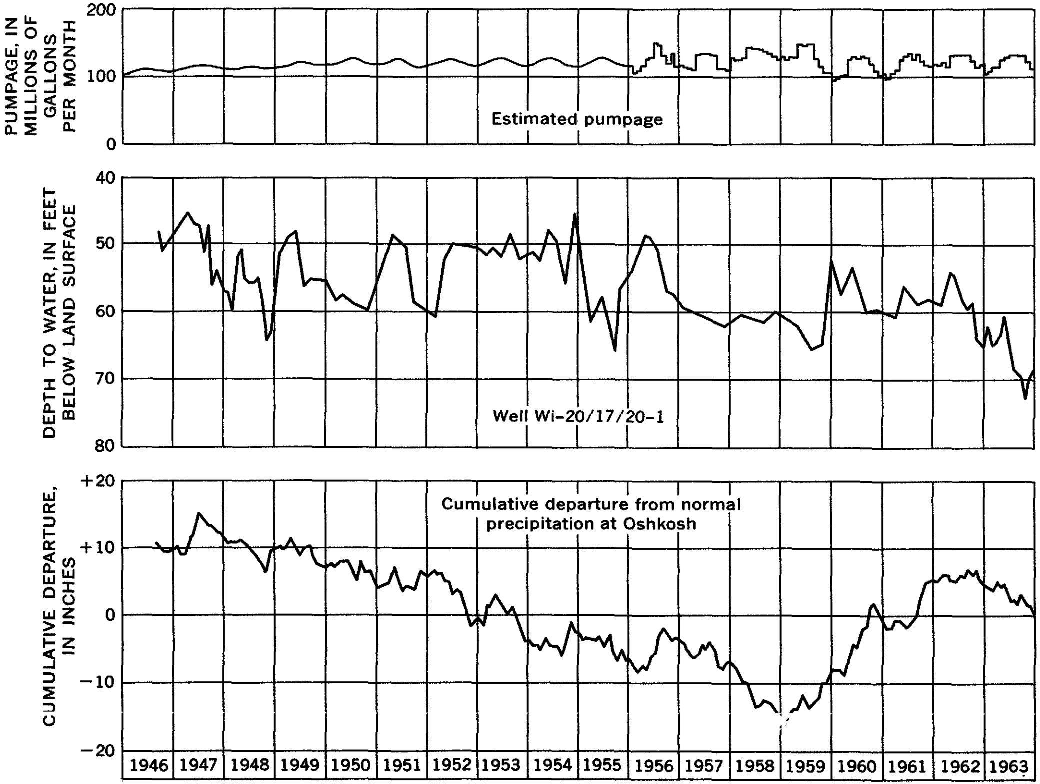

FIGURE 8.—Well Wi-20/17/20-1, estimated pumpage in the Neenah-Menasha area, and cumulative departure from normal precipitation, 1946–63.

pumping is generally greatest in the summer. The water level declined sharply from May to October when pumping was greatest and rose during the fall and early winter months as pumping decreased. Pumping and a decrease in rainfall in 1963 caused a greater decline in water levels than in the previous year.

The many flowing and pumped domestic wells in the remainder of the county and the municipal wells at Omro and Winneconne probably have lowered the water levels only slightly. A well at Omro was reported in 1915 to have a head of 17 feet above the Fox River (Weidman and Schultz, 1915, p. 629). A head of 4 feet above land surface or 8 to 10 feet above the river was measured in Wi–18/15/17–30 in 1963. The many flowing wells recently drilled for cottages and houses surrounding Lake Poygan and the Wolf River have lowered the piezometric surface slightly in these areas, but older records are not available for comparison.

In general, those wells unaffected by pumping that are located in the highland or recharge areas, near ground-water divides, have water levels that are deeper and tend to fluctuate more than water levels in those wells located in the lowland or discharge areas near rivers and lakes.

Because the piezometric surface in Winnebago County fluctuates continuously and unequally in different areas, the configuration of the surface changes continuously. Ground-water divides are not stationary but shift in response to changes in recharge and discharge and the cones of depression created by pumping become deeper or shallower in response to changes in pumping (fig. 7). However, over a long period of time, the average recharge and natural discharge from the ground-water reservoir remains fairly constant, and the general configuration of the piezometric surface does not change except in response to major changes in pumping.

Water-level measurements in wells used to construct the piezometric map (pl. 4) were made between July 29 and August 4, 1963. Precipitation was deficient in the county for about 9 months before the time of the measurements, and water levels probably were below normal when the measurements were made. Above-normal temperatures were recorded in June and July 1963; consequently, pumpage was above normal and the cones of depression at Oshkosh and Neenah-Menasha were deeper than normal, as indicated by the hydrograph of Wi–20/17/22–17 (fig. 7).

QUALITY OF GROUND WATER

The quality of ground water in Winnebago County is generally good; however, it is very hard and locally high in iron, and saline water occurs in the sandstone aquifer on the eastern edge of the county.

Dissolved mineral constituents in ground water are derived from the soil and rocks with which the water comes into contact as it moves into and through the aquifer. The concentration depends on the solubility of the rocks, the solvent, and the length of time that the water is in contact with the rocks. Dissolved mineral constituents in ground water, therefore, may become highly concentrated in areas of the aquifer in which the movement of water through the aquifer is retarded, such as in areas having low permeability or in the area of impermeable Precambrian mounds.

The source and significance of dissolved mineral constituents and properties of water are summarized in table 4. Where applicable, limits recommended for drinking water by the U.S. Public Health Service (1962) are listed. Water containing dissolved mineral constituents above the recommended limits is not necessarily harmful or unusable for all purposes and actually may be suitable for many purposes.

Partial chemical analysis of water from 49 wells, most of which penetrate the sandstones of Cambrian and Ordovician ages, are listed in table 5.

Ground water in Winnebago County ranges from moderately hard to very hard. In the saline-water area in the eastern part of the county, hardness ranges from 600 to 2,200 ppm, increasing from west to east. Ground water in the northwestern corner of the county is only moderately hard as indicated by samples from three wells that ranged from 64 to 110 ppm. In the remainder of the county ground water is very hard, ranging from 200 to 600 ppm.

The concentration of iron in ground water in the sandstones of Cambrian and Ordovician ages generally is high throughout Winnebago County. Analyses of 49 samples averaged 1.6 ppm of iron and ranged from 0.02 to 10 ppm. The map showing distribution of iron in ground water (fig. 9) indicates that concentrations generally are greatest along the ground-water divide west of Neenah-Menasha in Winnebago County. High concentrations of iron also are generally associated with areas of fairly slow moving water and marsh deposits. The progressive eastward increase of iron in ground water along the eastern side of the county is associated with the saline-water zone and is caused by restricted ground-water movement.

Although iron is a problem in the county, it is not detrimental to health, and it is fairly easy to remove by precipitation, filtration, or aeration. Staining of plumbing fixtures and reduction of the efficiency of wells caused by precipitation of iron in well screens, pump bowls, pipes, and other areas of turbulance cause the greatest problems where the ground water has a high concentration of iron.

TABLE 4.—*Significance of dissolved mineral constituents and properties of water*

Constituent or property	Source or cause	Significance
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown sediment. More than about 0.3 ppm stains laundry and utensils reddish brown. Objectionable for food processing, beverages, ice manufacture, brewing, and other processes. Federal drinking-water standards state that iron should not exceed 0.3 ppm. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Manganese (Mn)	Dissolved from some rocks and soils. Not so common as iron. Large quantities often associated with high iron content and with acid waters.	Same objectionable features as iron. Causes dark brown or black stain. Federal drinking-water standards recommend that manganese should not exceed 0.05 ppm.
Calcium (Ca) and magnesium (Mg).	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see "Hardness"). Water low in calcium and magnesium desired in electroplating, tanning, and dyeing and in textile manufacturing.
Sodium (Na) and potassium (K).	Dissolved from practically all rocks and soils. Found also in sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers, and a high sodium ratio may limit the use of water for irrigation.
Bicarbonate (HCO_3) and carbonate (CO_3).	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot-water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium they cause carbonate hardness.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Usually present in mine waters and in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in the brewing process. Federal drinking-water standards recommend that the sulfate content should not exceed 250 ppm.
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage; found in large amounts in sea water and industrial brines.	In large amounts in combination with sodium gives salty taste to drinking water. In large quantities increases the corrosiveness of water. Federal drinking-water standards recommend that the chloride content should not exceed 250 ppm.
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	Federal drinking-water standards recommend that the dissolved solids should not exceed 500 ppm. Water containing more than 1,000 ppm of dissolved solids is unsuitable for many purposes.
Hardness as $CaCO_3$.	In most water nearly all the hardness is due to calcium and magnesium, dissolved from soils, dolomite, and limestone.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called noncarbonate hardness. Water of hardness up to 60 ppm is considered soft; 61–120 ppm, moderately hard; 121–200 ppm, hard; more than 200 ppm, very hard.
Hydrogen-ion concentration (pH).	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline water may also attack metals.
Temperature	----------	Affects usefulness of water for many purposes. For most uses, a water of uniformly low temperature is desired. Shallow wells show some seasonal fluctuations in water temperature. Ground water from depths over 60 feet usually is nearly constant in temperature, which is near the mean annual air temperature of the area.

Manganese is present in only minor quantities and is not a problem in Winnebago County.

Saline water underlies the eastern edge of Winnebago County, including Neenah-Menasha and Oshkosh, and is part of a large saline-water area, described by Ryling (1961), which includes parts of Brown, Outagamie, Calumet, Fond du Lac, and Dodge Counties. Saline water, as defined by Ryling, contains more than 250 ppm sulfate or chloride, or more than 1,000 ppm total dissolved solids. In Winnebago County, only sulfate and dissolved solids exceed these limits, but other dissolved mineral constituents generally are slightly higher in the saline-water area than in other parts of the county (table 5). The saline-water area is the result of the retardation of ground-water movement through the aquifer by Precambrian mounds east and south of Winnebago County.

Dissolved solids in ground water in Winnebago County range between 200 and 400 ppm over most of the county, but are as high as 1,700 ppm in the saline-water area (fig. 10). The concentration of dissolved solids in the saline area increases from west to east towards Lake Winnebago. Dissolved solids in water in Winnebago County are made up largely of sulfate, calcium, and magnesium, especially in the saline-water area in the eastern part of the county.

The concentration of sulfate in ground water is very high in the saline-water area, but generally is low in other parts of the county. Concentrations range from about 100 to 900 ppm in the saline-water area and increase from west to east as shown in figure 11. Sulfate concentration in other parts of the county generally range from about 10 to 100 ppm.

Concentrations of sodium, potassium, and chloride in ground water are low in Winnebago County. Chloride ranges from about 2 to about 100 ppm, well below the recommended upper limit of 250 ppm. Sodium and potassium range from about 2 to 64 ppm. These constituents have only slightly higher concentrations in the saline-water area than in other parts of the county.

The temperature of ground water generally is nearly constant and is slightly higher than the mean annual air temperature. Recorded ground-water temperatures in Winnebago County ranged between 49° and 54°F. The temperature of water from shallow wells may vary slightly with seasonal changes in air temperature, but water from deep wells has a more uniform temperature and generally is slightly warmer than water from shallow wells. The constant low temperature of ground water makes it an excellent source for cooling water and for other purposes.

TABLE 5.—*Chemical analyses of ground water from selected wells in Winnebago County*

[Results, except for pH, in parts per million. Agency making analysis: USGS, U.S. Geological Survey; WSLH, Wisconsin State Laboratory of Hygiene; OFSC, Oshkosh Filter and Softener Co., Oshkosh, Wis.; Siebel, J. E. Siebel Sons Co., Chicago, Ill.; Nalco, Nalco Chemical Co., Chicago, Ill. Principal water-bearing formation: Opg, Platteville-Galena unit; Osp, St. Peter Sandstone; Ꞓss, sandstones of Cambrian age]

Well	Owner	Date of collection	Depth of well (feet)	Agency making analysis	Principal water-bearing formation	Water temperature (°F)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids	Hardness as $CaCO_3$: Carbonate	Hardness as $CaCO_3$: Noncarbonate	pH
Wi-17/14/ 8- 60	Koro Creamery	8- 6-63	300	USGS	Ꞓss	53.5	0.2	---	---	---	5.4	385	32	11	353	354	38	7.5
30-328	Orville Retzlaff	8- 6-63	184	USGS	Osp	52	.5	---	---	---	5.5	308	59	7	343	319	66	7.5
15/21-309	Utica Center School	8- 6-63	265	USGS	Ꞓss	53	1.2	---	---	---	4.3	380	27	5	324	334	22	7.5
16/15-528	State Highway Commission of Wisconsin	8- 7-63	180	USGS	Opg	49	.47	---	---	---	22	328	8	6	274	235	0	7.5
25-287	Eugene Wiechman	8- 6-63	400	USGS	Ꞓss	51	4.1	---	---	---	8.1	244	184	3	500	372	172	7.6
30-299	Carl Berger	8- 6-63	90	USGS	Osp	52	.18	---	---	---	14	428	163	34	622	528	177	7.3
17/17-286	Society of Jesuits	8-20-63	300	USGS	Ꞓss	---	1.8	---	---	---	64	238	114	100	556	326	131	7.4
28-289	R. H. Lippold	8-20-63	176	USGS	Osp	---	1.5	---	---	---	18	152	145	10	370	252	127	7.7
18/14/ 3-225	Lyle Coats	8- 6-63	120	USGS	Ꞓss	52	.07	---	---	---	14	528	72	12	526	512	79	7.4
28-384	Joe Miller	8- 6-63	54	USGS	Ꞓss	53	1.2	---	---	---	4.6	390	26	3	325	332	12	7.6
15/ 1-260	A. H. March	8- 7-63	170	USGS	Ꞓss	52	2.8	---	---	---	13	355	52	14	384	333	42	7.4
17- 5	City of Omro	4-23-45	202	WSLH	Ꞓss	---	.2	0.2	56	34	---	386	15	7	316	340	---	7.6
35-263	Plainview School	8- 6-63	200	USGS	Osp	52	3.8	---	---	---	12	380	8	1	284	290	0	7.5
16/14-356	Rockwell Standard Corp	10- 1-62	630	WSLH	Ꞓss	---	.9	---	---	---	---	176	---	---	---	220	---	7.4
22-275	William Wietz	8- 7-63	330	USGS	Ꞓss	53	1.0	---	---	---	13	266	50	5	298	242	24	7.5
24-366	Guernsey Dairy Co	6-23-55	210	OFSC	Osp	---	.06	---	---	---	---	---	---	45	---	260	---	---
-382	Oshkosh Gas Co	8-23-39	268	---	Ꞓss	---	---	---	92	43	16	357	114	29	497	406	---	---
25- 41	Oshkosh Brewing Co	7-29-55	516	Siebel	Ꞓss	---	.02	---	---	84	---	368	109	19	412	307	160	---
19/14/13-214	Charles Hanke	7-23-63	110	USGS	Ꞓss	49	.4	---	---	---	9.7	382	9	2	286	298	0	7.5
18-219	Clarence Keller	7-23-63	120	USGS	Ꞓss	---	1.5	---	---	---	8.7	425	19	7	346	350	2	7.4
15/ 1-147	Elmer Raehl	8- 7-63	200	USGS	Ꞓss	52	.35	---	---	---	3.2	418	13	4	355	348	5	7.3
3-150	Clarence Perry	8- 7-63	78	USGS	Ꞓss	53	2.5	---	---	---	6.6	390	9	2	[illegible]	312	0	3.0
21- 34	Village of Winneconne	11-14-47	[illegible]	WSLH	Ꞓss	---	.05	.08	81	41	---	444	14	8	368	355	---	7.3
16/ 1- 23	Concord Cheese Co	5-22-62	306	USGS	Ꞓss	51	.6	---	75	66	---	405	118	68	604	459	127	7.9
19-168	Emil Schmoker	6-15-62	217	USGS	Ꞓss	49	10.0	---	81	32	---	414	13	1	347	334	0	7.4
36- 61	Winnebago County Hospital.	12- 4-59	625	WSLH	Ꞓss	---	.4	0	105	37	---	366	12	9	514	408	---	7.6

17/ 7-109	Baer Brothers	5-22-62	124	USGS	Opg	49.5	.8		75	20		252	95	4	378	269	62	8.1
9-178	John Wrase	8-20-63	140	USGS	Osp		.77				4.8	405	51	4.0	400	375	42	7.3
31- 39	Winnebago State Hospital.	1- 7-63	716	Nalco	Ꞓss		1.6	0	238	18	36	222	375	60	910	670		7.8
20/14/16-136	F. Lange	6-15-62	363	USGS	Ꞓss		.2		18	5		126	16	2	130	64	0	8.0
17-134	Richard Krenke	6-15-62	302	USGS	Ꞓss	55	.4		27	10		154	11	2	147	109	0	7.8
31-139	Robert Monsted	6-15-62	307	USGS	Ꞓss	52	.8		45	24		278	15	8	256	211	0	7.4
15/15-116	Elan Lee	8- 7-63	86	USGS	Ꞓss	51.5	1.1				3.2	365	14	2	303	302	2	7.7
19-120	Alfred Zellmer	6-15-62	275	USGS	Ꞓss	52	.06					170	17	10		110	0	8.0
16/ 2- 92	Charles Luedtke	5-22-62	355	USGS	Ꞓss		9.0		69	36		370	18	2	312	320	17	7.9
3- 93	Winagamie Golf Course	7-26-63	235	USGS	Ꞓss		4.6				2.2	362	48	2	340	339	42	7.9
15-111	Frank Roblee, Sr.	5-24-62	160	USGS	Osp	50	.9		75	44		402	34	12	383	368	38	8.0
23- 25	Ridgeway Country Club	5-22-62	595	USGS	Ꞓss		5		62	53		445	31	5	405	373	8	8.1
17/ 1- 45	Hoffman Shopping Center.	5-22-62	590	USGS	Ꞓss	50	3.2		234	39		290	498	4.0	1,010	745	508	7.8
2- 18	Banta Publishing Co.	7-26-63	320	USGS	Ꞓss	49	1.4				14	390	245	4.0	688	556	236	7.3
3- 7	Wisconsin Rendering Co.	5-22-62	365	USGS	Ꞓss	49.5	.7		64	34		305	45	15	345	300	50	8.0
16- 62	J.W. Hewitt Machine Co.	5-22-62	660	USGS	Ꞓss	54	.4		143	35		317	254	4	652	502	241	8.0
20- 1	Oak Hill Cemetery	5-22-62	340	USGS	Ꞓss	52.5	.8		139	35		285	265	4	648	491	258	7.9
21- 11	Kimberly Clark Corp.	5-22-62	665	USGS	Ꞓss	52	1.2		207	40		320	414	8	882	682	419	7.5
22- 16	Marathon Co.	7-22-63		USGS	Ꞓss	54	1.8				14	330	698	10	1,360	988	717	7.2
56	Bergstrom Paper Co.	7-26-63	595	USGS	Ꞓss	52	1.0				14	295	956	7	1,710	1,220	978	7.1
28- 59	Galloway Milk Co.	5-22-62	600	USGS	Ꞓss	51	1.0		340	34		277	758	8	1,380	989	762	7.6

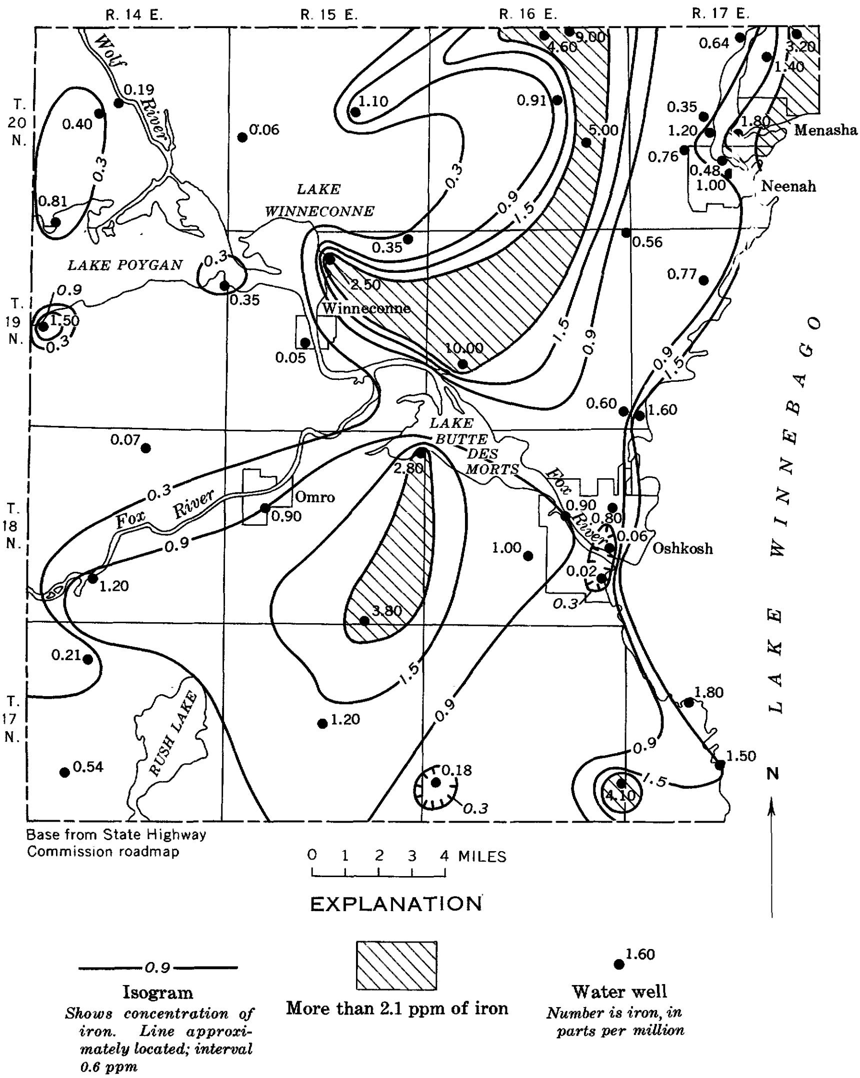

FIGURE 9.—Distribution of iron in ground water in the sandstone aquifer, Winnebago County.

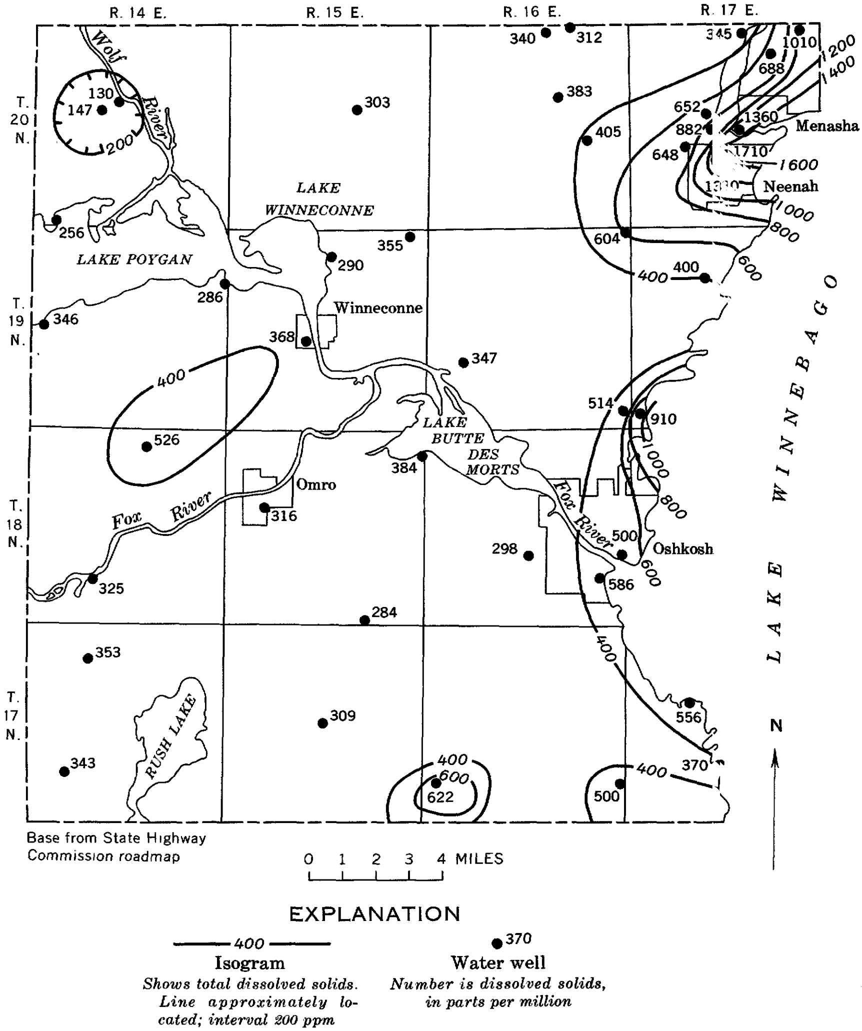

FIGURE 10.—Distribution of dissolved solids in ground water in the sandstone aquifer, Winnebago County.

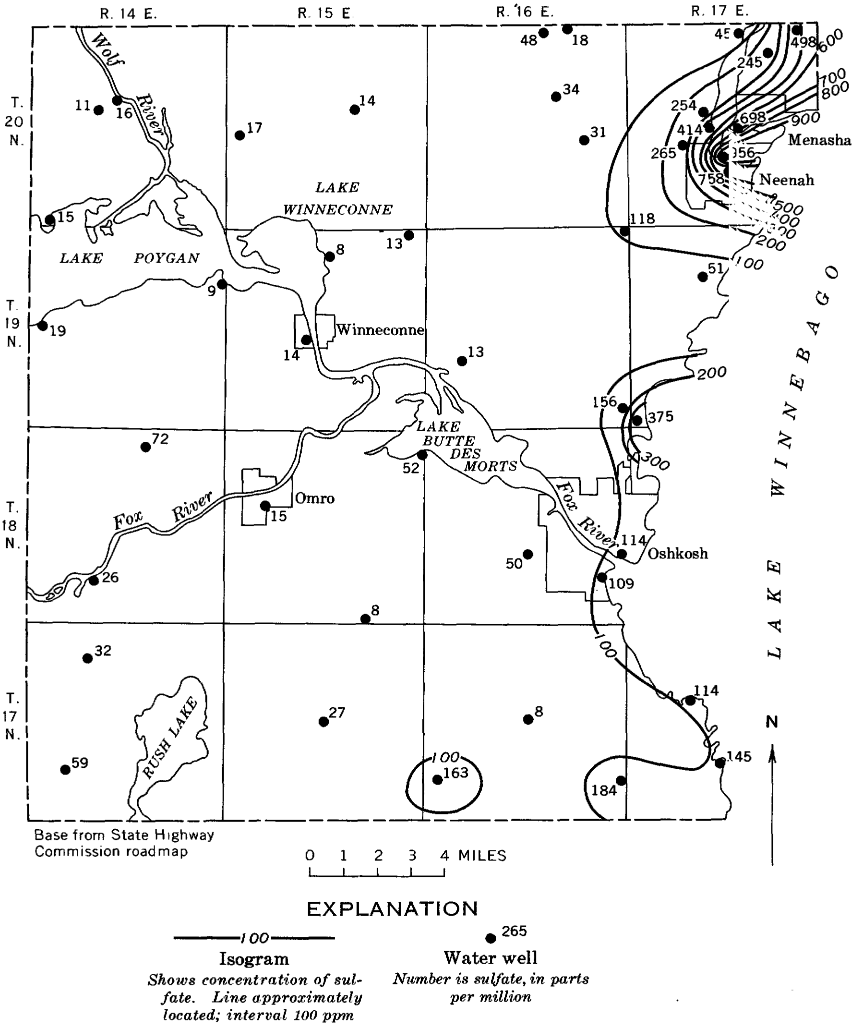

FIGURE 11.—Distribution of sulfate in ground water in the sandstone aquifer, Winnebago County.

AVAILABILITY AND USE OF WATER

Winnebago County has abundant and readily available supplies of ground and surface water for nearly all anticipated uses. The supplies are not uniformly available in all areas, however, and may vary with time and man's use.

The availability of surface water is dependent upon the storage of water in the Lake Winnebago Pool, the inflow to the pool from the Wolf and upper Fox Rivers, and the outflow of the pool to the lower

Fox River. The greatest inflow to the pool is from the Wolf River; measured at New London, the inflow is about 1,200 cfs (cubic feet per second) during 50 percent or more of the time (fig. 12). The Fox River contributes about 840 cfs (measured at Berlin) during 50 percent or more of the time (fig. 12). The outflow from the pool, measured at the Rapide Croche Dam on the lower Fox River, is about 3,750 cfs during 50 percent or more of the time (fig. 12). Assuming that the flow of the Fox River at Rapide Croche Dam for the period 1918–54 is representative of the long-term flow, the flow-duration curve can be used to estimate the future availability of water from the Lake Winnebago Pool. For example, discharge from the pool, measured at Rapide Croche Dam, equaled or exceeded about 1,200 cfs during 95 percent of the time.

Surface water is not readily available in areas distant from the Lake Winnebago Pool because of the scarcity of lakes and the small flow of streams.

Estimated quantities of ground water available to wells in Winnebago County range from about 10 gpm to about 1,000 gpm (fig. 13). In places where the sand and gravel layers in the drift aquifer are thick, the sand and gravel generally yield as much as 50 gpm to wells.

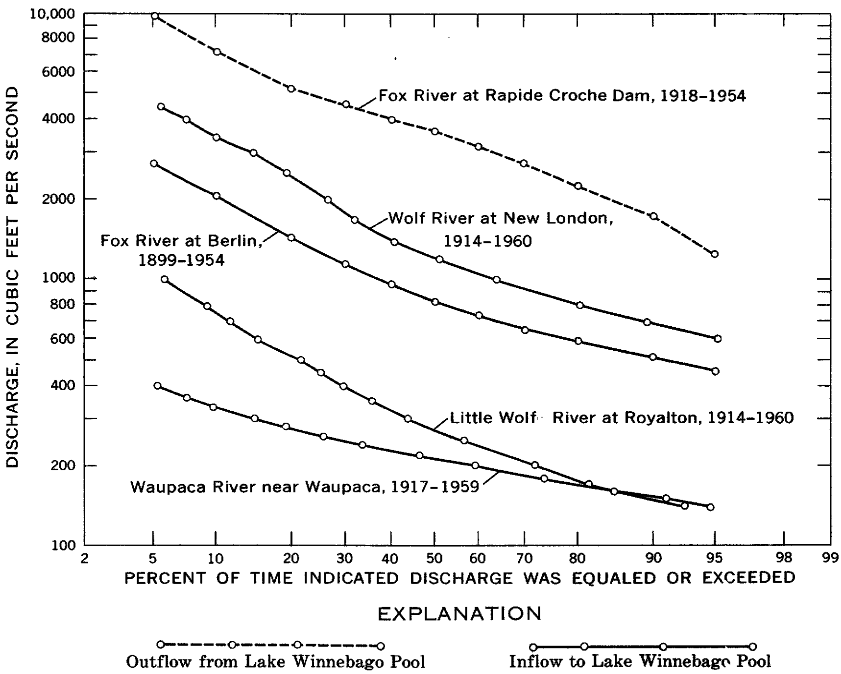

Figure 12.—Duration curves of daily flow of major streams flowing into and out of the Lake Winnebago Pool.

The Platteville-Galena unit also yields as much as 50 gpm, but the yields may be greater in areas where the dolomite is highly fractured. The sandstone aquifer probably yields as much as 1,000 gpm to fully-penetrating wells in places where the aquifer is of sufficient thickness.

The total use of water in Winnebago County from both surface- and ground-water sources was estimated to be 53.6 mgd in 1962. Surface water from Lake Winnebago and the Fox River supplied the domestic needs of about 72 percent of the people in Winnebago County and provided an estimated 77 percent of the water used for all purposes. Ground water supplied the remaining 23 percent of the total water used in the county; however, because of its countywide availability, it is the principal source of water to communities other than Neenah, Menasha, and Oshkosh, to many industries, and for rural domestic and stock use.

A summary of the estimated use of surface water in 1962 for various purposes in municipal areas and in the remainder of the county is shown in table 6. The two largest users are the municipal powerplant of Menasha, which diverts large quantities of water for cooling purposes, and the combined pulp and paper industry in Neenah and Menasha, which uses water for processing, cooling and air conditioning, and sanitary purposes. Municipal supply for Neenah, Menasha, and Oshkosh, the three principal cities in the county, is the third largest user of surface water.

The municipal use of water in Neenah, Menasha, and Oshkosh has increased from about 7.5 mgd in 1950 to 11.3 mgd in 1960 because of increased population and an increased use of municipal water by industries. If municipal pumpage increases at the same rate, it will amount to about 27 mgd by the year 2000.

Most of the large quantities of water pumped out of Lake Winnebago and the Fox River for municipal and industrial use is returned to the surface-water bodies, but with some alteration of chemical quality and an increase in temperature. The temperature of discharged surface water used for cooling purposes by the powerplant at Menasha is raised as much as 18°F, depending on the time of year. Surface water pumped for municipal use is returned as treated sewage effluent. Water used by the pulp and paper industry also is returned to the Fox River as treated effluent.

The average daily use of ground water for all purposes in Winnebago County in 1962 is estimated at about 9 mgd (table 6). Ground water is used for public supply in the city of Omro, the village of Winneconne, the Winnebago State and County Hospitals, all rural schools and churches, and a shopping center. Industrial use of ground water includes condenser cooling, washing and processing, boiler use,

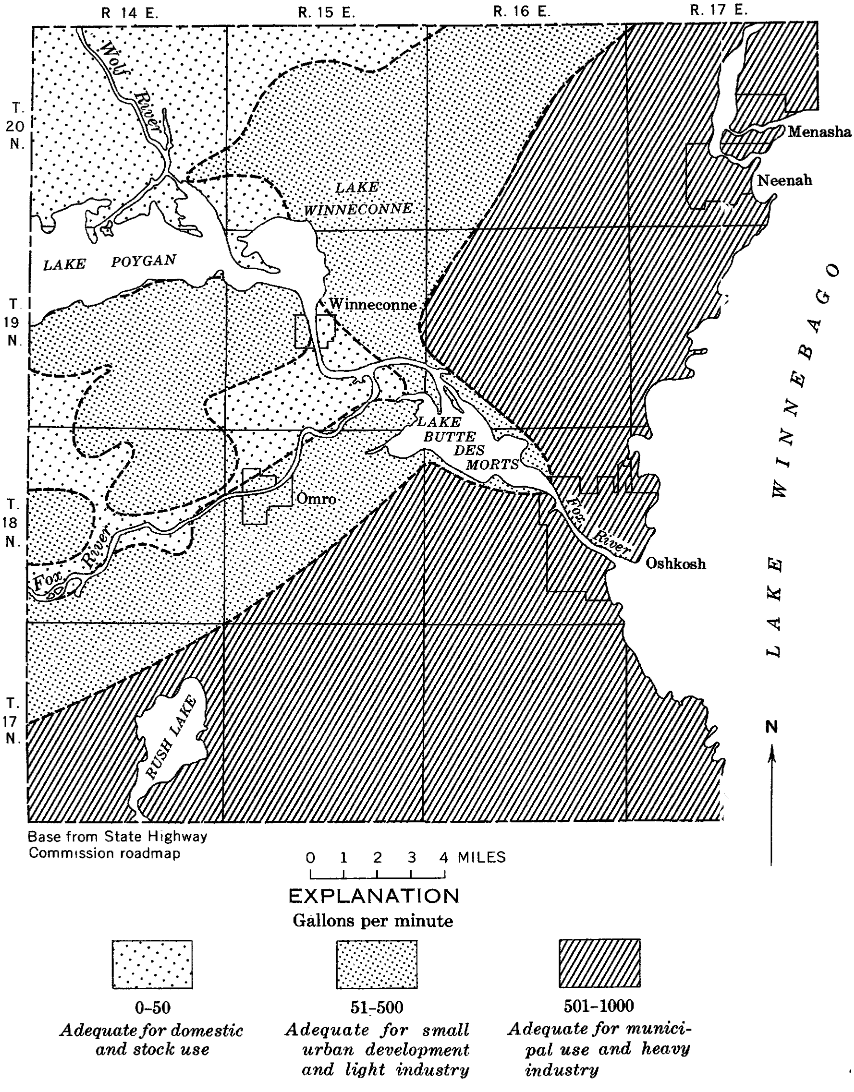

FIGURE 13.—Estimated availability of ground water, Winnebago County.

brewing, and air conditioning. The largest user of ground water in the county is the pulp and paper industry. Ground water is used for rural domestic and stock-watering purposes and a small amount is used for lawn irrigation by several golf courses and cemeteries.

The greatest use of ground water is in Neenah and Menasha with a total pumpage of nearly 4 mgd in 1962, or about 44 percent of the total estimated amount used in the county. The use of ground water in Oshkosh was about 0.9 mgd, or about 10 percent of the total ground water used in the county.

TABLE 6.—*Estimated average daily use of water in Winnebago County, 1962*

[Excludes power generation]

Type of use	Amount of use by area (mgd)						Total use
	Neenah	Mena-sha	Oshkosh	Omro	Winne-conne	Other	
Public supply							
Municipal:							
Ground water	0.0	0.0	0.0	0.2	0.1	0.0	0.3
Surface water	3.5	4.6	4.2	.0	.0	.0	12.3
Other:							
Ground water	.0	.0	.0	.0	.0	.4	.4
Surface water	.0	.0	.0	.0	.0	.0	.0
Total public supply	3.5	4.6	4.2	.2	.1	.4	13.0
Industrial							
Pulp and paper manufacture:							
Ground water	2.1	1.2	.0	.0	.0	.0	3.3
Surface water	9.9	7.8	.0	.0	.0	.0	17.7
Other manufacturing:							
Ground water	.0	.0	.5	.0	.0	.3	.8
Surface water	.1	.1	.1	.0	.0	.0	.3
Dairy products processing:							
Ground water	.4	.0	.1	.1	.2	.3	1.1
Food processing:							
Ground water	.0	.0	.0	.0	.0	.1	.1
Brewing and malting:							
Ground water	.0	.0	.2	.0	.0	.0	.2
Air conditioning:							
Ground water	.2	.0	.1	.0	.0	.0	.3
Cooling in electrical power production:							
Surface water	.0	14.4	.0	.0	.0	.0	14.4
Total industrial	12.7	23.5	1.0	.1	.2	.7	38.2
Rural							
Domestic (total nonurban use):							
Ground water							1.4
Farm livestock:							
Ground water							1.0
Total rural							2.4
Total use							53.6

Over the period 1953 to 1962, for which some pumpage records are available, the industrial use of ground water increased only slightly both in the county and in the Neenah-Menasha and Oshkosh areas. The muncipal use of ground water by the city of Omro and the village of Winneconne increased by about 30 percent and 230 percent, respectively, over the same period. Population figures indicate an increase of about 19.5 percent in the rural population between 1950 and 1960 (U.S. Dept. Commerce, 1960). Rural use of ground water probably increased a corresponding amount during this period.

The amount of water lost by consumptive use, principally by evaporation, in Winnebago County is difficult to determine because of the many contributing factors. However, the following estimates of consumptive use generally can be applied for planning purposes. About 10 percent of the water pumped for municipal supply is lost by evaporation from steam boilers, lawn irrigation, and other miscellaneous uses (Wirth, 1959, p. 33). Water withdrawn for all industrial consumptive uses is about 2 percent (MacKichan and Kammerer, 1961, p. 17). Consumptive use of water by the pulp and paper industry is estimated at only about 1 percent (Wirth, 1959, p. 33).

The recreational use of the extensive lakes and rivers in Winnebago County cannot be overlooked because of its importance to local residents and to tourists, but a detailed analysis of such use is beyond the scope of this report. Quantitative data and recommendations for recreational use of water in Winnebago County are available from the Wisconsin Department of Resource Development.

PRESENT AND ANTICIPATED WATER PROBLEMS

Water problems in any area generally can be listed under the following headings: (1) Supply in relation to demand, (2) distribution, (3) natural quality, (4) manmade pollution, (5) variability, and (6) floods. Consideration of these problems in Winnebago County is given in the following discussion.

SUPPLY IN RELATION TO DEMAND

Winnebago County is fortunate in having an abundant supply of both ground and surface water. Total recharge to the ground-water reservoirs greatly exceeds local pumpage throughout the county, even during periods of scanty rainfall. If pumpage increases at a normal rate in the future, there is little danger of seriously depleting the ground-water supply for a long period of time. A problem of declining water levels in wells may arise in local areas of high demand if well spacing is inadequate. Interference between closely spaced wells could seriously reduce the efficiency of individual wells.

Surface water in the county also greatly exceeds the amount presently used. Although streamflow may be seriously diminished during periods of drought, water is retained in the county by storage in the Lake Winnebago Pool, and part of this water is available for use. The generally nonconsumptive uses of surface water also permit the water to be reused for other purposes. If surface-water use increases at a normal rate, a shortage of supply is not anticipated in the near future, except possibly during periods of severe drought.

DISTRIBUTION

Ground and surface water are fairly well distributed throughout Winnebago County, and for most of the area major distribtuion problems do not exist and are not expected to arise in the near future.

Numerous lakes and streams make surface water readily available over about two-thirds of the county, and extensive aquifers make ground water available over most of the county. However, surface water is not readily available from about one-third of the county. The sandstone aquifer is fairly thin, and only small to moderate quantities of water are available in the preglacial buried channels in the northwestern part of the county and in the upper Fox River valley (pl. 1).

NATURAL QUALITY

The principal water-quality problems in Winnebago County are algae and hardness in surface water and iron, hardness, and salinity in ground water.

Growth of algae in the shallow Lake Winnebago Pool during the summer creates serious aesthetic and treatment problems. Hardness is generally only a minor problem, but for some uses the water must be treated.

Dissolved iron in ground water occurs over a large part of the county, and saline ground water occurs on the eastern side of the county. However, the water still is usable for many purposes, and treatment can make the water usable for almost all purposes. Pumping at Neenah-Menasha, the Winnebago State and County Hospitals, and Oshkosh has locally reversed the natural movement of ground water. This westward movement of water has created the possibility that highly mineralized water from the saline-water zone may move toward the areas of pumping and eventually may contaminate the sandstone aquifer locally.

The sulfate content in ground water apparently has increased gradually since before 1934 in wells in the city of Neenah, and also has increased since 1957 in wells at the Winnebago State Hospital (table 7). This increase may be related to a westward migration of saline water because of pumping. However, additional analyses are needed over a period of time to prove this conclusion. Other constituents in ground water in these pumping areas and at Oshkosh remained constant during the same period (table 7).

MANMADE POLLUTION

Pollution of surface water in Winnebago County is a minor and local problem at present, but may be expected to increase in the future. Streamflow generally is sufficient to dilute sewage and industrial wastes that are discharged into the Fox and Wolf Rivers before they enter the county, and to dilute wastes that are discharged to the Lake Winnebago Pool within the county. Sewage and other organic wastes

TABLE 7.—*Chemical analyses of ground water at Neenah, Oshkosh, and the Winnebago State Hospital showing changes in chemical quality*

[All values in parts per million]

Well	Owner	Date of collection	Iron (Fe)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids	Hardness as $CaCO_3$
Wi-20/17/27-28	City of Neenah	Pre-1934	2.2	305	892	11	1,639	940
20/17/28-59	Galloway Milk Co., Neenah.	1963	1.0	277	956	8	1,380	1,751
Unknown	Peoples Brewing Co., Oshkosh.	Pre-1934	1.0	331				319
Wi-18/16/25-41	do	1955	.02	307	109	19	412	467
Unknown	Rockwell Standard Corp., Oshkosh.	Pre-1934	2.4	280				254
Wi-18/16/14-356	do	1962	.9	176				220
19/17/31-37	Winnebago State Hospital.	1957	.9	370	268		964	645
	do	1958	.9	273				608
	do	1961		266	330		740	600
19/17/31-39	do	1957	.9	236	310		1,002	674
	do	1958	.7	297				540
	do	1963	1.6	222	375		910	670

discharged to streams consume oxygen and provide nutrients which promote the growth of algae. Chemical wastes discharged to streams may locally render the water unsuitable for ordinary uses. Expanding industries and cities with inadequate and overtaxed sewage and waste-disposal systems should take care not to pollute surface water in the Fox and Wolf River basins.

Pollution of ground water is a potential problem in areas of Winnebago County where dolomite of the Platteville-Galena unit or of the Prairie du Chien Group crops out or is overlain by only a thin layer of unconsolidated deposits. Because ground water moves through solutionally enlarged joints, fractures, bedding planes, and other large openings in dolomite, there is very little purification of water in the formation. Impurities introduced into the formation, may be carried for long distances and pollute large areas. Flushing of a polluted aquifer requires a great length of time before the ground water is usable.

Polluted water from a defective private sewage system in a dolomite area could enter shallow wells that are open in the formation. Dumping of rubbish and industrial wastes in dolomite quarries or highly permeable sand and gravel pits overlying dolomite also is a potential cause of ground-water pollution in shallow wells.

A potential ground-water pollution problem exists in a large area of the Lake Winnebago drainage area (p. 28), especially near Neenah-Menasha. The area is underlain by dolomite of the Platteville-Galena unit (pl. 1) and the glacial drift is thin over a large part of the area (fig. 4). The potential for pollution would be increased in this area by development that did not include proper methods of waste treatment and disposal. A potential pollution problem also exists along the escarpment of the Prairie du Chien Group in the western and central parts of the county (pl. 1, fig. 4).

Casing off all or a large part of the dolomite and drilling into underlying sandstone is the best method to prevent polluted water from entering wells in the dolomite areas. Well owners also should have their well water checked periodically for bacteriological content to insure that the aquifer has not become polluted.

Sand and gravel layers and lenses in the drift aquifer generally are not subject to pollution, because in most places they are overlain by thick deposits of clay and silt. However, if these sand and gravel layers occur near, or crop out at, the land surface, they are susceptible to pollution as a result of improper waste treatment and disposal. Pollutants introduced into a sand and gravel layer generally travel only short distances before they are filtered out, but wells close to the source of pollution may become polluted. Salt used on roads and man-made organic compounds, such as gasoline or pesticides, may travel much greater distances because they do not break down readily and are not filtered out by the aquifer. This type of pollution has not been reported, but these pollutants can be carried into the drift aquifer and make the water unusable for long periods of time.

The presence of detergent or ABS (alkyl benzene sulfonate) in ground water has not been reported and does not appear to be a current problem in Winnebago County. The source of ABS in ground water generally is from private sewage systems. It is recommended that ABS in drinking water should be limited to 0.5 ppm because higher concentrations may cause undesirable taste and foaming (U.S. Public Health Service, 1962, p. 24). The presence of ABS in water from a well indicates that the water may contain other harmful pollutants from sewage systems. The presence of ABS in water may be indicated by foaming when a sample of water is shaken in a small bottle.

Pollution of ground water in the sandstones of Cambrian and Ordovician ages is unlikely because of the filtering properties of sandstone and the thickness of overlying material through which recharge must travel to reach the artesian aquifer. Pollutants may enter the sandstone through wells that are inadequately sealed at the surface or through dolomite that is exposed or near the surface.

VARIABILITY

Variability refers to the changes that can occur in the county in the amount of streamflow and the amount of ground water in storage. Generally, variability is not a problem in Winnebago County because of the control on the surface water (Lake Winnebago Pool) and the large amount of water available from the ground-water reservoirs.

FLOODS

Flooding is not a major problem in Winnebago County because of the reservoir control and storage of the Lake Winnebago Pool. Flooding of minor streams is not a current problem because of the low density of population and agricultural use of land.

SUGGESTIONS FOR DEVELOPMENT OF WATER RESOURCES

In the next several decades an expanding economy will place greater demands on the water resources of Winnebago County. Because this expanding economy depends on the availability of large supplies of good-quality water, the water resources of the county should be developed in an orderly and efficient manner. To choose the best possible method of developing and using water, water managers need to formulate comprehensive plans for use and management of ground and surface water and to consider the effects of water development on all aspects of the local economy. The following suggested methods of development may be useful to water managers in the county for planning purposes.

GROUND-WATER DEVELOPMENT

Ground-water development in Winnebago County is expanding and is expected to continue expanding in the future. This development will be influenced by surface-water use, by distance of water transportation, by relative costs, and by water quality.

In developing a ground-water supply, water levels decline around a center of pumping, and pumping lifts are increased. The greatest decline in water levels would be in areas where heavily pumped wells are very closely spaced. A good development plan should have wells spaced at distances that will minimize increased pumping lifts due to well interference without overly increasing the costs of connecting or transmitting lines. Consequently, estimates of well discharged, well spacing, and pumping lifts should be made when selecting new well sites. The well discharge for a new well generally may be estimated from the specific-capacty data for other wells in the area. Before a new well is drilled in an area where little or no information on the aquifer is available, a test well should be drilled and pumped to determine yield.

Estimation of the optimum spacing between a new well and existing well or between wells in a new well field should be based on computation of well interference for different well spacings for an assumed period and rate of pumping. Such estimates may be made from the Theis nonequilibrium formula, the coefficients of transmissibility and storage for the aquifer being determined by aquifer tests or other methods. Such computations for wells tapping the sandstone aquifer in eastern Winnebago County are shown by figures 14 and 15. These curves show the amount of interference that will occur in 1 month, 1 year, and 5 years at 100 to 20,000 feet from a well pumping continuously at a rate of 500 gpm (fig. 14) and the interference that will occur at any time between 10 and 4,000 days at 1,000, 10,000, and 20,000 feet from a well pumping continuously at rate of 500 gpm (fig. 15). For example, the drawdown in a well spaced 1,000 feet from another well pumping at a rate of 500 gpm for 30 days would be about 20 feet, whereas the drawdown in a well spaced 10,000 feet from the pumping well would be about 6 feet (fig. 14). After 2,000 days, or about 5½ years of pumping, drawdown in the well spaced at 1,000 feet would be about 33 feet compared to about 18 feet in a well spaced at 10,000 feet from the pumped well.

Water-level declines for any rate of pumping can be determined from the curves by the direct proportionality of drawdown to the rate of pumping. For example, if the rate of pumping is 300 gpm instead of 500 gpm, water-level decline will be 0.6 of that shown on the curve. The interference that will occur from more than one pumping well is the sum of the interference of all wells.

In most places in Winnebago County, the beds confining water in the sandstone aquifer only impede or retard the vertical movement of water; water in the confining beds, in the overlying alluvium, and from surface water moves downward in response to the lowered piezometric head around a pumping well. Although the rate of movement of this water, called vertical leakage, is probably small, large quantities of water may be contributed to the aquifer over a long period of time. More work is required to determine the amount of water that is contributed to the aquifer by leakage. The curves in figures 14 and 15 are based on the assumption that all water pumped is withdrawn from storage and are not adjusted for recharge to the aquifer. The drawdowns shown by the curves are greater than those which actually would occur.

Additional wells in the Neenah-Menasha and Oshkosh areas should be located as far as feasible from the center of the cones of depression beneath the cities to reduce interference from other pumping wells. Because recharge to the cones of depression is greatest from the west at Neenah-Menasha and from the west and southwest at Oshkosh (pl. 4), dispersal of wells in these directions would be more effective in reducing water-level declines than dispersal in any other direction. Locating wells close to surface-water bodies might induce recharge and reduce water-level declines.

Periodic water-level measurements in wells tapping the sandstone aquifer, especially in the Neenah-Menasha and Oshkosh areas, are necessary for determining water-level trends and predicting the decline of water level that will result from additional development. All pumpage from high-capacity wells should be metered and correlated with changes in water levels.

Because highly mineralized water may be moving toward the centers of pumping on the eastern edge of the county, new sandstone-aquifer wells should be located as far to the west as is practical, to decrease the possibility of tapping this saline water. The quality of water from wells in this area should be monitored to detect saline-water migration. If there is a migration of saline water, the monitoring program would aid in its control.

SUPPLEMENTAL USE OF GROUND WATER WITH SURFACE WATER

Surface water is used extensively in Winnebago County for municipal and industrial purposes, and the present supply is far in excess of demand. Surface water is an excellent source of supply during most of the year; however, it is not readily available in all parts of the county, and high water temperatures and the growth of algae are inherent problems during the summer months. A possible method of helping to alleviate these problems, especially during the summer months, is the supplemental use of ground water from a network of adequately spaced wells. Ground water generally does not need the expensive treatment required for surface water. The supplemental use of ground water would reduce the amount of treatment required for algae and would lower the temperature of water.

Comparison of costs of installation, operation, and maintenance of a surface-water system with costs of a ground-water system is beyond the scope of this report, but the various factors should be evaluated to determine the most economical system to use. Generally, installation costs for a ground-water system are considerably less than for a surface-water system, but other costs may be comparable. Considering costs, the year round supplementing of present surface-water facilities with ground water should be considered as a means of expanding present municipal water-supply systems.

Emergency supplies of water can be obtained from ground-water systems in the event of a natural or manmade disaster, whereby surface-water sources might become unusable. The ground-water supplies should be safe, at least for the period of time needed for decontamination of surface water. Existing high-capacity wells in Winnebago County, a large percentage of which are shown on plate 1, should provide adequate water for emergency use. A ground-water system supplementing a municipal surface-water supply also would provide an emergency source of water.

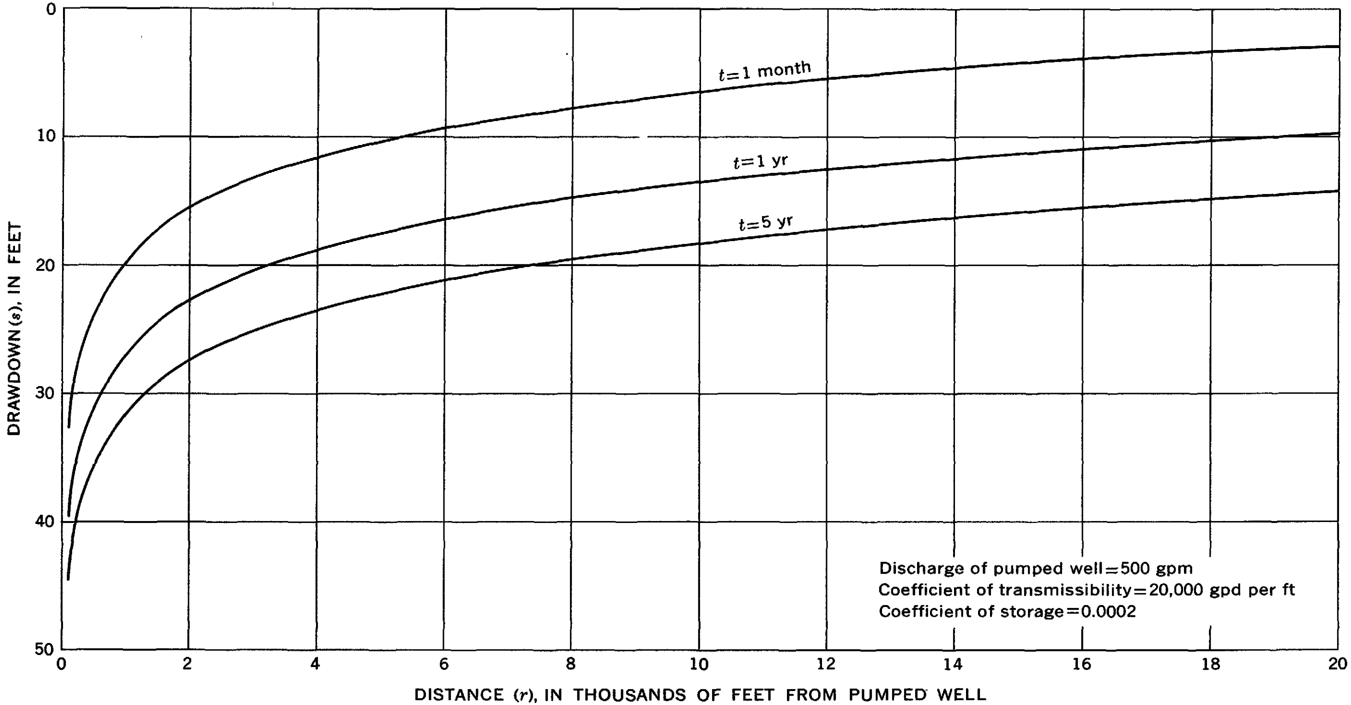

FIGURE 14.—Theoretical distance-drawdown curves for an infinite aquifer, based on coefficients of transmissibility and storage determined for the sandstone aquifer at the Winnebago State and County Hospitals.

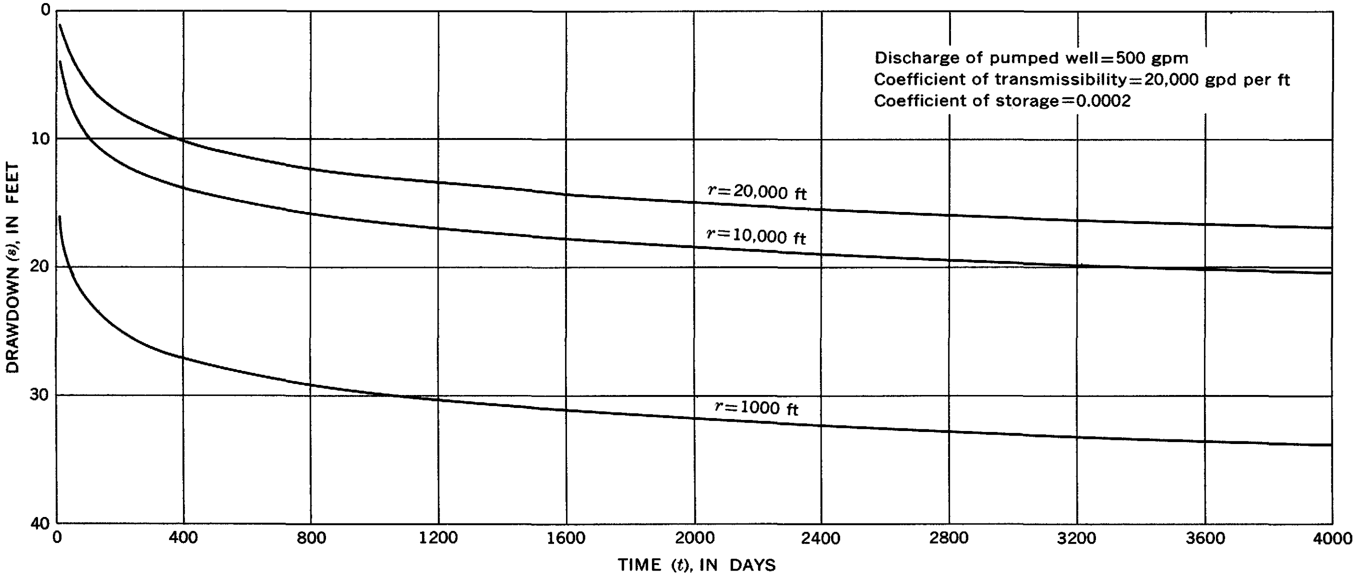

Figure 15.—Theoretical time-drawdown curves for an infinite aquifer, based on coefficient of transmissibility and storage determined for the sandstone aquifer at the Winnebago State and County Hospitals.

LAKE MICHIGAN AS A SOURCE OF SUPPLY

Water from Lake Michigan, about 45 miles east of Neenah-Menasha, could be transported into Winnebago County by pipeline and would provide an abundant water supply for many years. Water from Lake Michigan is colder and less mineralized than water from the Fox River and algae are not a serious problem. Although developing and transporting Lake Michigan water to this area would be costly, such a development might be economical if a sufficient number of communities and industries were included in the system. Because of the high cost of development, local sources of surface and ground water should be carefully evaluated before Lake Michigan is considered as a source of supply.

CONCLUSIONS AND RECOMMENDATIONS

Winnebago County has generally good quality ground water and surface water available over most of its area and in quantities that will not limit forseeable development. Water from the Lake Winnebago Pool, which has a storage capacity of 25 billion cubic feet and an average discharge of about 4,190 cfs, is hard, is locally polluted, contains algae during the summer months, and requires treatment, but generally it is suitable for municipal and most industrial uses. Water from the pool ranges in temperature from 32° to 80° F annually.

The sandstone aquifer, present throughout the county, is a dependable source of water for municipal, industrial, and domestic uses. Yields up to 1,000 gpm may be obtained from fully penetrating wells in the eastern and southern parts of the county where the sandstone has a maximum thickness of about 600 feet. The aquifer is confined under artesian pressure by the overlying Platteville-Galena unit and glacial drift. Water from the sandstone aquifer is hard to very hard and contains iron in some places. A saline-water zone, containing dissolved solids in excess of 1,700 ppm and sulfate in excess of 900 ppm, is present on the eastern edge of the county. Mineralization in this zone increases from west to east. In the remainder of the county, water from the sandstone aquifer is of good quality, generally containing 200 to 400 ppm dissolved solids. Temperature of the water ranges from 49° to 54° F.

The Platteville-Galena unit, present, in the eastern and southern parts of the county, yields as much as 50 gpm to wells and is a dependable source of water for domestic and farm uses. The water is hard to very hard but otherwise is of good quality. Pollution is a potential problem because of the poor filtration properties of dolomite and because the unit crops out at the land surface.

A drift-filled preglacial bedrock channel, having a maximum depth of about 300 feet, extends from Waupaca County through the northwestern corner of Winnebago County and into Waushara County, and underlies the Wolf River and Lake Poygan. A preglacial channel also underlies the upper Fox River in Winnebago County. Unconsolidated layers and lenses of sand and gravel in these preglacial channels yield as much as 50 gpm to wells and are dependable aquifers for domestic and farm use. These deposits are confined by clay till and are not subject to pollution. Water from the sand and gravel deposits is generally of good quality and is less mineralized than water from the underlying sandstone aquifer. The quality and temperature of the water remain nearly constant, the temperature ranging from 49° to 54° F.

The total estimated use of water in the county in 1962 was 53.6 mgd, of which 44.7 mgd was supplied from the Lake Winnebago Pool and 8.9 mgd from ground-water sources. Although more surface water than ground water is used in the county, ground water is the principal source of supply for communities other than Neenah, Menasha, and Oshkosh, for many industries, and for all rural domestic and stock use. Industry is the largest user of surface and ground water in the county.

The area of greatest use of ground water in 1962 was Neenah-Menasha, having an estimated annual pumpage of 1.4 billion gallons (3.8 mgd). Pumpage in the Oshkosh area was estimated at 0.5 billion gallons per year (1.4 mgd). Only about 10 percent of the water used for municipal purposes and 1 to 2 percent of the water used for industrial purposes was used consumptively, the remainder being returned to the Lake Winnebago Pool and the lower Fox River.

Pumping of water from the sandstone aquifer has lowered water levels 110 to 120 feet in Neenah-Menasha and 25 to 30 feet in Oshkosh below the reported levels in 1915. Water levels in the remainder of the county are at about the same level as those reported in 1915. The piezometric surface of the sandstone aquifer indicates that ground water is moving toward the Wolf and Fox Rivers and Lake Winnebago from ground-water divides which generally coincide with topographic divides formed by escarpments of the Prairie du Chien Group and Plateville-Galena unit.

Present water problems in the county include the growth of algae and local pollution in the Lake Winnebago Pool, iron in water from the sandstone aquifer over a large part of the county, and saline ground water along the eastern edge of the county. Potential water problems include rapid decline of water levels of interference between closely spaced wells, migration of saline ground water to areas of pumpage in the eastern part of the county, surface-water pollution from inadequately treated sewage and industrial wastes, and pollution of ground water in dolomite aquifers.

Development of the water resources of the county should follow a comprehensive plan which takes into consideration all aspects of water use. The use of ground water to supplement present surface-water supplies would be a fairly inexpensive method to expand water supply at Neenah-Menasha and Oshkosh and to reduce the algae-treatment problems during the summer months. Existing wells and proposed supplementary ground-water supplies would provide adequate emergency sources of water. In the Neenah-Menasha and Oshkosh areas, dispersal of wells toward the west, which is the direction of greatest recharge, would be more effective in reducing water-level declines than dispersal in any other direction and would also decrease the possibility of tapping saline water in the sandstone aquifer. A program of monitoring ground-water levels, pumpage, and quality of water in the Neenah-Menasha area is necessary to insure proper development of the ground-water resources.

An abundant supply of good quality water could be obtained from Lake Michigan by pipeline, but the cost of such an installation probably would require the cooperative use of the water by a number of communities and industries.

REFERENCES

Alden, W. C., 1918, The Quaternary geology of southeastern Wisconsin, with a chapter on the older rock formations: U.S. Geol. Survey Prof. Paper 106, 356 p.

Bean, E. F., 1949, Geologic map of Wisconsin: Wisconsin Geol. and Nat. History Survey.

Berkstresser, C. F., Jr., 1964, Ground-water resources of Waupaca County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1669–U, 38 p.

Birge, E. A., and Juday, C., 1911, The inland lakes of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 22, 259 p.

Drescher, W. J., 1953, Ground-water conditions in artesian aquifers in Brown County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1190, 49 p.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536–E, 174 p.

Knowles, D. B., 1964, Ground-water conditions in the Green Bay area, Wisconsin, 1950–60: U.S. Geol. Survey Water-Supply Paper 1669–J, 37 p.

Knowles, D. B., Dreher, F. C., and Whetstone, G. W., 1964, Water resources of the Green Bay area, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1499–G, 67 p.

LeRoux, E. F., 1957, Geology and ground-water resources of Outagamie County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1421, 57 p.

MacKichan, K. A., and Kammerer, J. C., 1961, Estimated use of water in the United States: U.S. Geol. Survey Circ. 456, 44 p.

Newport, T. G., 1962, Geology and ground-water resources of Fond du Lac County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 16?4, 52 p.

Ryling, R. W., 1961, A preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin: Wisconsin Geol. and Nat. History Survey Inf. Circ. 5, 23 p.

Smith, L. S., 1908, The water powers of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 20, 354 p.

Summers, W. K., 1965, Geology and ground-water resources of Waushara County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1809–B, 32 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519–524.

Thwaites, F. T., 1943, Pleistocene of part of northeastern Wisconsin: Geol. Soc. American Bull., v. 54, p. 87–144.

——— 1957, Buried Precambrian of Wisconsin: Wisconsin Geol. and Nat. History Survey map.

U.S. Army Corps of Engineers, 1922, Survey of Fox River: U.S. 67th Cong., 2d sess., House Doc. 146, 170 p.

U.S. Department of Commerce, 1960, 1960 Census of population, Wisconsin: U.S. Dept. Commerce Bur. Census, Advance Rept., PC(A1)–51, 19 p.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

Weidman, Samuel, and Schultz, H. R., 1915, The underground and surface water supplies of Wisconsin: Wisconsin Geol. and Nat. History Survey Bull. 35, 664 p.

Wirth, H. E., 1959, Water use in Wisconsin: Wisconsin State Board of Health, 36 p.

Wisconsin Conservation Department, 1962, Winnebago County wetlands: Wisconsin Conserv. Dept., Wisconsin Wetland Inventory, 70 p.

Wisconsin Committee on Water Pollution, 1956, Evaluation of stream loading and purification capacity: Wisconsin Comm. on Water Pollution Bull. 101, 110 p.