Geology and Ground-Water Resources of Waushara County, Wisconsin

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1809-B

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

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By W. K. SUMMERS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GEOLOGY AND GROUND-WATER RESOURCES OF WAUSHARA COUNTY, WISCONSIN

By W. K. Summers

ABSTRACT

Abundant ground water for irrigation is available in the outwash deposits in western Waushara County, and many more large-capacity wells can be developed in these deposits without seriously lowering the water level.

Pumping for irrigation temporarily lowers water levels in the vicinity of the wells but has not lowered regional water levels. Pumpage has probably intercepted and utilized some of the recharge that would have been rapidly discharged from the aquifer.

Ground water is continuously being discharged to streams and to the atmosphere by evapotranspiration, but intermittent recharge from precipitation replaces the discharged water. Recharge and discharge are in approximate balance, maintaining about the same amount of ground water in storage. Further recharge to the aquifer is rapidly discharged to streams.

The sandstones, till, and glaciolacustrine deposits in Waushara County generally yield small to moderate amounts of water to wells but do not produce enough water for irrigation; recent alluvium may yield large quantities of water to wells.

In general, the ground water is of good quality, except for hardness and local high-iron concentrations.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of this investigation was to determine the occurrence of ground water in Waushara County, the suitability of the water for development, and the possible effects of irrigation development on the water system. Special consideration is given to the availability and quality of ground water for irrigation.

Studies were made of the geology of the county and of the movement, recharge, discharge, and chemical character of ground water. An inventory of selected wells was made to obtain information on ground-water levels and type of material penetrated. Streamflow measurements were made and evaluated, and water samples from selected wells, springs, and streams were analyzed for chemical content. The location of data-collection sites is shown in plate 1. Estimates were made of the amount of ground water being used, and geologic and piezometric maps were constructed.

The investigation was made by the U.S. Geological Survey in cooperation with the University of Wisconsin Geological and Natural History Survey and was conducted under the immediate supervision of C. L. R. Holt, Jr., district geologist, Ground Water Branch.

GEOGRAPHY

Waushara County is in central Wisconsin (fig. 1) and includes Tps. 18–20 N., Rs. 8–13 E. Wautoma, the county seat, is about 70 miles north of Madison and 85 miles west of Lake Michigan. The county is approximately rectangular. It is about 36 miles long and 18 miles wide and has an area of about 650 square miles.

POPULATION

The population of Waushara County was 13,497 in 1960; nearly all the population live on farms or in towns of less than 2,500 people (U.S. Dept. Commerce, 1960). During the summer, the population is temporarily increased by the influx of tourists, vacationers, and itinerant laborers.

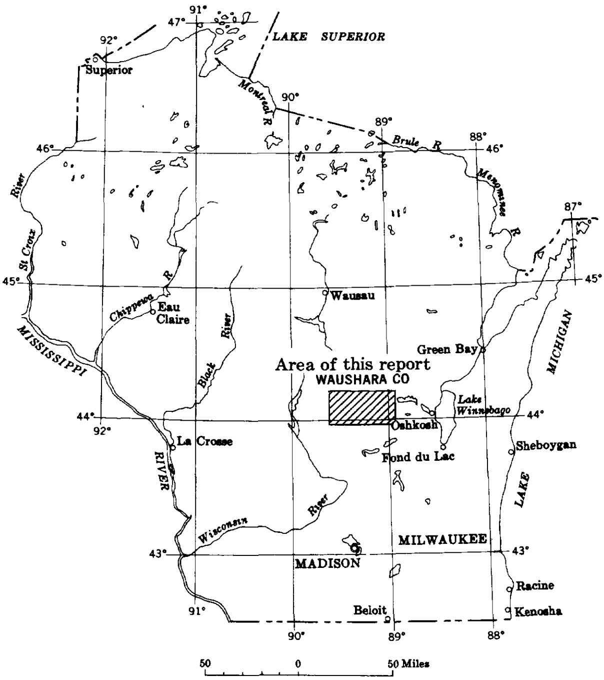

FIGURE 1.—Location of area.

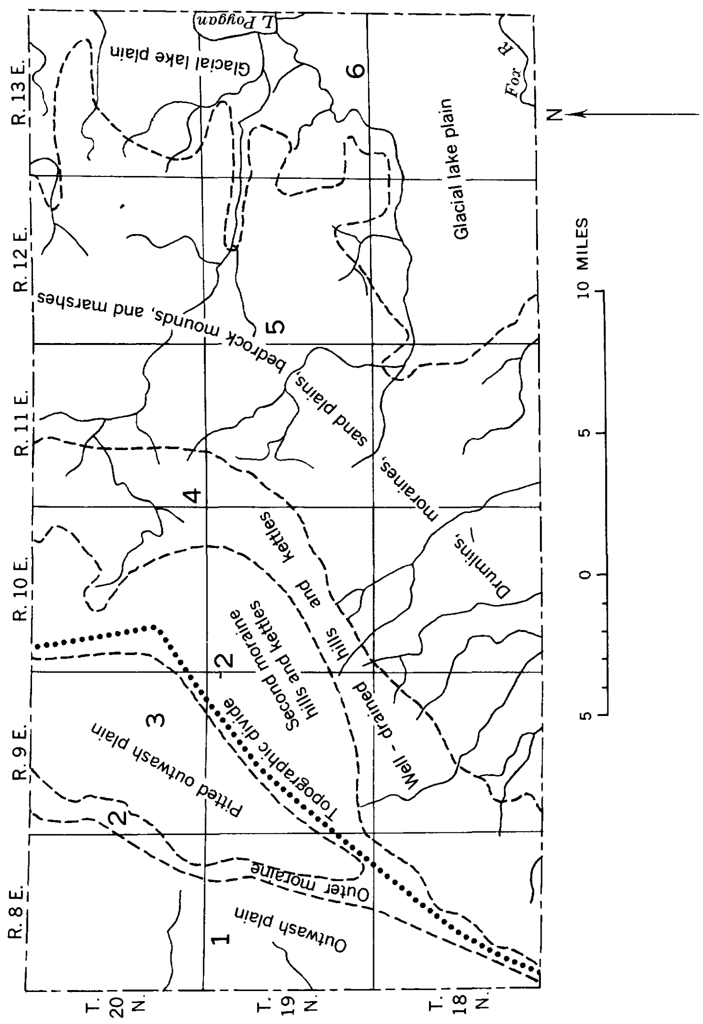

FIGURE 2.—Topographic features of Waushara County, Wis.

TOPOGRAPHY AND DRAINAGE

The streams of Waushara County are part of two major drainage systems, and nearly all of the streams have their headwaters within the county. The streams of western Waushara County are part of the Wisconsin River system; those streams in the eastern part of the county are part of the Fox River system.

For the purposes of this report, Waushara County is divided into six areas, each of which has a characteristic topography (fig. 2).

Area 1 includes an outwash plain in the extreme western part of the county. This area is a broad, flat plain that slopes 10 to 20 feet per mile westward toward the Wisconsin River.

Area 2 includes the Outer and Second moraines (Thwaites, 1943, p. 121 and 125) and is east of the outwash plain. The moraines form two ridges that trend southwestward from the north edge of the county and merge in the area between Hancock and Coloma. The crest of the Second moraine forms a topographic divide between the Wisconsin River basin and the Fox River basin. The maximum altitude of this divide is 1,285 feet above mean sea level, the highest altitude in the county.

Area 3 includes a pitted outwash plain lying between the Outer and Second moraines. In general, the slope of this plain is 10 to 20 feet per mile westward. The pits are broad, shallow depressions less than 10 feet deep, except near Hancock and Plainfield where northwestward-trending chains of elongate kettle holes reach a depth of 100 feet or more. In areas 2 and 3 most of the runoff from precipitation and snowmelt drains into pits and kettles rather than draining into the Fox and Wisconsin Rivers.

Area 4 includes a belt of hills and kettles, 1 to 7 miles wide, lying east of, and roughly parallel to, the Second moraine. The regional slope of this belt is as much as 100 feet per mile eastward. The surface-drainage pattern is well formed, and many tributary streams of the Fox River have their headwaters in this area.

Area 5 includes a belt of drumlins, moraines, sand plains, bedrock mounds, and marshes in the east-central part of the county. The surface-drainage pattern is well formed. The region has a southeastward slope of 5 to 20 feet per mile.

Area 6 includes a glacial lake plain on the east edge of the county. The ancient lake bottom forms a gently rolling plain, and former islands in the ancient lake form low hills. Before drainage ditches were dug, about 70 percent of this area was marsh and swamp. The land surface slopes from 0 to about 5 feet per mile eastward, and the lowest altitude in the county is the surface of Lake Poygan, about 747 feet above mean sea level.

ECONOMIC DEVELOPMENT

Agriculture is the principal source of income in Waushara County. Although dairying was the largest source of farm income in the county in 1959, truck farming of such crops as potatoes, cucumbers, snap beans, and lettuce has grown rapidly and is probably taking over first place, according to the Wisconsin Department of Resource Development (1960). A land-use classification showed that land used for agriculture decreased from about 81 percent in 1950 to about 68 percent in 1959. The better soils, however, are being used more intensively, and irrigation has increased the yield per acre.

The pickle-canning industry has rapidly expanded in recent years and is gaining in commercial importance. Several small factories are also in the county. Marl, sand, gravel, sandstone, and granite are produced. The Wisconsin Conservation Department maintains a trout hatchery near Wild Rose. The tourist industry is important to the economy of the county.

CLIMATE

The climate of Waushara County is typically continental having warm humid summers and cold winters. July is the warmest month and has an average temperature of 72°F; January is the coldest month and has an average temperature of about 17°F. The maximum recorded temperature in the county was 112°F on July 13 and 14, 1936, and the minimum recorded temperature was −43°F on January 31, 1951. The 1931–55 mean annual temperature was 45°F. The growing season averages about 135 days from the middle of May through September.

The average annual precipitation is about 30 inches over most of the county and includes the average annual snowfall, which generally ranges from about 40 inches in the central and western parts of the county to about 45 inches in the northeastern part of the county. About 60 percent of the precipitation occurs from June through September, the heaviest rainfall occurring in June.

PREVIOUS INVESTIGATIONS

Prior to the present investigation, no comprehensive study has been made of both the geology and ground-water resources of Waushara County. Several earlier reports, however, contain specific information on individual aspects of the geology and ground-water resources of the county.

Weidman and Schultz (1915) summarized the general characteristics of ground-water conditions in the county. Chamberlin (1877) described the artesian conditions in the eastern part of the county.

The bedrock geology of the area is shown on the "Geologic Map of Wisconsin" (Bean, 1949), and the "Waushara Granite" is described by

Buckley (1898), Weidman (1898), and Hobbs and Leith (1907). The glacial deposits of the county were studied by Irving (1877) and by Thwaites (1943). Alden (1918) mapped the glacial deposits along the south edge of the county. A soil survey of the county was made by Whitson and others (1913).

Other reports that have been useful to the author are listed in the references at the end of the report.

WELL- AND SPRING-NUMBERING SYSTEM

A three-part system of letters and numbers is used to designate wells and springs in this report (fig. 3). The first part of the well number, "Ws" indicates that the well or spring is in Waushara County. The second part of the well number gives the township designation which is based on the Federal system of land subdivision and consists of the township north of the Wisconsin base line, the range east of the fourth principal meridian, and the section number, respectively. The third part of the well number, the serial number, is assigned in the order that the well or spring was inventoried in the county. Springs are distinguished from wells by the letters "sp" prefixed to the serial number. Because of space limitations, only the serial numbers of wells and springs are shown on the maps in this report.

ACKNOWLEDGMENTS

The success and value of a study such as this depends largely on the cooperation and assistance of many persons. The cooperation of well owners, well drillers, civic officials, and private citizens is gratefully acknowledged.

The author wishes to thank G. F. Hanson, State Geologist, for supplying sample logs prepared by the University of Wisconsin Geological and Natural History Survey. Members of the State Board of Health contributed greatly to the report by giving access to files of well records and pumpage data. Chemical analyses of water samples were made by the State Laboratory of Hygiene and by the Permutit Co.

ROCK UNITS AND THEIR WATER-BEARING CHARACTERISTICS

To evaluate properly the water resources of an area it is first necessary to define the extent and character of the rock framework of the area in which the water occurs. The following sections describe the composition, thickness, and water-bearing characteristics of the rock units that form this framework.

The rock units in Waushara County include crystalline rocks of Precambrian age, sandstone of Cambrian age, and glacial drift and alluvium of Quaternary age. Table 1 summarizes the description and the significant water-bearing characteristics of these rocks.

PRECAMBRIAN ROCKS

Precambrian rocks underlying Waushara County are composed predominantly of granite as indicated by outcrops and rock samples from wells, but other types of igneous and metamorphic rock may be present

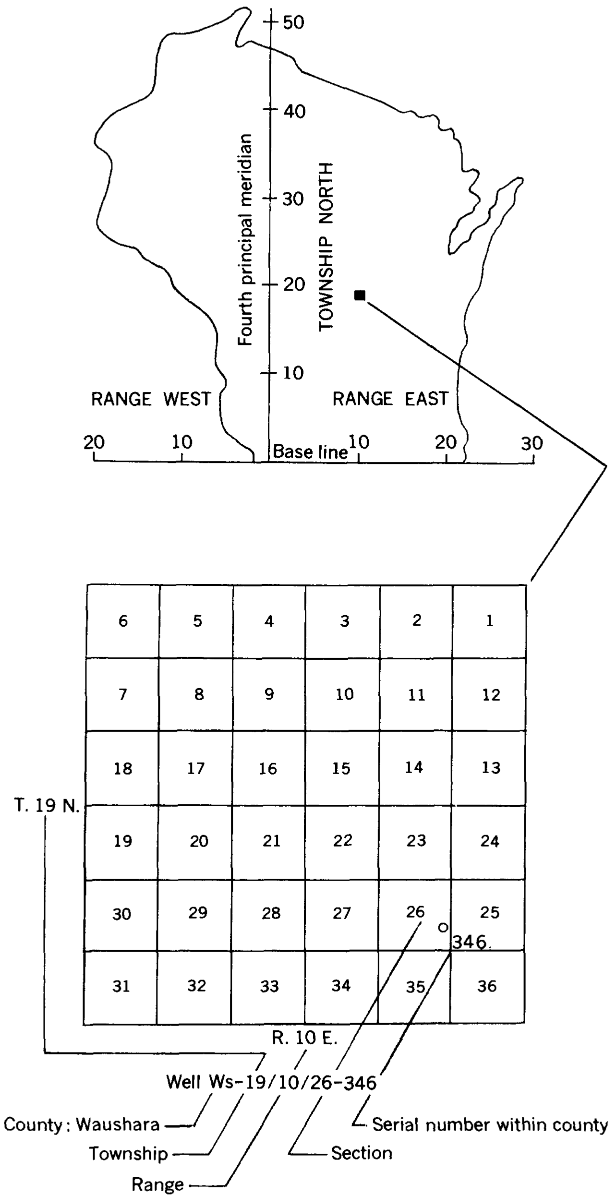

FIGURE 3.—Well-numbering system in Wisconsin.

TABLE 1.—*Rock units and their water-bearing characteristics in Waushara County, Wis.*

Age	Rock unit				Description	Maximum thickness (feet)	Water-bearing charactertics		
							Maximum reported yield (gpm)	Average specific capacity of wells (gpm/ft)	Remarks
Quaternary	Alluvium				Clay, silt, sand, gravel, peat, and marl, sorted and stratified.	20(?)	700		Sand and gravel yield moderate amounts of water to wells. Clay, silt, peat, and marl do not generally yield water to wells.
Quaternary	Glacial drift	Outwash			Sand and gravel, well sorted and stratified.	>154	>1,300	53	Yields large amounts of water to wells.
Quaternary	Glacial drift	Morainal deposits			Sand, gravel, and sandy till, unsorted to sorted, unstratified to stratified.	183	70	2.4	Yield small to moderate amounts of water to wells.
Quaternary	Glacial drift	Intermorainal outwash and till			Sand, gravel, and sandy till, unsorted to sorted, unstratified to stratified.	204	750	10	May yield small to large amounts of water to wells.
Quaternary	Glacial drift	Glaciolacustrine deposits	Sand	Central Waushara County	Sand, fine- to medium-grained, stratified.	<100	420	4	Generally yields 15 to 20 gpm. A well drilled where sand was 100 ft in thickness yielded 420 gpm.
Quaternary	Glacial drift	Glaciolacustrine deposits	Sand	Eastern Waushara County	Sand, fine- to medium-grained, stratified, interbedded with silt.	50	160	3	Generally yields 5 to 20 gpm; larger yields are scarce.
Quaternary	Glacial drift	Glaciolacustrine deposits	Silt		Silt, clay, and clay till stratified, interbedded with sand.	300(?)			Generally not an aquifer. May yield 1–2 gpm to wells.
Quaternary	Glacial drift	Sand and gravel between glaciolacustrine deposits and sandstone			Sand, gravel, and some silt.	100	5	1	Generally not an aquifer. May yield 100 gpm where thick.
Cambrian	Sandstone				Sandstone, fine- to coarse-grained, sorted, stratified, fractured.	280	500	7	Generally yields small to moderate amounts of water to wells.
Precambrian	Crystalline rocks				Hard, massive, igneous, and metamorphic rocks, fractured to unfractured.	Unknown			Generally not an aquifer.

in the county. Weidman (1898, p. 48) described this granite from outcrops near Redgranite where a prominent mound rises above the general Precambrian surface and crops out at the land surface.

The Precambrian rock surface in Waushara County is probably relatively flat containing a general southeastward slope of about 20 feet per mile (Thwaites, 1957).

Only eight wells are recorded that reach the Precambrian surface in Waushara County and five of these wells are in Redgranite. Well Ws–18/8/14–11 penetrated granite at a depth of 380 feet and well Ws–18/13/15–52 at 410 feet. The depth to the Precambrian surface probably is generally less than 400 feet in most of the county.

In general, Precambrian rocks are impermeable, and only a small amount of water exists in fractures in the rock. Therefore, the Precambrian surface forms the lower boundary of the ground-water reservoir in Waushara County. The Precambrian mound near Redgranite may influence the movement of ground water in the saturated sediments above the Precambrian surface.

SANDSTONE OF LATE CAMBRIAN AGE

Sedimentary rocks of late Cambrian age overlie the crystalline rocks of Precambrian age in Waushara County. These sedimentary rocks consist predominantly of fine- to coarse-grained well-sorted quartz sandstones interbedded with a few thin beds of shale, siltstone, and conglomerate. The rocks are poorly to well cemented with quartz, dolomite, and iron oxides. The beds are white, gray, red, pink, or brown. Although these rock units of late Cambrian age can be differentiated into recognized geologic units, they act as a single hydrologic unit. Therefore, in this report, they are treated as a single unit and are referred to as sandstone.

In Waushara County, the sandstone crops out in two areas in T. 19 N., R. 8 E., and in T. 19 N., R. 11 E. (pl. 3).

The sandstone beds dip gently eastward in the eastern part of the county and southward in the southwestern part of the county. The maximum thickness of the observed sandstone in the county was 280 feet in well Ws–18/8/14–11. In general, the sandstone is thickest along the south county line and thinnest along the north county line.

The sandstone contains water in pore spaces and in fractures. Water moves through the sandstone most easily parallel to the bedding. Vertical movement between sandstone beds is restricted by interbedded shale and siltstone.

Relatively high yields were obtained from wells in areas where the sandstone was overlain by sand and gravel. Moderate yields were obtained from wells in areas where the sandstone was overlain by silt. High yields were also obtained in areas where the wells penetrated the thickest sections of sandstone.

BEDROCK SURFACE

The bedrock surface underlying the glacial drift in Waushara County has a relief of about 600 feet and slopes gently southeastward at about 10 to 15 feet per mile (pl. 2). Several mounds of granite rise above the general bedrock surface and crop out near Redgranite, Lohrville, and Mount Morris. A sandstone mound crops out on the west edge of the county. A deep valley cut in the bedrock surface extends from near Lake Poygan southward along the east edge of the county and probably represents a major preglacial drainageway.

QUATERNARY DEPOSITS

GLACIAL DRIFT

The glacial drift of Waushara County is composed of unconsolidated sediments deposited in a variety of landforms and has been considered to be part of the Cary and Valders Stades of the Wisconsin Glaciation (Thwaites, 1943). The drift is more than 250 feet thick in some places in the county. Both the landform and the composition of the drift define the glacial deposits shown on the surficial geologic map of Waushara County (pl. 3). The glacial deposits include the following: Stratified sand and gravel in outwash plains; deposits of sand, gravel, and sandy till found in terminal moraines, drumlins, and other ice-contact forms; deposits of sandy till, grading into well-sorted sand and gravel in the intermorainal plains; deposits of glaciolacustrine sand and clayey silt; buried sand and gravel between the glaciolacustrine deposits and the sandstone.

The glacial drift is partly covered by more recent alluvium. A loess blanket as much as 2 feet in thickness covers the hills.

OUTWASH SAND AND GRAVEL

In this report, outwash is restricted to deposits of sand, gravel, and silt that are extramorainal and that form the two broad flat plains of western Waushara County (pl. 3). These plains cover about 120 square miles in Waushara County and are part of the central sand plain that covers parts of Portage, Wood, and Adams Counties (Drescher, 1956). Some of the outwash gravel, sand, and silt deposited in glacial drainage channels is included with the alluvium because they cannot be differentiated.

The outwash deposits are stratified and generally well sorted. Clay and silt beds, as much as 5 feet thick, occur locally. Grain sizes may differ greatly in adjacent beds, and the average grain size is likely to be larger near the moraine than at some distance from the moraine.

The thickness of the outwash deposits in western Waushara County averages about 100 feet and range from less than 1 foot at the sandstone outcrop in sec. 31, T. 19 N., R. 8 E., to 154 feet in wells Ws-20/9/2-386 and Ws-20/9/24-411. The thickness of outwash is generally least where the bedrock surface has the highest altitude.

The outwash sand and gravel deposits form the most permeable aquifer in the county and generally yield more water to wells than any other rock unit. Most of the irrigation wells in the county obtain water from outwash deposits. Several of these wells have been pumped at rates of as much as 1,300 gpm (gallons per minute). If an average porosity of 30 percent, an area of 120 square miles, and an average depth of 100 feet for the outwash plains is assumed, about 760 billion gallons of ground water are in storage in the outwash plain. Because discharge by natural and artificial means over a long period of time should not exceed natural recharge and because of economic reasons such as increasing costs with increasing pumping lifts, only a relatively small part of the water in storage is available for irrigation, industry, municipal, and domestic development.

MORAINAL DEPOSITS

Morainal deposits are those associated with the terminal moraines, drumlins, and ice-contact forms. Sandy till is the principal material in the terminal moraines and drumlins. The sandy till is a heterogeneous mixture of clay, silt, sand, gravel, and boulders that is unsorted and unstratified; it is deposited directly from glacial ice with little or no washing. The clay content of the till appears to be greatest in the drumlins and moraines of the east half of the county.

The principal ice-contact forms are kames and crevasse fillings, some of which are shown on plate 3. The material in these forms ranges from well-sorted stratified sand and gravel lenses to poorly sorted sandy gravel deposits. The stratified material may have steep dips and crossbedding is common. In some places, ice-contact deposits are overlain by a thin layer of silty, sandy till.

The morainal deposits occur in a very broad northeast-trending belt across the central part of the county (pl. 3). These deposits range from 0 to 183 feet (known maximum) in well Ws-20/11/10-12. Glaciolacustrine sediments partly cover the morainal deposits in the center of the belt.

Morainal deposits are less permeable than outwash because of the higher clay content and poor sorting of till. The maximum reported yield from the morainal deposits was 70 gpm from well Ws-20/11/10-374, which penetrated 111 feet of sand and gravel. Yields of 15 gpm are common.

INTERMORAINAL OUTWASH AND TILL

The glacial drift between the moraines ranges from unsorted sandy till to well-sorted stratified sand and gravel. The greatest reported thickness of these deposits was at well Ws–19/12/29–355, where 204 feet of sand and gravel were penetrated.

The intermorainal deposits are generally more permeable than the morainal deposits and less permeable than the extramorainal outwash sand and gravel. Most wells penetrating this material supply enough water for domestic and stock purposes. At some places, fairly large quantities of water are obtained, as at well Ws–20/11/5–410 which was pumped at the rate of 750 gpm for 10 hours with a drawdown of 40 feet.

GLACIOLACUSTRINE DEPOSITS

Large areas of central and eastern Waushara County are underlain by glaciolacustrine sand and silt (pl. 3) deposited in glacial Lake Oshkosh (Thwaites, 1943, p. 139). These deposits blend with the other glacial deposits, and the boundary between them is indistinct.

The glaciolacustrine deposits in central Waushara County consist predominantly of stratified sand. The sand is well sorted, consisting of either fine-, medium-, or coarse-grained material. It is free of gravel, but may be interbedded with red clayey silt. For example, well Ws–20/10/36–246 penetrated 93 feet of glaciolacustrine deposits—18 feet of silt and clay, 33 feet of fine sand, and 42 feet of medium to coarse sand. Well logs indicate that the total thickness of sand in the glaciolacustrine deposits is generally much less than 100 feet.

Wells in the glaciolacustrine sand in central Waushara County generally yield from 15 to 20 gpm, although one well (Ws–18/9/27–394) was pumped at the rate of 420 gpm for 8 hours. The extensive use of the glaciolacustrine sand as a source of water for homes and farms makes it an important aquifer locally.

The glaciolacustrine deposits in the eastern part of the county consist of beds of sand interbedded with red clay and silt. The glaciolacustrine deposits in well Ws–19/13/34–110 consist of 165 feet of clay, 30 feet of sand, and 5 feet of gravel. Although most of the sand consists of glaciolacustrine sand, some may be outwash sand, alluvial sand, or dune sand. Correlations of sand beds shown on well logs indicate that some beds extend for several miles. Sand beds range from 0 to about 50 feet in thickness, and changes in thickness occur in short distances.

The red clay in the glaciolacustrine deposits is not easily differentiated from a red clay till (Valders till of Thwaites, 1943), and the two units were not differentiated in plate 3.

Many wells tapping the interbedded sands in eastern Waushara County flow at rates ranging from 0.2 to 7.5 gpm, and several wells are reported to have been pumped at 20 gpm or more. One well (Ws–18/12/8–161) was pumped at a rate of 160 gpm. Flowing wells are shown by an appropriate symbol in plate 1, as is the approximate western limit for flowing wells in the glaciolacustrine deposits.

The silt in eastern Waushara County yields sufficient quantities of water for domestic and stock purposes. Larger supplies probably cannot be developed because the permeability of the silt is low and the thickness is irregular.

SAND AND GRAVEL BETWEEN GLACIOLACUSTRINE DEPOSITS AND THE SANDSTONE

Sand and gravel beds which may be proglacial outwash, preglacial alluvium, or interglacial alluvium lie between the glaciolacustrine silt and sandstone. At some places the sand and gravel is well sorted. The thickness of the sand and gravel ranges from about 10 feet where the bedrock is relatively shallow to 100 feet in the buried valleys. Wells Ws–18/13/22–335, Ws–18/13/23–334, Ws–19/13/25–379, Ws–19/13/28–133, Ws–19/13/33–116, Ws–20/12/25–179 and 319, and Ws–20/13/34–189 probably draw water from these sand and gravel beds, and most of these wells yield less than 5 gpm.

ALLUVIUM

The alluvium of Waushara County is thin and consists of sand and gravel deposits in the stream valleys and abandoned drainageways (pl. 3). In this report the muck or peat in kettles and marsh areas, the marl in some of the kettle lakes, and the sand dunes are included with the alluvium. The alluvium generally ranges from 15 to 20 feet in thickness.

Thin beds of clay in the Lake Poygan area, mapped as alluvium, were probably deposited during a higher stage of Lake Poygan. These clays retain moisture, and water percolates through them slowly. Marsh vegetation occurs at the surface except where drainage ditches are used to drain areas for farming.

The water-bearing characteristics of the alluvium vary depending on the type of deposit. The sands and gravels have water-bearing characteristics similar to those of the outwash. The peat is moderately permeable. The marl in the kettle lakes is relatively impermeable. Beds of silt, clay, peat, and marl are not sources of water.

Wells in the alluvium are shallow and can be excellent water producers. Some irrigators have dug large pits in the alluvial sand and gravel and have used them as a source of water. As much as 700 gpm of water is pumped from a few of these pits.

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GROUND WATER

An understanding of the hydrologic system of an area requires not only a knowledge of the extent and character of the enclosing rock, but also an understanding of the source, occurrence, and movement of ground water and its relation to streams and lakes.

SOURCE AND OCCURRENCE

In Waushara County, water occurs mostly in the alluvium and glacial drift of Quaternary age and in the sandstone of Cambrian age; it occurs in small quantities in the crystalline rocks of Precambrian age. The source of nearly all ground water in Waushara County is precipitation in the form of rain or snow. Of the total precipitation, part returns to the atmosphere by evaporation and transpiration, part flows into streams and lakes as direct runoff, and the remainder seeps into the ground.

Ground water occurs under both water-table and artesian conditions in the county. Water in the unconsolidated beds of sand and gravel is generally unconfined and is said to occur under water-table conditions. Confined or artesian conditions exist locally where the water in the sand and gravel deposits is confined by layers of silt or clay. The confining material is not totally impermeable, and there is slow leakage through the beds. In considering the movement of ground water over a long period of time, the unconsolidated deposits may be considered as a single aquifer that has a common piezometric surface (imaginary surface that coincides with the static level of water in the aquifer), rather than as several aquifers.

Hydrostatic pressure causes the water to rise above the bottom of a confining layer in a well, called an artesian well, that penetrates a confined aquifer. An artesian well will flow if the hydrostatic pressure causes the water in the well to rise above the land surface.

The shape of the piezometric surface for water held in the unconsolidated deposits in Waushara County is depicted in plate 1 by contour lines based on the altitudes of water levels in wells measured in July 1957. The maximum altitude of the piezometric surface was more than 1,100 feet in T. 20 N., R. 9 E.; the minimum altitude was about 747 feet in secs. 25 and 36, T. 18 N., R. 13 E., where the Fox River crosses the county line. Thus, in July 1957, the total relief of the water table in the county was more than 350 feet.

RECHARGE

Recharge to the ground-water body in Waushara County is from rainfall and snowmelt. It is generally greatest in the spring, when water from melting snow and from heavy rains saturates the ground and water percolates downward to the water table. During the growing season, most of the precipitation is returned to the atmosphere by direct evaporation and by evapotranspiration by plants, and little, if any, water reaches the water table. In the winter, frost prevents water from soaking into the ground.

A value for the approximate annual recharge rate to the ground-water reservoir in Waushara County was determined by estimating the average annual rate of ground-water discharge to the Fox River above the gaging site at Berlin, Wis., and the Waupaca River above the gaging site near Waupaca, Wis. Geologic and hydrologic conditions in the Waupaca River basin are similar to those in the western part of Waushara County, and geologic and hydrologic conditions in the Fox River basin are more representative of those in the eastern part of the county. Examination of the stream hydrograph for the Waupaca River near Waupaca, Wis., for the years 1960–61 indicates that about 90 percent of the stream runoff is derived from ground water. The average annual runoff of the Waupaca River near Waupaca is about 10.6 inches (see section on discharge to streams); so, the average annual recharge to the ground-water reservoir in the western part of Waushara County is probably about 9 to 10 inches. The ground-water contribution to the Fox River above Berlin, Wis., was more difficult to determine because the flow of the stream is influenced considerably by surface-water storage in the swamps and marshes bordering the river. The ground-water contribution to the Fox River, however, is probably equal to about 60 to 70 percent of the basin runoff, or about 6 to 7 inches per year. These values probably represent the approximate average annual recharge rate in the eastern part of Waushara County. The average annual recharge rate for Waushara County as a whole probably ranges from 6 to 10 inches, and may average about 8 or 9 inches.

MOVEMENT AND DISCHARGE

Ground water moves down the hydraulic gradient in Waushara County from areas of recharge to areas of discharge along a path that is approximately perpendicular to the contours shown on the water-table map (pl. 1). The slope of the water table generally ranges from 5 to 40 feet per mile, but may be as much as 80 feet per mile in the morainal deposits or less than 5 feet per mile in the glaciolacustrine silts. The changes in hydraulic gradient are caused by variations in the permeability of rocks, variations in the thickness of saturated materials, variations in precipitation that affect the rate of recharge, and variations in the discharge of water from wells.

Ground-water divides separate the water moving toward different discharge areas. The altitude of the water table is highest along the ground-water divides and lowest along the streams and lakes. Ground-water divides occur between each of the streams, but their exact positions are difficult to define without detailed water-level data for each interstream area. The major ground-water divide, shown as a dashed line on plate 1, trends northeast from sec. 18, T. 18 N., R. 8 E., to sec. 5, T. 20 N., R. 9 E. East of this divide, ground water moves southeastward toward the Wolf and Fox Rivers. West of the divide, ground water moves westward toward the Wisconsin River. This ground-water divide is not coincident with the topographic divide and is as much as 7 miles to the west of the topographic divide in T. 20 N. (pl. 1).

Water also moves out of the county as underflow through the unconsolidated materials in the stream valleys; however, data are not available to estimate the amount of water moving in this manner. Because most of the streams in this general area originate within the county, only very little water probably moves into the county itself.

Ground-water discharge is about equal to the recharge and is estimated to be about 8 inches per year or about 25 to 30 percent of the average annual precipitation of 30 inches.

STREAMS AND SPRINGS

Perennial streams in Waushara County receive water from surface and ground-water runoff. Surface runoff is that water moving over the land surface after rains and during snowmelt when the ground is frozen. Because the glacial material is permeable in most of the county, much of the water from rains soaks rapidly into the ground and very little moves overland toward streams. Therefore, streamflow is derived mainly from ground water, and streams receive a major part of their flow from ground-water reservoirs.

Data are not available for the total stream discharge; however, the order of magnitude may be illustrated by the discharge of Fox River near Berlin and Waupaca River near Waupaca. On the Fox River, a recording gage 2.5 miles upstream from Barnes Creek has measured the total stream discharge from a basin of approximately 1,430 square miles in area. About 160 square miles of this basin lies in Waushara County. During the period 1898 to 1958 the stream discharge, expressed in terms of runoff depth in inches, has ranged from 5.6 inches in 1958 to 15.4 inches in 1929 and has averaged 10.4 inches, or nearly 35 percent of the average annual precipitation in the county. The Waupaca River basin lies a few miles north of Waushara County in Portage and Waupaca Counties and does not drain any of the land in Waushara County. Geologic and hydrologic conditions in the Waupaca River basin, however, are similar to those in the western part of Waushara County. During the period 1916–61 runoff from the 305 square miles in the Waupaca River basin above the stream gage at Waupaca has averaged about 10.6 inches. From the values for average runoff from the two basins, it may be assumed that the average annual runoff in Waushara County is about 10.5 inches.

Springs are also discharge points for the ground-water reservoir. Most of the springs in Waushara County (pl. 1) are gravity depression springs which discharge less than 100 gpm into streams; however, a few springs, such as Mecan Springs (sec. 6, T. 18 N., R. 9 E.) consist of many springs discharging into a small area (Wisconsin Conserv. Dept., 1956). On October 3, 1956, the flow of Mecan Springs at streamflow-measurement site 4 (pl. 1) was about 6,700 gpm. On September 19, 1958, the flow of the springs at Mill Pond (sec. 25, T. 19 N., R. 9 E.) at streamflow-measurement site 8 was about 2,700 gpm (L. A. Posekany, Wisconsin Conserv. Dept., oral commun., 1958).

EVAPOTRANSPIRATION

Evaporation from water surfaces and from moist soil and transpiration by plants are together considered as evapotranspiration. The average evapotranspiration rate from the combined sources of surface water, ground water, and soil moisture was estimated to be about 19 to 20 inches per year in Waushara County. This value was obtained by subtracting the estimated average annual runoff from the average annual precipitation in the county, and it agrees with the evapotranspiration rate of 21 inches per year determined by C.B. Tanner (written commun., 1958) for the State of Wisconsin as a whole. The evapotranspiration rate is greatest during the summer and least during the winter.

The stage of Roche a Cri Creek (fig. 4) fluctuated daily because some of the ground water flowing toward the stream was intercepted and transpired by plants during the warm hours of the day.

WELLS

The estimated ground-water discharge in 1957 from wells in Waushara County was about 3 million gallons a day for all uses. The discharge was determined by a partial pumpage inventory in 1957 and

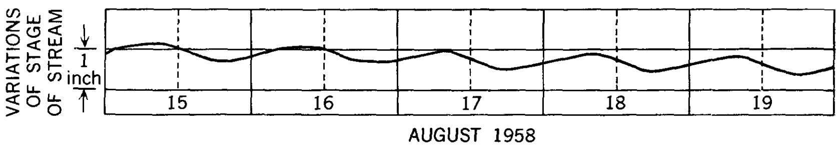

FIGURE 4.—Variations of stage of Roche a Cri Creek at Ingalls Bridge, Waushara County, Wis., August 15–19, 1958. (From records of Wisconsin Conserv. Dept.)

estimated from the 1960 census of population. Discharge from wells represents only a small fraction of the amount of ground water available for use in the county.

WATER-LEVEL FLUCTUATIONS

Water-level fluctuations reflect changes in the amount of water being added to or taken from storage in the ground-water reservoir. Rising water levels indicate that recharge is greater than discharge; falling water levels indicate that discharge is greater than recharge. The relationship between precipitation and recharge in Wisconsin is discussed and illustrated by Drescher (1955), and by Audini, Berkstresser, and Knowles (1959, p. 24).

Short-term fluctuations reflect local day-to-day variations in natural recharge and discharge. Most of the time, water levels are declining because of the continuous flow of ground water to points of discharge. The hydrograph of well Ws–18/10/1–105 (fig. 5) illustrates this decline except for the short period during which 0.68 inch of precipitation fell in the area. The well is a shallow water-table well and is in sand; therefore, the response to recharge was rapid and the water level in the well rose 0.3 foot in a few hours. In a relatively short time, the water level returned to its normal rate of decline.

In general, the amount of water in storage, especially in the outwash plains of western Waushara County, remains relatively constant. Discharge from the aquifer to streams and evapotranspiration is in approximate balance with recharge to the aquifer, and water levels change only a few feet. If recharge is above normal, discharge to streams increases; and conversely, if recharge is below normal, discharge to streams decreases, and the balance is maintained.

Water levels also fluctuate in response to pumping from wells. When water is withdrawn from a well, the water level declines in the vicinity of the well, and the shape of the water table or piezometric surface becomes an inverted cone whose apex is at the well. The profile of the cone of depression in the vicinity of well Ws–19/8/15–258 is shown in figure 6. After the well had been pumped for 14.5 hours at

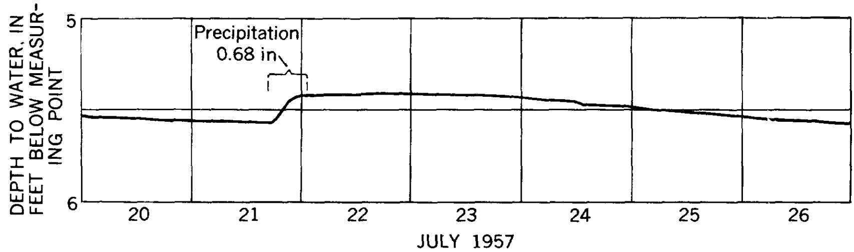

FIGURE 5.—Effect of precipitation on the water level in well Ws–18/10/1–105.

an average rate of 27 gpm, the effects of the pumping extended out about 110 feet from the well. Although the profile is based on water-level measurements in selected wells at a specific time, it does depict the general shape of the cross section through a cone of depression which is formed when a well is pumped. The size and shape of the cone of depression around a given well will depend on the hydraulic properties of the aquifer materials, on the length of time and rate of pumping, on geologic or hydraulic boundaries, and on the amount of recharge to the ground-water reservoir.

When pumping wells are closely spaced, the cones of depression formed by each well will lower the water levels in nearby wells. Because of these lower water levels, pumping lifts will be increased, and the yields of some of the wells will be diminished. In Waushara County, there is little interference between wells because they are adequately spaced.

At the present time all fluctuations caused by the pumping of wells in Waushara County may be considered as short-term fluctuations. No area in the county is known where constant pumping of a water-supply well has resulted in the continued lowering of the water table over a long period of time. Although pumpage for irrigation is large,

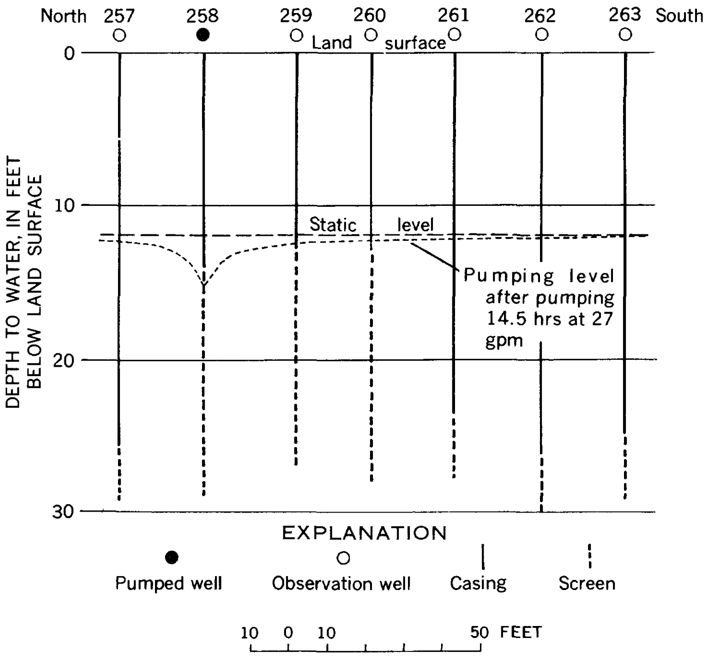

FIGURE 6.—Profile of water-table surface during aquifer test of well Ws-19/8/15-258, October 2–3, 1956.

withdrawals are intermittent and of short duration. Because pumpage withdraws water from storage, some of the recharge that is naturally discharged from the aquifer goes into storage and effectively increases the amount of water available for use.

Seasonal and long-range fluctuations reflect differences between recharge and natural discharge during the year and from year to year. These fluctuations are shown in figure 7. Seasonal fluctuations for each year show that water levels generally decline during the summer, fall, and winter and rise during the spring.

Water levels decline in the summer and early fall because natural discharge generally exceeds recharge from precipitation. After vegetation is killed by frost in the fall, precipitation great enough to overcome soil-moisture deficiencies will recharge ground water and result in rising water levels. Such water-level recoveries occurred in 1954 and 1959. During the winter when the ground is frozen and most of the precipitation is in the form of snow, there is also little or no recharge to the aquifer. In the spring, when the ground thaws and the snow melts and little moisture is being lost by evapotranspiration, recharge exceeds discharge and water levels rise, sometimes very rapidly.

From 1954 to 1959 there was a general downward trend in water levels resulting from a long-term trend of below-normal precipitation between late 1954 and early 1959; however, by 1960 and 1961 water levels had recovered nearly to the 1954 levels because of a long-term trend of above-normal precipitation beginning in early 1959.

LAKE LEVELS

The fluctuation of levels of landlocked lakes or lakes with uncontrolled outlets reflect changes in ground-water levels. The stage of Silver Lake, a landlocked lake in T. 18 N., R. 11 E., was measured annually in April after the breakup of the ice during the period 1943–53. The changes in lake stage reflect the long-term trend of precipitation as shown by the cumulative departure from the normal precipitation curve (fig. 8).

SPECIFIC CAPACITIES OF WELLS

The specific capacity of a well is the ratio of the discharge to the drawdown of the water level in the well and is expressed in gallons per minute per foot of drawdown as follows:

$$\text{Specific capacity} = \frac{\text{discharge (gpm)}}{\text{drawdown (ft)}}$$

Specific capacity is only a guide to the water-yielding characteristics of an aquifer because the construction and development of a well, the

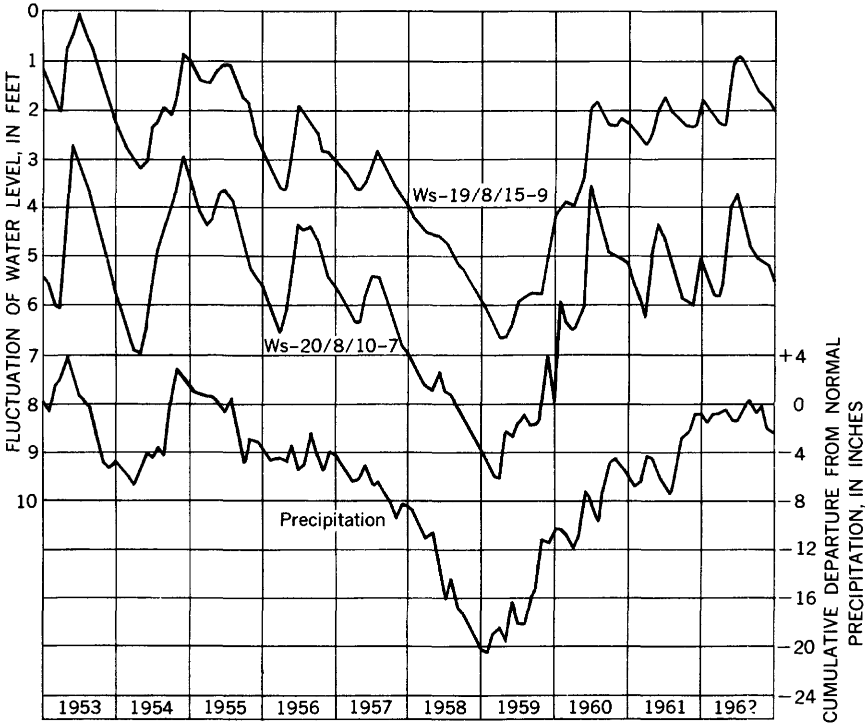

FIGURE 7.—Fluctuation of water levels in two wells in Waushara County, Wis., and cumulative departure from normal monthly precipitation at Hancock. (Precipitation from records of U.S. Weather Bur.)

discharge rate, the length of the test, and other factors all affect the decline of water levels in a pumping well. The specific capacities of 140 wells were tabulated (table 2) as an aid in determining the water-yielding characteristics of the several water-bearing formations. The information, computed from drillers' records and short-term tests, probably is fairly valid.

High specific capacities generally indicate a high potential yield of the aquifer; low specific capacities generally indicate small yields. Table 2 shows that the specific capacity for outwash sand and gravel is much higher than that of the other deposits.

UTILIZATION OF WATER

The withdrawal of ground water in Waushara County in 1957 was estimated from a partial inventory of pumpage and from the 1960 census at about 725 million gallons. About 473 million gallons were

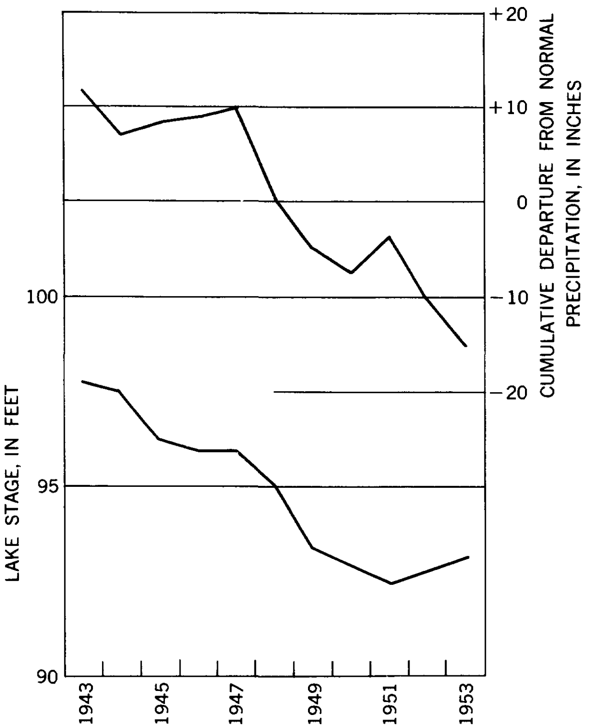

FIGURE 8.—Hydrograph showing stage of Silver Lake in T. 18 N., R. 11 E., Waushara County, and annual cumulative departure from normal precipitation at Hancock, Waushara County, Wis. (From records of Wisconsin Public Service Comm. and U.S. Weather Bur.)

TABLE 2.—*Specific capacities of wells in Waushara County, Wis.*

Aquifer	Number of wells tested	Specific capacity (gpm per ft)		
		Range		Average
		Low	High	
Alluvium	0	----------	----------	----------
Outwash sand and gravel	18	23	97	53
Morainal deposits	15	.3	5.0	2.4
Intermorainal deposits	6	1	19	10
Glaciolacustrine deposits:				
Sand in western Waushara County	19	.1	20	4
Sand in eastern Waushara County	42	.1	13	2.7
Sand and gravel between lacustrine deposits and sandstone	3	.2	1.3	.8
Sandstone	37	.4	50	7
Crystalline rocks	0	----------	----------	----------

used for municipal, industrial, irrigation, domestic, and livestock uses. The various uses are shown in table 3.

The volume of ground water discharged by wells in Waushara County is increasing annually. Modernization of homes and farms has increased the domestic and stock use of water. The number of farms equipped with supplemental irrigation equipment has increased steadily since 1948. This situation has resulted in a large increase in the volume of pumped water. For example, the estimated withdrawal for irrigation was 47 million gallons in 1955, 37 million gallons in 1956, 66 million gallons in 1957, and more than 154 million gallons in 1958. The amount of water used by industry and summer camps has increased regularly, but data are not available to estimate the amount. About 250 million gallons is discharged annually from wells flowing continuously at rates averaging about 3 gpm and is probably not effectively used.

The village of Coloma (population 380), Hancock (population 450), and Plainfield (population 660) operate public water utilities, but Wautoma (population 1,466) and Wild Rose (population 582) have wells for fire protection only. The volume of water pumped by the village of Coloma increased erratically from about 5 million gallons in 1949 to 12.3 million gallons in 1958 and averaged about 7.2 million gallons per year, or about 20,000 gallons per day. The Hancock utility began operation in July 1958 and pumped about 1.6 million gallons in that year.

TABLE 3.—*Utilization of ground water in Waushara County in 1957*

Use of water	Discharge (millions of gallons per year)	Percent of total usage
Municipal	11	2.3
Industrial	40	8.4
Irrigation	66	13.9
Domestic:		
Rural	137	29.0
Summer camps (Boy Scouts, YMCA, etc.)	2	.4
Itinerant labor camps	7	1.5
Livestock (horses, cattle, hogs, sheep, and poultry)	210	44.5
Total used	473	100.0
Discharge from flowing wells: Not used	250	

CHEMICAL QUALITY

The water from wells in Waushara County ranges from soft to very hard and is good for most uses. Except for areas having excessive iron, more than 0.3 ppm (parts per million), the chemical constituents were within the requirements for potable water recommended by the U.S. Public Health Service (1962).

The chemical character of ground water in Waushara County remains about the same from year to year. As water slowly moves downgradient toward areas of discharge, it dissolves minerals from the soils and rocks through which it moves. Knowledge of the concentrations of the various mineral constituents in ground water is necessary to determine the suitability of water for industrial, irrigation, and domestic uses.

Chemical analyses were made of samples of water from 118 wells, 2 springs, and 2 streams. Table 4 lists analyses of water from selected wells in the sandstone and in the glacial drift in Waushara County. The distribution of iron, dissolved solids, and hardness in water from the glacial drift are plotted in figures 9, 10, and 11. These figures do not show any definite correlation between the distribution of the chemical constituents and the geology of the area; however, the lack of any definite pattern may be caused by the heterogeneity of the deposits or by insufficient data.

IRON

More than 0.3 ppm iron in water is undersirable, according to the U.S. Public Health Service (1962, p. 7). The largest areas having more than 0.3 ppm iron in solution are in T. 18 N., Rs. 10 and 13 E.; T. 19 N., Rs. 11 and 12 E.; and T. 20 N., Rs. 8 and 13 E. (fig. 9).

The iron concentration in the glacial drift ranged from zero or a trace in about one-half of the wells to 48 ppm in well Ws–19/12/4–68, and was generally less than 1 ppm. Of the 95 samples of water from the glacial drift, 35 contained more than 0.3 ppm iron. The iron concentration in the sandstone ranged from 0 in several wells to 13 ppm in well Ws–20/13/19–176. Of the 19 samples from the sandstone, 10 contained more than 0.3 ppm. No correlation could be made between the amount of iron in solution and the depth from which the water came.

DISSOLVED SOLIDS

The concentration of dissolved solids in water of the glacial drift ranged from 102 to 462 ppm (fig. 10). The concentration of more than 400 ppm occurred in T. 20 N., R. 13 E. Of the 97 samples analyzed for dissolved solids, 81 contained less than 300 ppm.

The dissolved-solids concentration in the water from the sandstone ranged from 134 ppm in well Ws–19/13/33–116 to 322 ppm in well Ws–20/13/18–167.

HARDNESS

Hardness is a measure of the concentration of dissolved calcium and magnesium bicarbonate in water; the calcium and magnesium is largely derived from carbonate rocks in the drift. The treatment of hard to very hard water may present a problem for industrial and domestic uses of water (Hem, 1959, p. 147). The concentration of hardness of water from the Quaternary deposits in Waushara County is shown in figure 11.

TABLE 4.—*Chemical analyses of water from selected wells in the sandstone and in glacial drift in Waushara County, Wis.*

[Results in parts per million except pH. T=less than 0.1 ppm. Analyses by Wisconsin State Lab. of Hygiene]

Well	Date of Collection	Depth of well (feet)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids	Hardness as $CaCO_3$	pH
Sandstone												
18/8/14-11	9- 5-45	390	0	37	19	205	0.5	4.0	T	178	152	7.6
13/15-52	11- 4-57	411	T	33	29	271	13	2.0	0.3	252	218	7.9
19/11/28-358	1-31-58	268	2.4	43	21	222	7.0	1.0	.1	206	190	7.5
12/29-355	11-29-57	327	8.0	31	19	195	4.5	7.5	T	194	174	8.1
20/13/19-176	5-29-56	229	13	57	13	267	0	1.0	.4	264	206	7.3
Glacial drift												
18/8/23-209	12-11-56	52	T	-----	-----	-----	-----	-----	-----	130	114	8.3
9/31-88	2-13-57	85	T	29	14	132	3.5	2.5	T	150	127	8.2
10/15-84	12-13-56	44	0.5	-----	-----	-----	-----	-----	-----	226	218	7.8
11/21-14	1-17-57	144	.1	-----	-----	-----	-----	-----	-----	168	160	7.7
18/12/8-162	5-23-56	114	.1	32	19	212	3.5	1.0	0.35	190	169	8.2
13/15-332	11- 7-57	80	T	14	2.4	183	20	1.5	.35	214	40	8.7
19/8/15-1	9-21-54	16	0	40	13	122	14	13	T	270	158	7.9
9/16-37	10-27-54	7	5.5	38	23	234	2.0	1.0	.1	192	189	7.6
10/21-78	5-13-58	96	0	43	26	220	18	3.0	T	218	204	7.9
11/22-56	5-23-57	127	.6	42	20	220	12	2.0	T	200	192	7.8
12/11-66	1-24-57	18	T	-----	-----	-----	-----	-----	-----	192	177	8.2
13/26-136	5-16-56	60	T	13	8.5	126	5.5	3.0	.45	-----	72	8.2
20/8/30-25	9-21-54	13	1.5	-----	-----	17	19	-----	T	-----	36	-----
9/30-32	10-27-54	13	1.0	8.8	4.2	32	6.5	1.0	.1	102	33	6.0
10/16-46	10-27-54	70	0	43	21	217	5.0	1.0	T	204	194	7.8
11/1-158	10-10-56	61	0	35	15	195	4.0	2.0	T	172	168	8.0
12/30-177	8- 5-56	98	.1	28	13	149	14	1.5	T	158	138	8.2
13/17-175	4-30-57	67	1.1	-----	-----	-----	-----	-----	-----	462	408	7.5

MINOR CONSTITUENTS

The ground water of Waushara County contains ions in solution other than calcium, magnesium, and iron. The sodium and potassium (Na and K) concentration was less than 20 ppm except in samples from wells Ws–18/13/15–332, 70 ppm; Ws–19/13/25–379, 42 ppm; and Ws–10/13/25–380, 74 ppm. The maximum concentration of sulfate (SO_4) was 20 ppm in well Ws–18/13/15–332. The maximum chloride (Cl) concentration was 13 ppm in well Ws–19/8/15–1. The fluoride concentration was less than 0.5 ppm in all wells tested.

An important consideration of water used for irrigation is the proportion of sodium to the total-cation concentrations. The proportion of sodium in ground water in Waushara County is very low and is not considered an irrigation problem.

TEMPERATURE

Ground water is advantageous in many industrial uses because of its relatively constant temperature. The temperature of water from wells deeper than 30 feet in Waushara County is generally about 50°F. Measurements have shown, however, that ground-water temperatures in wells having depths less than about 60 feet are influenced by seasonal variations in the air temperature. The temperature of the ground water below 60 feet may increase by as much as 1°F per 100 feet of depth (Summers, 1961, p. 225).

The temperatures of ground water discharging from 179 flowing wells and 120 springs in Waushara County were measured in January and February, 1956, by the Wisconsin Conservation Department. Although air temperatures were continuously below 32°F, ground-water temperatures were recorded as high as 51°F for some springs and 53°F for some wells. The most common temperatures for both flowing wells and for springs were 48°F and 49°F. The temperature of water from deep wells flowing more than 2 gpm were warmest; temperatures from wells and springs flowing less than 2 gpm were coldest.

SUMMARY

This study has shown that there is abundant ground water for irrigation in the outwash plain in western Waushara County, and many more irrigation wells can be developed in the aquifer without seriously lowering the water level.

Outwash deposits of sand and gravel in western Waushara County cover 120 square miles, average about 100 feet in thickness, and form the most productive aquifer in the county. Yields of as much as 1,300 gpm have been reported for this aquifer. It is estimated that 760 billion gallons of ground water are in storage in the outwash plain,

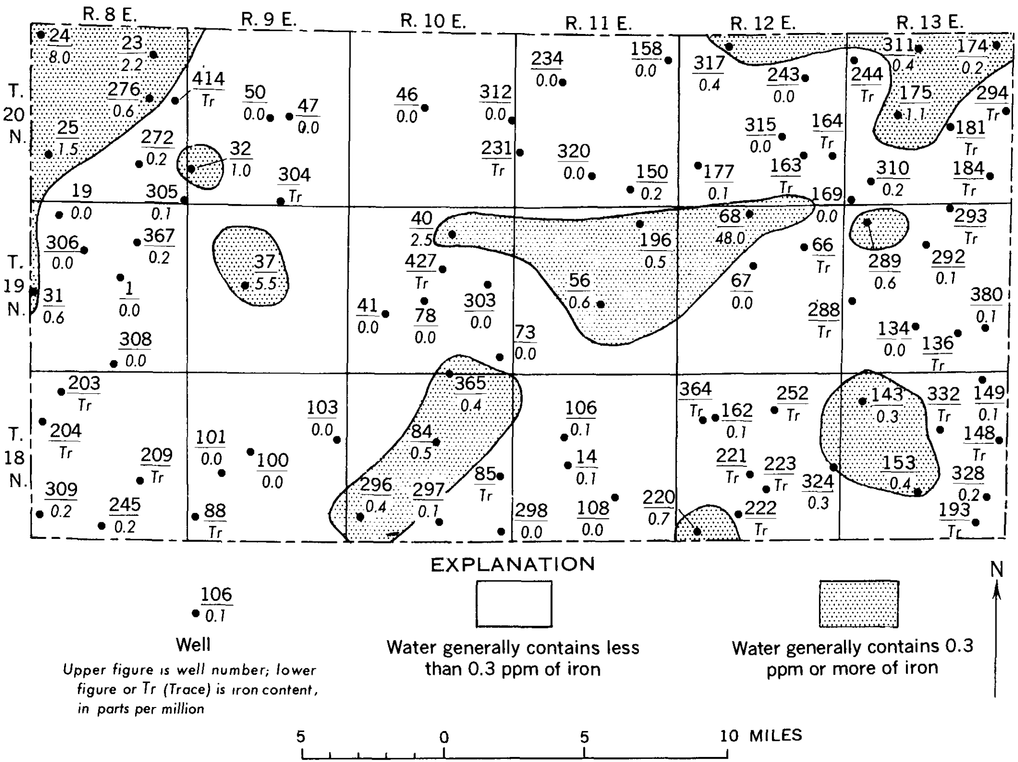

FIGURE 9.—Distribution of iron in water from deposits of Quaternary age, Waushara County, Wis.

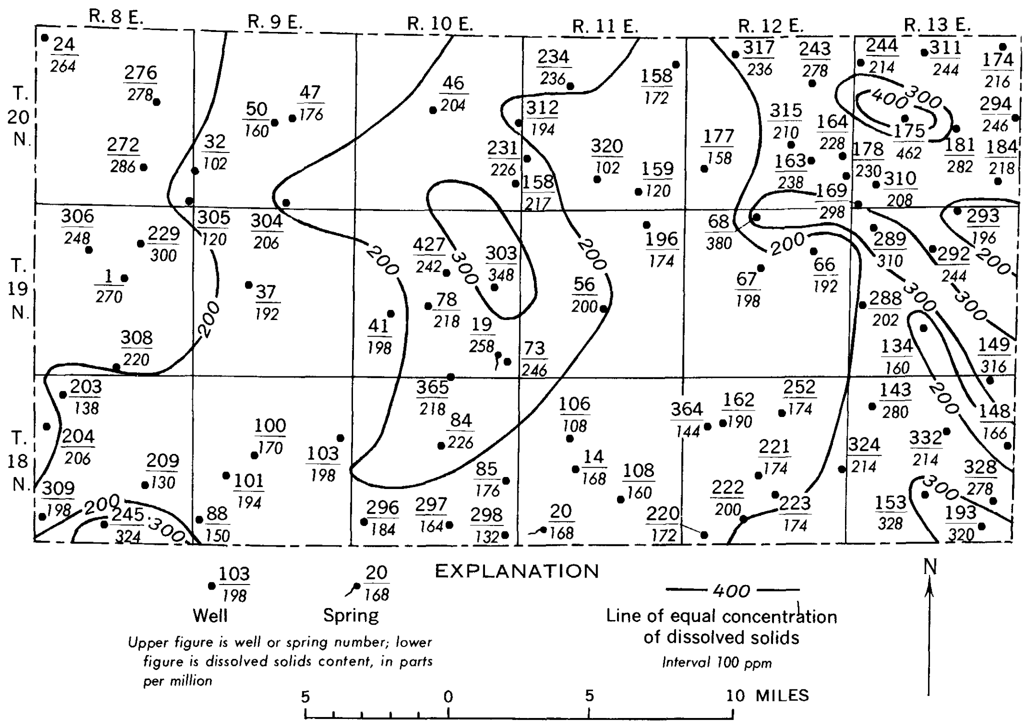

FIGURE 10.—Distribution of dissolved solids in water from deposits of Quaternary age, Waushara County, Wis.

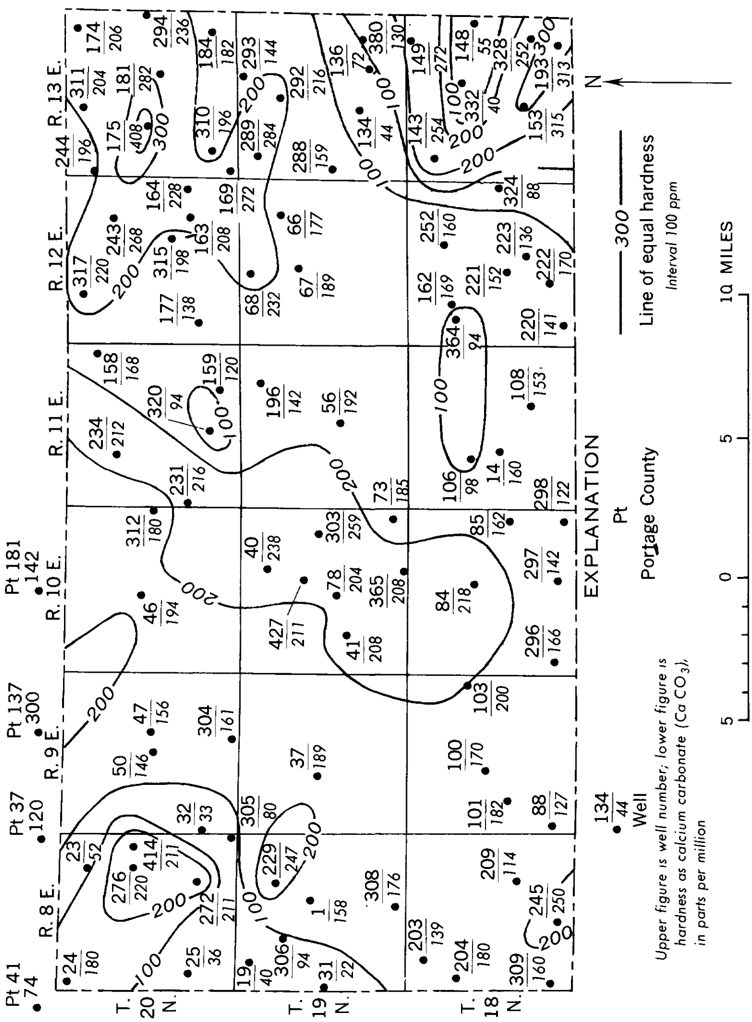

FIGURE 11.—Distribution of hardness of water from deposits of Quaternary age, Waushara County, Wis.

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a part of which is available for irrigation, industrial, municipal, and domestic development. Although ground water is being discharged continuously to streams and by evapotranspiration, intermittent recharge from precipitation replaces the discharged water and maintains approximately constant amounts of water in storage. Because the recharge and discharge are in approximate balance, further recharge to the aquifer is rapidly discharged to streams and is lost to local use. Pumpage has probably intercepted and utilized some of this water.

Pumping for irrigation temporarily lowers water levels in the vicinity of wells in the outwash plain, but it has not lowered regional water levels because the quantity of water removed has been less than the recharge to the aquifer. There is little interference between irrigation wells, because the wells are usually spaced at least one-eighth mile apart.

Morainal deposits occur in a broad belt across the central part of the county. Because of poor sorting and clay and silt content, these deposits generally yield enough water for only domestic and stock use.

Intermorainal deposits range in composition from unsorted sandy till to well-sorted sand and gravel. Irrigation wells may be developed in intermorainal deposits of well-sorted sand and gravel that are similar in water-bearing properties to the outwash-plain deposits. The unsorted sandy till yields only small quantities of water to wells.

Glaciolacustrine deposits occur in the central and eastern part of the county. These deposits consist of stratified sand in the central part of the county and clay, silt, and sand in the eastern part of the county. In general, these deposits yield enough water for only domestic and stock use.

Deposits of sand and gravel underlying glaciolacustrine deposits yield varying amounts of water to wells but in general yield only small quantities.

The lower boundary of the reservoir is formed by impermeable granitic rocks that underlie the county generally at a depth of less than 400 feet.

Alluvium consists of thin sand and gravel deposits in stream valleys and abandoned drainageways and of peat, marl, and sand dunes in marshes and kettles. Thick deposits of sand and gravel may yield large quantities of water to irrigation wells and pits. Peat, marl, and sand dunes are not sources of water.

Sandstones, underlying most of the county, are thickest along the southern border of the county and are thinnest along the northern border. The sandstones generally yield only small to moderate amounts of water to wells and do not provide a good source of water for irrigation.

Ground water occurs under both water-table and artesian conditions throughout the county and moves by gravity from areas of recharge to areas of discharge. The general direction of movement in most of the county is toward the southeast. Recharge to the ground-water reservoir is from precipitation and snowmelt, most of the recharge occurring in the spring. Ground water is discharged to streams and lakes and to the atmosphere by evapotranspiration.

In general, the chemical quality of water is not a problem, except in local areas where water is hard to very hard and concentrations of hardness and iron may be excessive. The water is of good quality for irrigation.

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EXPLANATION

1100 Water-table contour
Contour interval 20 feet; datum is mean sea level

Approximate western limit of area of flowing wells, except for Wild Rose area

High-capacity well
M, *municipal or industrial well;* IR, *irrigation well;* F, *flowing well. Pumped at rate of 100 gpm or more, 1956–58*

High-capacity irrigation pit
Pumped at rate of 100 gpm or more, 1956–58

Low-capacity well
D, *destroyed well;* F, *flowing well. Includes high-capacity wells used only for emergency supply*

Spring

424
1059
Upper figure is well or spring number; lower figure, where shown, is altitude of water table

× *1086*
Altitude at water table at spring stream, pond, marsh, lake, or quarry

Quarry

24
Streamflow measuring site

Stream site at which water was collected for chemical analysis

Base modified from Wisconsin State Dept. of Agriculture, Land Cover Maps, 1939
D, denotes drainage ditch

TRUE NORTH
MAGNETIC NORTH
2°
APPROXIMATE MEAN DECLINATION, 1965

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—W64252

MAP OF WAUSHARA COUNTY, WISCONSIN, SHOWING CONFIGURATION OF WATER TABLE, JULY 1957 AND LOCATION OF WELLS, SPRINGS, AND STREAMFLOW-MEASUREMENT SITES

SCALE 1:62 500

1 ½ 0 1 2 3 4 5 MILES

1 .5 0 1 2 3 4 5 KILOMETERS

EXPLANATION

—500—
Contour approximately located on the bedrock surface
Contour interval 100 feet; datum is mean sea level

• 135/685
Well ending in bedrock
Upper figure is well number; lower figure is altitude of bedrock

• 110/487
Well ending above bedrock
Upper figure is well number; lower figure is altitude of bottom of well

× SS 902
Sandstone

× 801
Granite

Altitude of outcrop

Base modified from Wisconsin State Dept. of Agriculture, Land Cover Maps, 1939
D, denotes drainage ditch

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1965—W64252

MAP OF WAUSHARA COUNTY, WISCONSIN, SHOWING CONFIGURATION OF THE BEDROCK SURFACE

SCALE 1:62 500

1 ½ 0 1 2 3 4 5 MILES

1 .5 0 1 2 3 4 5 KILOMETERS

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1965

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-SUPPLY PAPER 1809–B
PLATE 3

EXPLANATION

Qal — Alluvium
Clay, silt, sand, gravel, marl, and peat

Qo — Outwash
Sand and gravel

Qm, Qmk — Morainal deposits
Qm, undifferentiated
Qmk, kame or crevasse filling. Sand, gravel, and sandy till deposited in terminal moraines, drumlins, and ice-contact forms

Qot — Outwash and till
Sand, gravel, and sandy till

Qgs, Qgst — Glaciolacustrine deposits
Qgs, sand
Qgst, silt

QUATERNARY

Css — Sandstone
Upper Cambrian — CAMBRIAN

pCr — Crystalline rocks
PRE-CAMBRIAN

Contact

Base modified from Wisconsin State Dept. of Agriculture, Land Cover Maps, 1939
D, denotes drainage ditch

APPROXIMATE MEAN DECLINATION, 1965

SURFICIAL GEOLOGIC MAP OF WAUSHARA COUNTY, WISCONSIN

SCALE 1:62 500

1 ½ 0 1 2 3 4 5 MILES

1 .5 0 1 2 3 4 5 KILOMETERS

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—W64252

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