Ground-Water Resources of Waupaca County Wisconsin

By C. F. BERKSTRESSER, JR.

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GROUND-WATER RESOURCES OF WAUPACA COUNTY, WISCONSIN

By C. F. Berkstresser, Jr.

ABSTRACT

Waupaca County is in east-central Wisconsin. No serious ground-water problems existed in 1960 except in a few localities where crystalline rock is near land surface or is covered by nearly impermeable till. The use of ground water for irrigation has not appreciably affected ground-water levels.

The county is covered by Pleistocene till, glaciolacustrine (lake), glaciofluvial (stream), and eolian (wind) deposits. In the northern three-quarters of the county these deposits overlie Precambrian crystalline rocks; in the remainder, they overlie sandstone of Cambrian age and, to a minor extent, dolomite of the Prairie du Chien Group of Ordovician age. The deposits of Pleistocene age, particularly outwash, are the principal sources of ground water except in those areas where the saturated thickness is slight or the permeability low. The sandstone of Cambrian age is an important aquifer in the southeastern part of the county. The crystalline rocks of Precambrian age yield little water except from fractures, joints, and weathered zones, and they are a source of water only in areas where better aquifers are absent.

Ground water in Waupaca County occurs under both water-table and artesian conditions. The source of this ground water is precipitation that falls on the county and percolates downward to the zone of saturation. Regional movement of ground water is to the Wolf River. In most of the county the direction of movement is eastward or southeastward, except in the southeastern corner of the county, where the movement is westward.

Water-level fluctuations reflect the variations of ground-water storage or artesian pressure in response to variations in recharge and discharge. Declining water levels from 1956 to 1959 reflect a period of below-normal precipitation, and rising water levels in late 1959 and 1960 reflect above-normal precipitation. Average precipitation, runoff, and evapotranspiration in 1959 are estimated to be 1,000, 400, and 600 mgd (million gallons per day) respectively. Pumpage in the county was estimated to be about 4 mgd in 1959, and about half of this amount was used for public supplies.

A pumping test of a well in outwash deposits near Waupaca indicated that at that point the coefficient of transmissibility is about 100,000 gpd (gallons per day) per ft, the permeability is about 1,000 gpd per sq ft, the coefficient of storage is about 0.2, and the specific capacity is 41 gpm (gallons per minute) per ft of drawdown. These hydraulic characteristics are probably in the same order of magnitude as the characteristics of outwash deposits in the county in general.

The water from wells in Waupaca County, although hard and generally containing iron, is good for most purposes.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

The people of Wisconsin are becoming more aware of the importance of ground water to an increasing population and an expanding agricultural and industrial economy. MacKichan (1957) reports that 347 million gallons of ground water were used daily in Wisconsin in 1955 for all purposes. In the State, about 40 percent of the pumpage for public supplies and 90 percent of the pumpage for rural supplies are from ground-water sources. In Waupaca County, all municipal and domestic supplies and probably more than 95 percent of the stock supplies are from ground-water sources. Water for industrial use, except for some washing of gravel and wetting of logs for veneering, is from wells.

The U.S. Geological Survey in cooperation with the Wisconsin Geological and Natural History Survey began a study of the ground-water resources of Waupaca County in 1958 (fig. 1). The study is part of a program to evaluate the ground-water resources of Wisconsin. The investigation, planned cooperatively with George F. Hanson, State Geologist, was under the immediate supervision of C. L. R. Holt, Jr., district geologist of the U.S. Geological Survey.

The purpose of the investigation was to determine (1) the use of ground water, with special attention to irrigation, (2) the location of additional ground-water supplies, (3) the water-bearing properties of the aquifers, including the geologic conditions that must be considered in planning water supplies, and (4) the chemical quality of the ground water.

The methods of investigation included the preparation of two geologic maps on U.S. Geological Survey planimetric maps at a scale of 1:62,500. Of the 674 wells inventoried, about 380 drillers' logs and about 40 sample logs compiled by geologists were available for study. The locations of the wells inventoried in Waupaca County are shown in plate 1. Water-level measurements were made in about 300 wells (34 of which were measured periodically) for use on compilation of the water-table and piezometric maps. Aquifer tests were made near Waupaca, New London, and Weyauwega. In addition, drawdown and recovery measurements for wells at Marion and Embarrass were available from other sources. Thirty-five samples of well water were collected for chemical analysis to supplement 88 analyses (including one of lake water) available from other sources. Water from eight wells was sampled at varioius depths during construction of the wells. Altitudes of wells, springs, and rock outcrops were determined with an aneroid barometer from benchmarks of the U.S. Geological Survey, U.S. Coast and Geodetic Survey, U.S. Corps of Engineers, Wisconsin

State Highway Department, and Waupaca County Highway Department.

PREVIOUS INVESTIGATIONS

Several investigations of the geology or ground-water resources in areas that include Waupaca County were made previous to this detailed study. Some of the first reports by Chamberlin (1877; 1883) discussed the general geology of the county. Additional geologic reports were prepared by Thwaites (1931; 1943), Martin (1932), and Bean (1949), and soil studies were made by Whitson and others (1921). Reports containing data on ground water were prepared by Kirchoffer (1905), Weidman (1907), Weidman and Schultz (1915), and the Wisconsin Bureau of Sanitary Engineering (1935). Extensive use was made of unpublished field notes by Thwaites, Bean, and others, and of data from the files of the Wisconsin Geological and Natural History Survey.

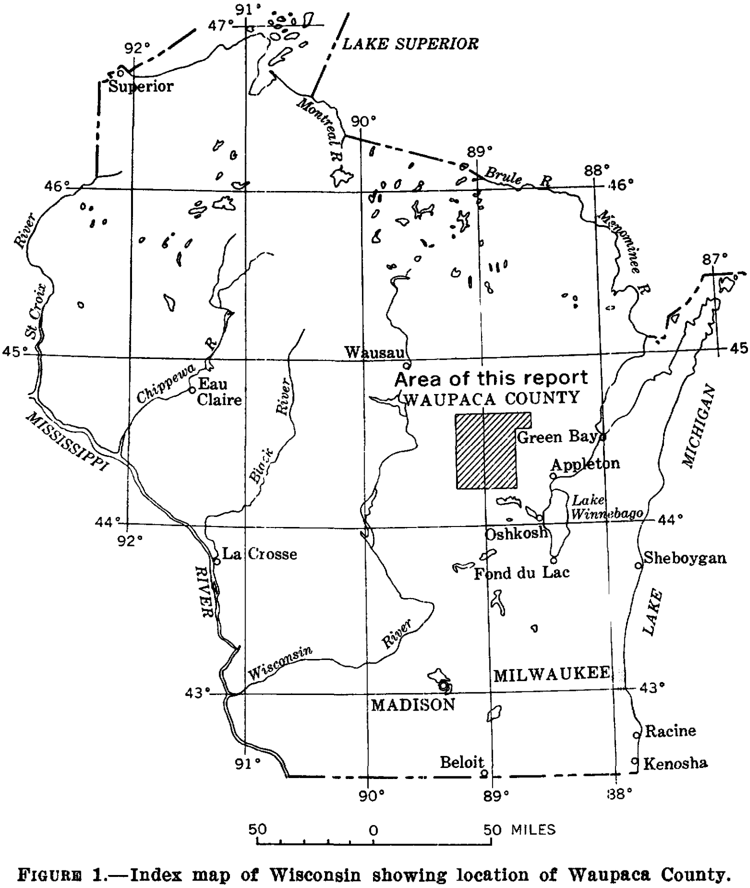

FIGURE 1.—Index map of Wisconsin showing location of Waupaca County.

ACKNOWLEDGMENTS

The writer is indebted to the numerous farmers, well drillers, city and county officials, and personnel in industry who supplied information and aided in the collection of field data.

NUMBERING SYSTEM

A system of letters and numbers is used to designate the location and number of wells, springs, lakes, and rock samples (fig. 2). The county designation, Wp, is derived from the county name. The township designation within the county is based on the Federal system of land subdivision, and it consists of the township, range, and section number. In Waupaca County, all townships are north of the base line and all ranges are east of the principal meridian. The letter E or W following a section number is used in oversized sections found only in T. 25 N., R. 15 E., and indicates the east or west half of the section. The last numeral is a serial number assigned in the order that the well was inventoried in the county. For example, Wp–22/14/35–1 was the first well inventoried in the county. Serial numbers followed by letters a, b, c, etc., indicate that two or more wells or test holes were constructed in approximately the same location. Serial numbers of springs, lakes, and rock- and soil-sample sites are preceded by the letters S, L, and R, respectively. Where a location is established, as on maps, only the serial number is used.

DESCRIPTION OF THE AREA

Waupaca County is located in the east-central part of Wisconsin (fig. 1) between lat 44°14′ and 44°41′ N., and long 88°36′ and 89°13′ W. The county consists of Tps. 21–25 N., Rs. 11–14 E., and T. 25 N., R. 15 E. The total area is 751 square miles, of which about 10 square miles is lakes and streams.

TOPOGRAPHY AND DRAINAGE

The topography of Waupaca County may be divided into moraine and outwash, glacial lake, and bedrock areas. The moraine and outwash area, which covers about three-quarters of the county, is hilly and dissected by rather broad valleys. Its landforms are a result of ice movement and stagnation. The land surface locally is pitted with numerous kettles, many of which contain lakes. In the glacial lake area, roughly the southeast quarter of Waupaca County, the valley of the Wolf River crosses the basin of glacial Lake Oshkosh. The land surface is almost flat although drumlins and eskerlike landforms give it locally a gently rolling appearance. The bedrock area, east of the

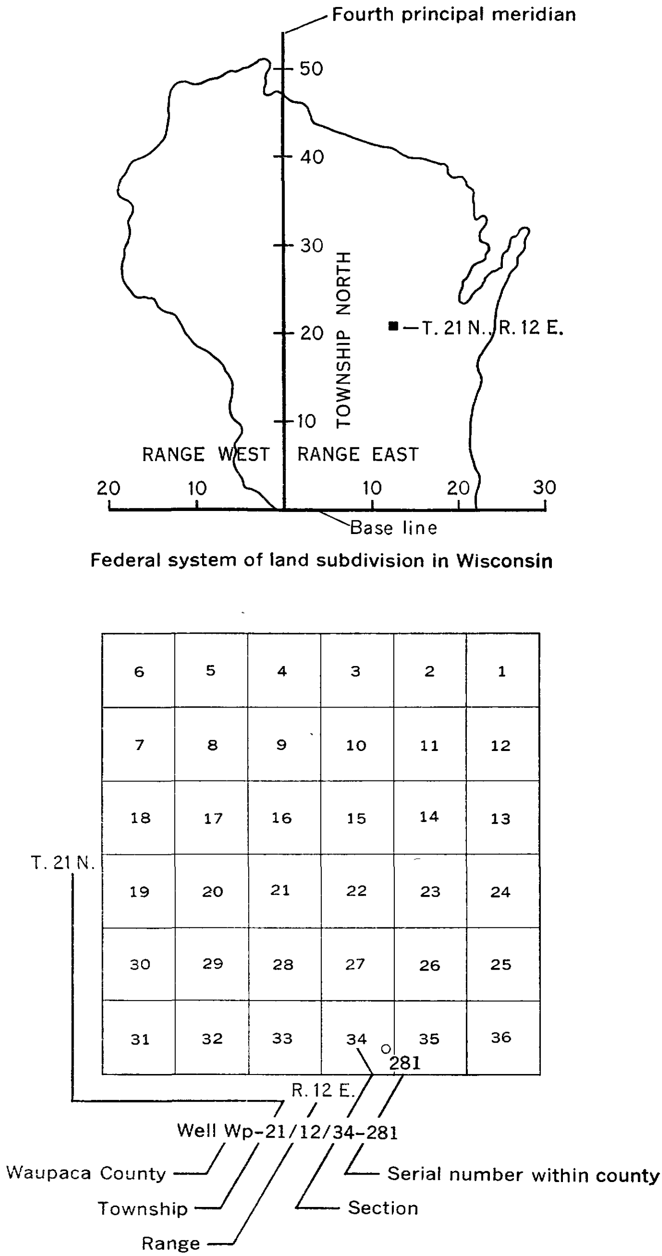

FIGURE 2.—Numbering system in Wisconsin.

lakebeds in the southeast corner of the county, is a flat-topped highland.

The land surface is commonly between 775 and 1,000 feet above sea level. The highest measured altitude is 1,198 feet at well Wp–24/11/18–130, but the tops of several moraines and drumlins near Northland are higher. The lowest altitude in Waupaca County is about 745 feet at the surface of the Wolf River where it flows out of Waupaca County.

Waupaca County is entirely within the Wolf River drainage basin. The Wolf River enters Waupaca County from the east at New London, and it flows 25 miles southwestward into Winnebago County. The gradient of the river in Waupaca County is less than 0.2 foot per mile.

The principal tributaries of the Wolf River in the county are the Waupaca, Little Wolf, and Embarrass Rivers (pl. 1). The northern and northeastern parts of Waupaca County are drained by the Embarrass River and its tributaries, which include the Pigeon River, Bear Creek, and Maple Creek. The central, west-central, and northwestern parts of Waupaca County are drained by the Little Wolf River and its principal tributary, the South Fork of the Little Wolf River. The southwestern and south-central parts of the county are drained by the Waupaca River and the Little River, respectively.

Streamflow data are collected at three gaging stations in Waupaca County. The periods of record, average, maximum, and minimum discharges in cfs (cubic feet per second), and drainage areas are tabulated below (Wells and others, 1960, p. 79–81).

Steam-gaging station	Period of record (years)	Discharge (cfs)			Drainage area (square miles)
		Average	Maximum	Minimum	
Wolf River at New London	62	1, 698	15, 500	150	2, 240
Waupaca River near Waupaca	42	240	2, 520	38	305
Little Wolf River at Royalton	44	40	6, 950	57	485

CLIMATE

The climate of Waupaca County is characterized by mild, humid summers and rather long, severe winters. The mean annual temperature is 45.7°F, and the mean annual precipitation is 29.5 inches. Total annual precipitation at Waupaca from 1895 to 1959 and the cumulative departure from average precipitation are shown in figure 3. Average monthly precipitation and temperature are shown in table 1. About 18 inches of precipitation falls during the growing season, May to September.

TABLE 1.—*Average monthly precipitation and temperature, in inches and degrees Fahrenheit*

[From records of U.S. Dept. Commerce Weather Bureau]

	Precipitation	*Temperature*
January	1.21	18.0
February	1.02	19.3
March	1.57	29.7
April	2.79	45.0
May	3.36	57.6
June	4.64	67.4
July	2.88	72.4
August	3.34	69.8
September	3.37	61.7
October	2.13	50.3
November	2.10	34.8
December	1.12	22.1

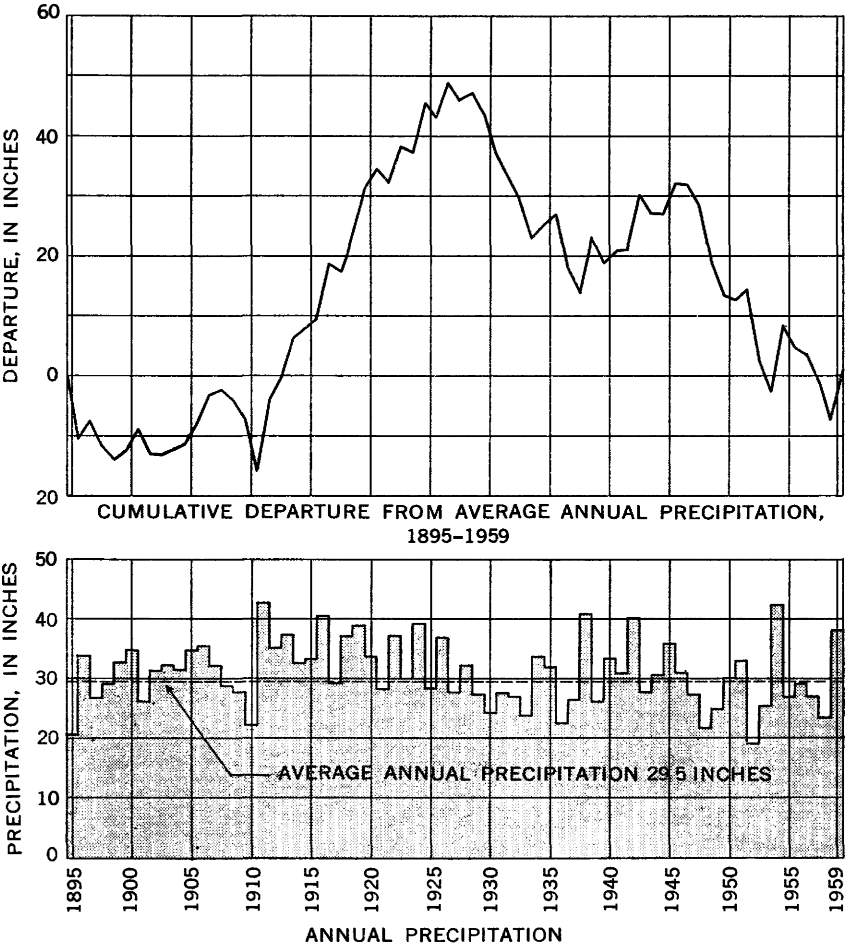

FIGURE 3.—Graphs showing precipitation at Waupaca, Wis. (From records of U.S. Dept. of Commerce Weather Bureau.)

CULTURE

The population of Waupaca County in 1960 was 35,340. From 1950 to 1960 the cities increased by about 7 percent, but the farm population decreased. In 1960, 36 percent of the population lived in cities and the remainder lived on farms or in unincorporated villages.

In 1951, the land was 60 percent in farms, 30 percent in woodlands or forest, and 10 percent in swamps (Wisconsin Conservation Dept., 1954). The estimated 2,820 farms average about 140 acres. Three-quarters of the farms were classified by the U.S. Census in 1954 as dairy farms. About 80 percent of the farm income is from livestock and livestock products. Principal cash crops include potatoes, corn, oats, and cucumbers.

Irrigation of crops is practiced in Waupaca County because of the uneven distribution of rainfall during the growing season. Irrigation of crops began about 1938 and increased on a modest scale until 1958, when it expanded rapidly during 3 consecutive years of below-average precipitation. The principal crop under irrigation in 1958–59 was potatoes. Other irrigated crops include beans, cucumbers, peppers, corn, berries, and melons.

The first industries were sawmills and grist mills that were dependent upon water power. Present-day industry in the county is largely independent of water power. The principal industries are cheese-making, wood products, truck manufacture, and tourist trade. Mineral industries include the production of sand and gravel, crushed rock, and brick clay.

ROCK UNITS AND THEIR WATER-BEARING PROPERTIES

The rocks that occur at the surface and at depth in Waupaca County may be classified in three groups: the crystalline rocks of Precambrian age, the consolidated sedimentary rocks of Cambrian and Ordovician age, and the unconsolidated deposits of Quaternary age. The character and extent of the bedrock units (pl. 2) and of the unconsolidated deposits (pl. 3) control occurrence and distribution of ground water. Discussion of these rock units is necessary to understand the hydrology of the area. A summary of the rock units and their water-bearing properties is given in table 2.

TABLE 2.—*Rock units and their water-bearing properties in Waupaca County, Wis.*

System	Geologic unit	Maximum depth to top (feet) [1]	Maximum thickness penetrated by wells (feet) [1]	Character	Water-bearing properties
Quaternary	Recent deposits	0	30	Alluvium, dune sand, peat, and marl.	Small to large yields depending on thickness and character of material.
	Pleistocene deposits	0	277	Glaciolacustrine deposits; fine sand, silt, clay, and peat.	Generally small yields.
				Till, unstratified and unsorted mixture of clay, silt, sand, gravel, and boulders.	Small to large yields depending on character of material.
				Glaciofluvial deposits; outwash, delta, and terrace deposits; chiefly well-sorted deposits of sand and gravel.	Generally large yields.
				Till and glaciofluvial deposits, undifferentiated.	Small to large yields depending on character of material.
Ordovician	Prairie du Chien Group	35	125	Dolomite, thin- to thick-bedded, locally massive, yellowish-gray to buff; sandy and shaly zones common.	Small yields from joints, solution channels, and sandy zones. Not important in county.
Cambrian	Upper Cambrian Series	265	160	Sandstone, very fine to coarse-grained, well-rounded, yellowish-orange to white or light-gray; alternating layers of soft and hard beds of sandstone; locally silty or shaly.	Small to moderate yields, depending on depth of well penetration, thickness of formation, and character of aquifer. Second most important source of water in county.
Precambrian	Crystalline rocks of Precambian age	303	Unknown	Granite, fine- to coarse-grained, pink, red, medium-gray, dark-gray. Gneiss, schist, and quartzite may occur locally.	Nearly impermeable; yields water locally from weathered or fractured zones.

[1] Reported in well logs.

PRECAMBRIAN ROCKS

Crystalline rocks of Precambrian age underlie Waupaca County and have been reached in many wells throughout the area. For the most part, the rocks of Precambrian age are covered by sediments of Pleistocene age and, in the southeastern part of the county, by sandstone of Cambrian age. The crystalline rocks crop out in several areas in the county, the most extensive of which are as follows: the area around Big Falls; a northwest-trending hill, locally known as Poppy's Rock, 3 miles south of New London; the northern part of Waupaca; and an area 4 miles north of Waupaca along the South Branch of the Little Wolf River (pl. 2).

In Waupaca County, exposures of crystalline rock are granitic, but gneiss, schist, and quartzite may be buried under glacial drift or sandstone. The granite is typically medium grained, but may be aplitic or pegmatitic. It is pink, red, or gray but may be very light gray or almost black. The granite shows little weathering in the outcrop or where overlain by glacial drift. A kaolinitic clay, a product of the alteration of crystalline rocks by acidic ground water (Thwaites, 1931, p. 747), may underlie the sandstone.

The bedrock geology and topography are shown on a map of Waupaca County (pl. 2). The geology is modified from the geologic map of Wisconsin (Bean, 1949) in accordance with field observations and with interpretations of drillers' logs.

The rocks of Precambrian age form a nearly impermeable foundation beneath the water-bearing units. Wells are developed in deposits of sand and gravel and sandstone wherever possible. However, the crystalline rocks may be the only source of water where they are at or near the surface, or where the glacial drift consists of poorly permeable material. In parts of north-central Waupaca County and particularly in the townships of Wyoming, Dupont, and Larrabee, the crystalline rocks are an important source of water for domestic and stock supplies because the glacial deposits do not readily yield water to wells or are above the local water table. To obtain water from the crystalline rocks, a well must intersect fracture or joint systems or penetrate a weathered zone that will yield an adequate quantity of water to the well. Such zones rarely yield more than 10 gpm (gallons per minute) to a well.

CAMBRIAN SYSTEM

The Cambrian System in Waupaca County consists predominantly of sandstone. Although divided into formations in other parts of the State, the sandstone is undifferentiated in this area.

Sandstone of Cambrian age is found principally in the southern part of the county (pl. 2). These rocks overlie crystalline rock and are covered generally by sediments of Pleistocene age. In the southeastern corner of the county, the sandstone is overlain by dolomite of the Prairie du Chien Group. Two buried sandstone outliers, rock separated from the main formation by erosion, occur in the central and northwestern parts of the county, 3 miles northeast of Manawa and 7 miles north-northwest of Iola (pl. 2). The geologic map of Wisconsin (Bean, 1949) shows sandstone in the southern part of T. 22 N., Rs. 11 and 12 E. and in most of T. 21 N., Rs. 11 and 12 E. Drillers' data collected during this study indicates that the Cambrian sandstone is not found as far north as shown by Bean (1949). The sandstone probably underlies the southern part of T. 21 N., Rs. 11 and 12 E.

The sandstone strata range from very fine to coarse grained in sand size and from orange through pale yellowish orange to light gray or white. The exposed sandstone, 2 miles north of Readfield, ranges from soft and friable to moderately hard and well cemented. It is similar to sandstone in western Outagamie County, 1.5 miles east of New London (LeRoux, 1957, p. 8). In drillers' logs the sandstone is reported as red or orange, hard, locally shaly, and becoming white and more coarse grained with increasing depth.

The greatest thickness of sandstone penetrated is 160 feet in well Wp–21/14/25–340, 1.5 miles east of Readfield. The maximum thickness in the county is about 400 feet near Readfield. This is based on the altitude of the sandstone-dolomite contact and the extrapolated altitude of the surface of the underlying crystalline rocks.

The surface of the sandstone, where overlain by dolomite, although apparently flat, actually dips gently southeastward. The surface, where overlain by sediments of Pleistocene age, is hilly due to erosion. The maximum relief is at least 330 feet and occurs about 1 mile southwest of Readfield where the sandstone is deeply incised by a valley of pre-Pleistocene drainage.

The sandstone is an important source of water in T. 21 N., Rs. 13 and 14 E., and in the southeastern half of T. 22 N., R. 14 E. The sandstone occurring in T. 21 N., Rs. 11 and 12 E. has been tapped by only a few wells. Most of the wells in this area obtain water from overlying deposits of sand and gravel. The outlier that is about 3 miles northeast of Manawa is a local aquifer, whereas the outlier in the northwestern corner of the county is too thin to be an aquifer. Where the land-surface altitude is below about 770 feet in the southern part of the county, wells that penetrate the sandstone may flow.

The wells drilled into the sandstone have a specific capacity ranging from about 1 to 10 gpm per foot of drawdown. The specific capacity of most of the wells would probably be greater if penetration into the sandstone were deeper. Most wells investigated penetrate only

10 to 50 feet of water-yielding rock. According to owners, most of the yields obtained are adequate.

Recharge to the sandstone probably occurs by downward percolation and lateral subsurface movement. Where the sandstone is overlain by the dolomite or by relatively permeable sediments of Pleistocene age, vertical percolation is almost certainly the main source of recharge. Where relatively impermeable sediments lie on the sandstone, the aquifer is supplied principally by lateral movement as indicated by local artesian conditions.

ORDOVICIAN SYSTEM

Rocks of the Prairie du Chien Group cap the hills and directly overlie the sandstone of Cambrian age in the extreme southeastern part of Waupaca County (pl. 2). The hills are covered by a thin layer of till. Outcrops of dolomite form bluffs or steep slopes.

The group consists mainly of dolomite, but sandy and shaly zones occur in some outcrops. The weathered surface of rock outcrops is pale brownish gray, pale yellowish brown, or tan; fresh surfaces are yellowish gray or light gray.

In Waupaca County the dolomite reportedly has a maximum thickness of 125 feet but is usually between 30 and 60 feet thick. The dolomite in Outagamie County has a maximum thickness of 235 feet (LeRoux, 1957, p. 7).

The rocks of the Prairie du Chien Group are not important as an aquifer in Waupaca County. Well Wp–21/14/13–357 obtains water from the dolomite. Well drillers and property owners report that the dolomite yields little water to wells, that the water is excessively hard, and that a more desirable supply is obtained by drilling through the dolomite into the sandstone.

Recharge to the dolomite is mainly by downward percolation of precipitation that falls on the overlying sediments. The dolomite in turn transmits water downward to the sandstone of Cambrian age.

BEDROCK TOPOGRAPHY

Before Pleistocene glaciation began, the surface of the bedrock was probably similar to the present-day topography in the "Driftless area" in southwestern Wisconsin. The "Driftless area" is characterized by well-defined divides and deeply incised valleys. Glacial erosion modified the bedrock topography in Waupaca County by planing hilltops and altering the shapes of the valleys. Rock debris was deposited over most of the bedrock in the county by glaciers and their associated streams and lakes.

The general character and most of the dominant features of the bedrock topography are shown on plate 2. The topography of the bedrock surface is shown by contour lines based on data from drillers' logs and on the altitude of outcrops. Poor distribution of subsurface control and the irregularity of the bedrock surface tend to limit the accuracy of this map.

The dominant feature of the bedrock topography is a deep valley in the southeastern part of the county. The valley follows the eastern Waupaca County line from near Embarrass to New London, and then trends southwestward to Fremont. The valley continues southward into Waushara County.

Tributary valleys near Fremont joint the major valley from the east and west. Those entering from the east are deep and narrow, and have a steep gradient. They are separated by flat-topped ridges and are continuous with those shown by LeRoux (1957, pl. 4). The tributary valleys that enter from the west drained a bedrock highland in western Waupaca County.

Bedrock data for western Waupaca County and eastern Portage County are scarce. In this area, the bedrock generally is covered by a thick mantle of glacial deposits that readily yield water to wells. Therefore, bedrock is rarely penetrated by wells.

The amount of water yielded by wells penetrating Quaternary deposits in Waupaca County is determined by the thickness and permeability of the deposits. Generally, the thickness is controlled by the bedrock topography. Deposits overlying bedrock valleys are thicker than those overlying bedrock hills. Permeable zones are more likely to be found in the thicker than in the thinner deposits.

QUATERNARY SYSTEM

Deposits of Quaternary age cover Waupaca County and are the principal source of water. The surficial geology is shown in Plate 3, adapted from Thwaites (1943).

The Quaternary System is divided into the Pleistocene and Recent Series. The Pleistocene Series is divided into stages on the basis of major continental ice-sheet advances. However, the lithologic and hydrologic characteristics of the Pleistocene sediments and those of the Recent Series are so simliar that separation of them is not possible without detailed field study. Deposits of Recent age locally mantle the sediments of Pleistocene age; where applicable in the following paragraphs, deposits of Pleistocene and Recent ages will be discussed together.

The deposits of Pleistocene age in Waupaca County are divided as follows: (1) till, (2) glaciolacustrine (lake), (3) glaciofluvial (stream), and (4) eolian (wind). The deposits of Recent age are principally alluvium, dune sand, and lake deposits including peat and marl.

TILL

Till is unstratified, unsorted glacial drift deposited from the ice without subsequent movement by water (Thwaites, 1943, p. 102). It may be heaped up as moraines or drumlins, or spread out thinly as ground moraine. Till deposits representing two or more ice-sheet advances may rest on top of one another, or may be separated by other sediments. Depressions called kettles resulted from the melting of blocks of ice that were buried in till. Lakes or ponds exist where the local water table is higher than the bottom of the kettles.

Till consists of clay, silt, sand, gravel, and boulders. Any single constituent may be predominant, but mixtures are common. During the investigation, 11 samples of till were collected for hydrometer or sieve analysis; an additional five analyses were obtained from the Soil Survey Division, Wisconsin Geological and Natural History Survey. The histograms of the till samples (fig. 4) show that silt and clay are common. By contrast, the glaciofluvial, glaciolacustrine, and eolian deposits (fig. 5) are predominantly sand or sand and gravel, and they contain only small amounts of silt and clay.

The till is very thin in some places, but it is at least 200 feet thick in the drumlins south of Waupaca. It commonly ranges in thickness from 20 to 100 feet.

Water yield from till is unpredictable. If a well penetrates till that consists predominantly of sand and gravel, comparable to sample Wp–24/12/32–R12 (fig. 4), small to moderate supplies of water may be yielded to the well. By contrast, a well penetrating a till comparable to sample Wp–24/13/32–R23 (fig. 4) probably would yield little or no water. The specific capacity for wells in till is generally less than 5 gpm per ft of drawdown.

GLACIOLACUSTRINE DEPOSITS

Glaciolacustrine sediments were deposited in the lakes of Pleistocene age that were between the ice front and the terminal moraines or highlands. These glacial lakes were drained as the ice sheets melted. Glaciolacustrine deposits are at or near the surface in the southeastern quarter of the county and in the northeastern corner of the county in T. 25 N., R. 15 E. A thin veneer of dune sand or ground moraine mantles lacustrine deposits in many places. In much of the eastern half of the county, lacustrine deposits are covered by thick deposits of till or glaciofluvial sediments.

Lacustrine deposits in Waupaca County are predominantly stratified silts or fine sands. The sieve analysis of sample Wp–22/13/15–R4 (fig. 5), a lacustrine sand, is typical of the coarser grained material. The fine glaciolacustrine sediments, usually reported as clay by the driller, are predominantly silt and typically contain less than 50 percent clay. Gravel generally is absent. Where gravel (including boulders) is associated with lake beds, its source is related to delta, beach, or ice-rafted material. Strata of lacustrine deposits may be separated by till or outwash. Peat is common in many parts of the county. It generally represents a late stage of lake development and may be interbedded with lacustrine sediments.

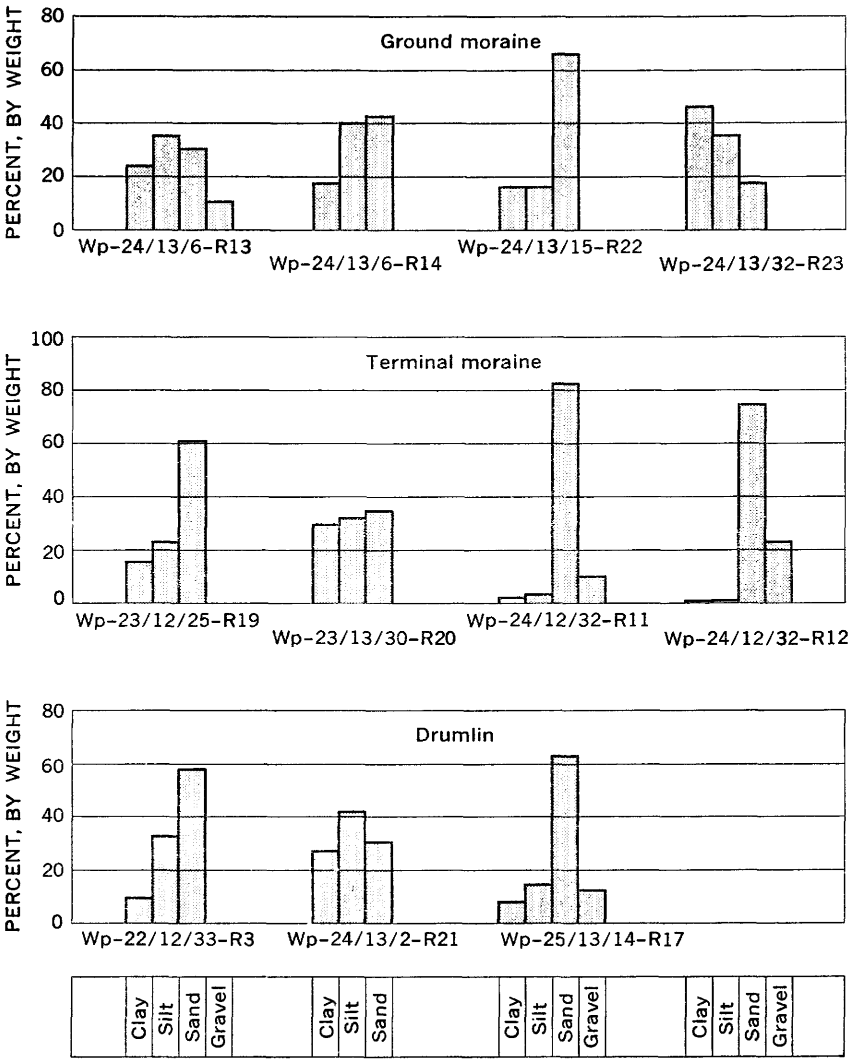

FIGURE 4.—Histograms of till samples, Waupaca County, Wis. Sampling locations shown on plate 3.

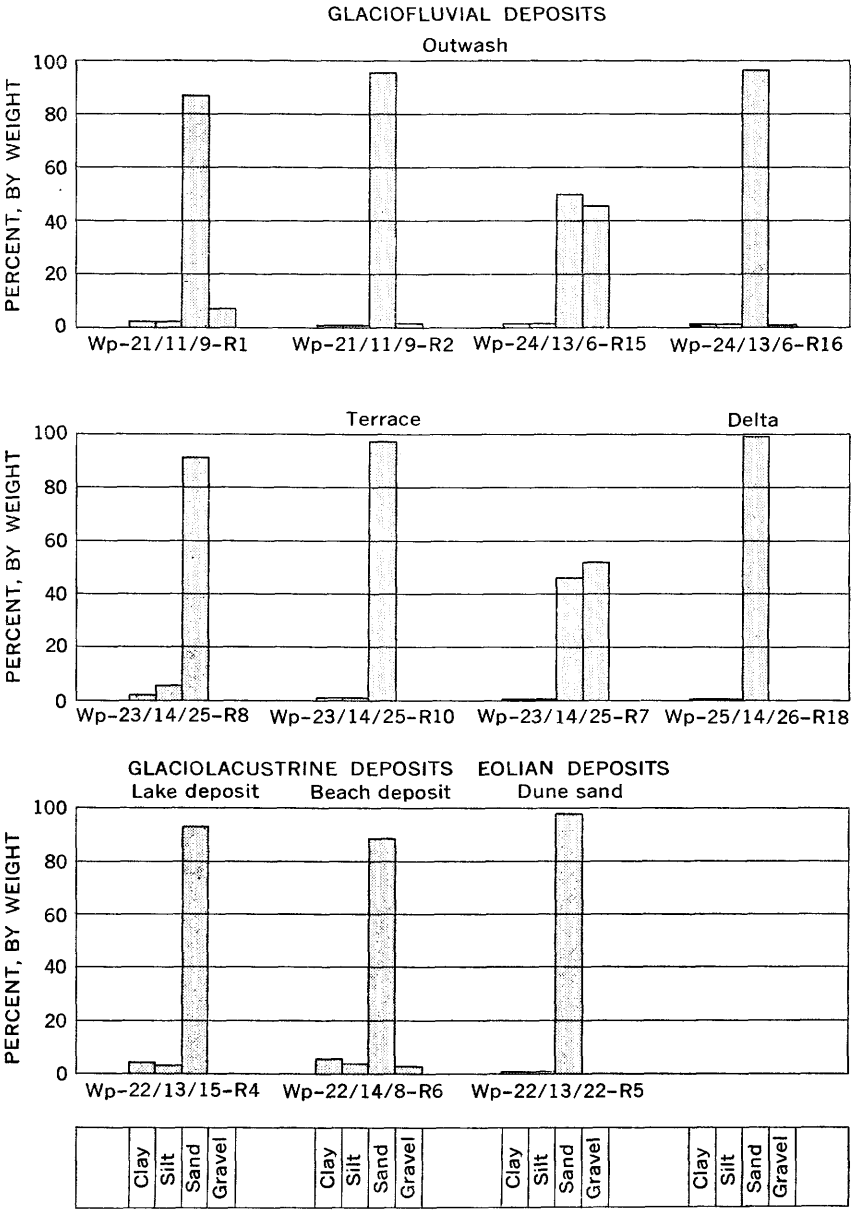

FIGURE 5.—Histograms of glaciofluvial, glaciolacustrine, and eolian deposits, Waupaca County, Wis. Sampling locations shown on plate 3.

Water-sorted beach deposits are marginal to lacustrine deposits and many are similar to outwash deposits. They are developed by wave action on the adjacent land.

The thickness of the lacustrine sediments is apparently between 100 and 200 feet, but may be as much as 300 feet in several places along the Wolf River. The thickness of interbedded nonlacustrine drift is at least 50 feet in wells Wp–21/13/21–308 and WP–22/14/35–383.

Most wells inventoried in lacustrine deposits yield between 5 and 25 gpm. The yields from wells range generally from less than 5 gpm to as much as 425 gpm. The specific capacity is generally less than 10 and may be less than 1 gpm per ft of drawdown.

Some wells in lacustrine deposits yield water that has a musty or sulfurous odor. The odor is a result of contact of ground water with organic material, such as peat, in these sediments.

GLACIOFLUVIAL DEPOSITS

Glaciofluvial deposits are materials that were sorted and stratified by melt water from the glaciers. They include outwash, delta, and terrace deposits, and the sediments associated with ice-contact features such as eskers, kames, and crevasse fillings. Outwash deposits were sorted and deposited by streams that flowed out from the ice front. Where glacial streams flowed into a lake, deltas of sand and gravel were formed. These may coalesce with outwash. The moving water also eroded the flanks of the drumlins and moraines; it removed the fine sediments and left behind the coarse materials associated with terrace deposits. Ice-contact features are the result of the movement of melt water between the ice and the adjacent till masses. The sediments in these deposits can change within a few feet laterally from a gravelly clay till to a well-sorted sandy gravel.

The surface of outwash plains and terraces is flat, in general, and has a gentle downstream gradient that may have been altered by erosion. Outwash deposits are found principally in the transverse valleys through the terminal moraines and in the broad, flat intermorainal valleys. Terraces are common along most of the course of the South Branch of the Little Wolf River and its tributaries in the western and northwestern parts of the country. The surface of outwash deposits may be pitted with kettles, or it may be hummocky because of a thin uneven layer of ground moraine. The "Chain o'Lakes" near Waupaca and the lakes about 5 miles north of Iola occupy kettles in outwash. Delta deposits are found in association with many lacustrine deposits. They also may occur near channels coalescing with the outwash deposits. The sorted materials of the ice-contact features are associated with most moraines and may grade imperceptibly into outwash.

Outwash deposits are predominantly sand, but locally, gravel may be the major constituent. Clay and silt commonly are present in minor amounts (fig. 5). Because these sediments have been sorted by water moving at varying rates, layers of sand, gravel, silt, and clay may be interbedded.

The thickness of outwash deposits varies from area to area, and the thickest deposits are in the southwestern part of the country. Well Wp-21/11/8-86 tapped 132 feet of fine to coarse sand.

The glaciofluvial deposits, particularly outwash and delta materials, are the principal aquifers in Waupaca County. All but one of the irrigation wells and all the municipal and industrial wells that yield more than 500 gpm obtain water from these deposits. The amount of water yielded to wells from these sediments is dependent upon three things; (1) the grainsize and the degree of sorting, (2) the thickness and areal extent of the saturated material, and (3) the length of screen in a well. Yields of 1,000 gpm with about 30 to 50 feet of drawdown are reported for several wells. Specific capacities generally are larger than 10 and may be over 160 gpm per ft of drawdown.

Recharge to the fluvial deposits is from local precipitation. In many places the deposits are permeable enough to absorb even unusually heavy precipitation with little runoff if the ground is not frozen.

EOLIAN DEPOSITS

Eolian deposits of Recent and Pleistocene age include dune sand and loess. These may occur either as a mantle or interbedded with deposits of other origin. In Waupaca County, dune sand is found mainly on the lake beds east of the Wolf River in the southeast part of the county and between the Embarrass and Wolf Rivers in T. 25 N., R. 15 E. Loess was tentatively identified overlying outwash or till in many places in west central Waupaca County, for example, on the north side of the town road in SE¼SW¼, sec. 17, T. 22 N., R. 11 E.

The eolian deposits, consisting of silt or sand, generally are well sorted. A sample from a dune derived from lake deposits, Wp-22/13/22-R5 (fig. 5), consists of 98 percent sand, 86 percent being medium and fine and 12 percent being very fine. The remaining 2 percent is silt and clay.

The thickness of the eolian deposits may be as much as 30 feet in the highest dunes, but is generally a few inches to 15 feet. Loess probably is less than 3 feet thick.

Although surficial eolian deposits are generally above the water table and are not important as aquifers, they may facilitate local recharge because of their permeability.

GROUND WATER

The water-yielding sediments of Quaternary and Cambrian age constitute a large ground-water reservoir. Assuming that the average thickness of saturated sediments is 100 feet and the average porosity is 10 percent and the area of the county is about 480,000 acres, the amount of water in underground storage is about 5 million acre-feet (16×10^{11} gallons) or about four times the average annual precipitation. Ground water in the county is distributed fairly evenly, although aquifers (water-yielding formations) are not. Water stored in saturated silt or clay is not readily available to wells, whereas water in saturated sand and gravel is.

The water table is the upper surface of the zone of saturation except where that surface is formed by a bed of relatively impermeable material which confines the water under artesian pressure. When a well penetrates a confined aquifer downdip from its intake area, hydrostatic pressure causes the water to rise above the confining layer. The imaginary surface to which water will rise in artesian wells is called the piezometric surface of the confined water. The height to which the water rises above the aquifer is called the piezometric or artesian head. The well will flow if the piezometric head is above land surface.

In the western part of Waupaca County, water in glaciofluvial deposits and in till generally is under water-table conditions. Glaciolacustrine deposits and till locally confine the water in sand and gravel aquifers near the village of Rural (well Wp–21/11/9–165) and along parts of the Wolf River.

In eastern Waupaca County, both artesian and water-table conditions occur within the ground-water reservoir, and it is possible to have a shallow water-table well and a deep artesian well.

The water table in most of Waupaca County is within 50 feet of land surface. Wells drilled through drumlins or moraines may tap water at greater depths, but generally within 120 feet of land surface. The water table in many parts of the county is at or only a few feet below land surface. Lake and stream surfaces are continuous with the water table. Most of the lakes and swamps in the county may be considered as exposures of the water table.

RECHARGE AND DISCHARGE

Ground water in Waupaca County is a renewable resource that is replenished from precipitation. Ground water moves down gradient and may be discharged from wells, through transpiration by plants, or from seeps and springs into streams.

The capacity of the soil to hold or to transmit water downward determines how much of the precepitation will pass through the soil and recharge the underlying reservoir. Because sandy soils generally are much more permeable than clayey soils, the proportion of rainfall reaching the zone of saturation in the areas of outwash and sandy till is greater than in the areas of clayey till and lake beds. Direct determinations of the amount of recharge to an aquifer are not possible without complex and detailed studies. The amount of recharge may be determined indirectly by measuring the discharge, if discharge from a ground-water reservoir, for a given period, is assumed to balance recharge.

Normally, recharge to the ground-water reservoir is greatest in the spring after the frost in the ground melts and water from snow melt and from spring rains percolates into the soil. During the warm months of the growing season, a large percentage of the precipitation that falls is transpired by plants or evaporated and is not available for recharge. After the first killing frost and before the ground freezes, recharge to the ground-water reservoir may increase. Evapotranspiration and evaporation are at a minimum during this period, and much of the precipitation that falls is available for recharge. However, average monthly precipitation is only 1–2 inches during October and November (fig. 3). Frost in the ground during the winter months prevents precipitation from reaching the ground-water reservoir.

In Waupaca County, ground water is discharged principally by seepage into streams and by evaporation and transpiration. A spring is a place of natural discharge of ground water upon the land surface or into lakes and streams. In Waupaca County two types, seepage springs and contact springs, have been observed. Seepage springs are found where the zone of saturation intersects the land surface. Depending upon the rate of discharge and upon the topography, the water may discharge into a stream, or it may accumulate in a pond or marsh and evaporate. During periods when the water table is relatively low, seepage springs may cease to flow. Contact springs, seen in the southeast corner of the county, occur where the contact between a permeable and comparatively impermeable formation is exposed at the surface. For example, ground water may percolate downward through the glacial drift to the top of the less permeable dolomite of the Praire du Chien Group, where some of the water moves laterally and issues as springs at the outcrop.

The evaporation and transpiration loss may be estimated by subtracting the average annual discharge, expressed in inches, of the Waupaca and Little Wolf Rivers from the average annual precipitation. Runoff, including ground-water discharge, for the two streams is about 36 percent of precipitation for a 22-year period. Average daily precipitation in the county is about 1,000 mgd (million gallons per day), about 400 mgd runs off in streams and about 600 mgd is lost through evapotranspiration. Pumpage from wells for all uses in 1959 was estimated to be about 4 mgd (p. U28).

MOVEMENT

When water reaches the zone of saturation, its direction of movement becomes nearly horizontal. Unless intercepted by a discharging well, the water continues its lateral movement to areas of natural discharge. The rate of movement is governed by the permeability of the material through which the water moves and by the steepness of the hydraulic gradient. In Waupaca County, the rate of movement in sand and gravel may be as high as a few feet per day, whereas in clay and silt the rate would be much lower.

The direction of ground-water movement and the configuration of the piezometric surface in Waupaca County in 1958–59 are shown in plate 4. The piezometric map represents the configuration of the water-table surface in areas where the principal aquifer is unconfined and the piezometric surface in areas where the aquifer is confined. The hydraulic gradient ranges from a few feet to nearly 60 feet per mile and averages about 14 feet per mile. The general direction of ground-water movement in the county is southeastward to the Wolf and Embarrass Rivers, which serve as drains. The movement locally may be in any other direction because ground water discharges into streams that intercept the piezometric surface or water table.

Pumping a well results in a steep hydraulic gradient toward the well, lowers the water surface around the well, diverts water from its normal path, and causes the water to move toward the well at an accelerated rate. The depression in the water table or piezometric surface is called a cone of depression. The steepness of the hydraulic gradient toward a well and the area of the cone of depression are governed by the capacity of the aquifer to transmit water and by the rate at which water is discharged from the well. At a given rate of pumping, an aquifer of low permeability will develop a steeper cone of depression than an aquifer of high permeability. The effects of pumping a well are illustrated in figure 7.

WATER-LEVEL FLUCTUATIONS

Fluctuations of water levels in wells reflect changes in the amount of ground water in storage or changes in artesian pressure. During periods of rising water levels the addition to storage exceeds discharge from storage, and during periods of falling water levels the reverse is true. The relation of precipitation to recharge is discussed and illustrated by Audini and others (1959). Unlike water stored in a surface reservoir, the surface of stored ground water may rise in some parts of an area and at the same time fall in other parts.

As part of the investigation in Waupaca County, water-level measurements were made periodically, usually once each month, in 34 observation wells. In addition, water-level recorders were installed in three wells during the period of field investigation. Measurements were made at infrequent intervals in numerous other wells during 1958–60. Records of representative wells are shown in table 3. Hydrographs for four of these wells and one each in Portage and Waushara Counties are given in figure 6.

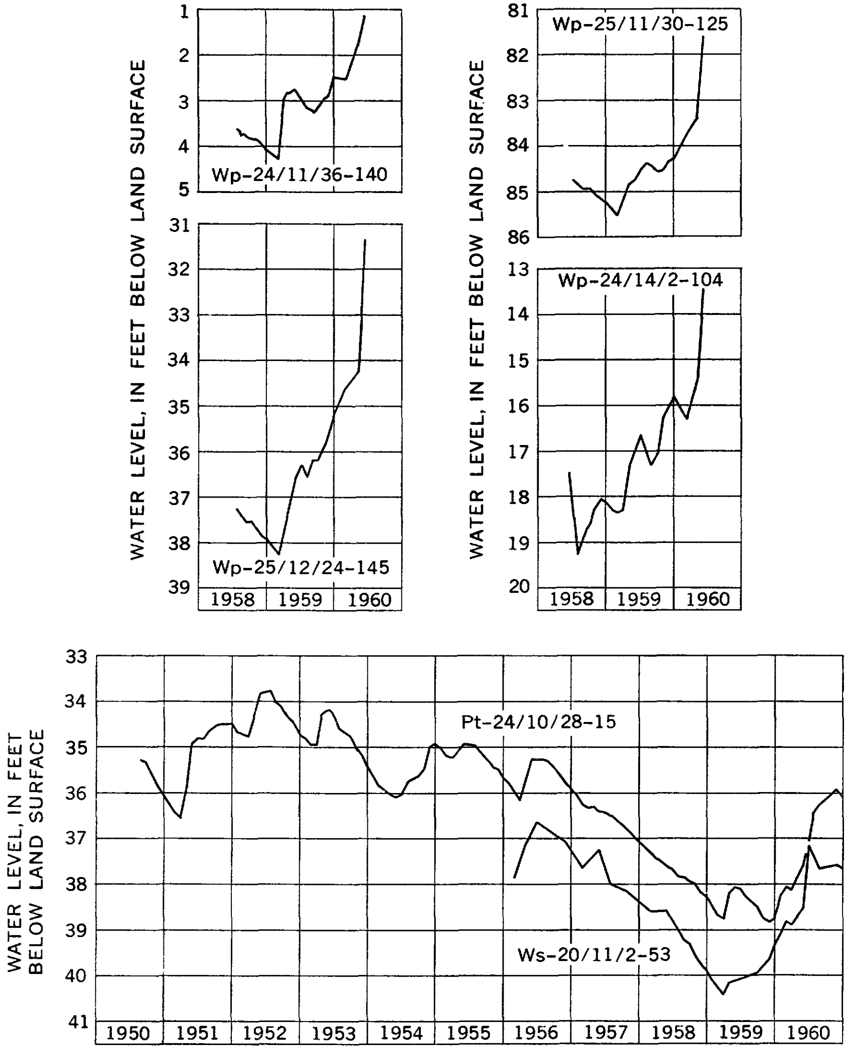

FIGURE 6.—Hydrographs for wells Wp–24/11/36–140, Wp–25/11/30–125, Wp–25/12/24–145, and Wp–24/14/2–104 in Waupaca County; well Pt–24/10/28–15 in Portage County; and well Ws–20/11/2–53 in Waushara County, Wis.

TABLE 3.—*Records of representative wells in Waupaca County, Wis.*

Well: See explanation of well-numbering system in text.
Type of well: Dn, driven; Dr, drilled; Du, dug; J, jetted.
Water level: Water levels shown in feet are reported; those in feet and tenths are measured.

Geologic source of water: Q, Quaternary System; O, Ordovician System; Є, Cambrian System; and pЄ, Precambrian rocks.
Use: D, domestic; In, industrial; Ir, irrigation; P, public supply; S, stock; U, unused.

Well Wp-	Quarter sections		Owner	Year completed	Type of well	Depth of well (feet)	Depth of casing (feet)	Diameter of well (inches)	Depth of screen (feet)	Geologic source of water	Altitude of land surface (feet)	Water level		Use
												Above (+) or below land surface (feet)	Date of measurement	
21/11/ 7-60	NW	NE	W. G. McCrosson	1958	Dr	120	107	20	107-125	Q	934	16.4	4-30-58	Ir
8-86	SW	SW	Laux and Mumbrue	1958	Dr	130	60	18	60-131	Q	930	26.8	6-18-58	Ir
9-38	SW	SE	Red Dot Foods, Inc	1957	Dr	80	45	20	45- 85	Q	911	28.0	4-30-58	Ir
-63	SE	SW	do	1941	Dr	94	------	4	------	Q	904	21.5	5-27-58	U
-165	NE	NE	Whittsley and Crow	------	Dn	28	25	2½	25- 28	Q	886	4.7	7-31-58	S
-184	SW	SE	Red Dot Foods, Inc	1959	Dn	32	31	1¼	31- 32	Q	911	28.8	5- 6-59	U
-186	SE	SW	do	1959	Dn	41	40	1¼	40- 41	Q	908	24.2	5- 6-59	U
16-185	NW	NE	do	1959	Dn	42	41	1¼	41- 42	Q	911	27.6	5- 5-59	U
18-231	NW	SE	A. Johnson	1959	Dr	68	49	18	49- 73	Q	943	30.7	10-27-59	Ir
20-252	NW	SE	L. Suhs	1959	Dr	46	30	18	30- 50	Q	903	8.6	6-12-59	Ir
27-47	SW	NE	Newsome Bros	1958	Dr	63	37	18	37- 68	Q	894	9.7 11.6	4-30-58 9- 1-59	Ir
32-42	SE	NW	E. Minton	1958	Dr	58	38	12	38- 63	Q	924	11.8	4-30-58	Ir
21/12/ 2-249	SW	NW	T. Johnson	1910	Dr	240	75	2	------	Q	796	+3.0	6- 5-59	D, S
3-248	SW	NW	do	1947	Dn	25	22	1¼	22- 25	Q	796	4	1947	S
13-276	NE	NE	A. Cohen	1956	Dr	113	113	6	------	Q	847	32.5	6-19-59	D, S
16-244	SW	SE	Lind Center School	1900	Dr	130	------	4	------	Q	806	+3.4	6- 4-59	D
18-85	SE	NW	Laux and Mumbrue	1958	Dr	153	8	18	87-159	Q	855	17.1	6-24-58	Ir
26-277	SE	NW	A. Baehman	1906	Dr	------	------	4	------	Q	800	+8.8	6-19-59	S
31-236	SW	NW	Cedar Lake School	1958	J	52	52	2	------	Q	------	26	9- -58	D
21/13/ 4-44	NE	SW	City of Weyauwega	1944	Dr	168	93	30, 16	63-168	Q	803	17	7- -44	P
-54	NE	SE	do	1931	Dr	94	74	24	74- 94	Q	796	14	1936	P
5-55	NW	SE	Mellen Bros	1957	Dr	140	138	4	138-140	Q	776	10.5	7-10-58	D
15-306	NE	NW	M. Ebert	1910	Dr	70	65	3	65- 70	Q	787	18	------	D, S
16-314	NE	SW	H. Koehler	1956	Dr	94	85	6	86- 94	Є	782	11	5- -56	D, S
17-292	NE	SW	O. Larsen	1937	Dr	65	60	4	60- 65	Є	828	36.2	6-22-59	D, S
21-308	NE	NW	A. Zemple	1957	Dr	125	111	4	111-125	Є	802	30.1	6-24-59	D, S
25-2	NE	SW	Village of Fremont	1950	Dr	205	109	8	109-205	Є	764	13.7	8- 3-50	P
35-311	SE	SE	E. Marquardt	1956	Dr	318	260	6	260-318	Є	771	6	1- -56	D, S

TABLE 3.—*Records of repesentative wells in Waupaca County, Wis.*—Continued

Well Wp-	Quarter sections	Owner	Year completed	Type of well	Depth of well (feet)	Depth of casing (feet)	Diameter of well (inches)	Depth of screen (feet)	Geologic source of water	Altitude of land surface (feet)	Water level		Use
											Above (+) or below land surface (feet)	Date of measurement	
21/14/ 4-371	NW NE	W. Seafeld	1958	Dr	150	130	4	130-150	Ꞓ	801	6	10- -58	D, S
8-154	NE NE	A. and C. Pomerening	1953	Dr	300	228	8	228-300	Ꞓ	789	2.3	1- 8-59	Ir
9-372	SE NE	F. Ernst	1958	Dr	200	170	4	170-200	Ꞓ	792	+.7	7-17-59	D, S
13-357	SE SE	C. Kaczor		Dr	55		4		O	877	30.0	7-16-59	D, S
17-312	NE SW	Minneapolis, St. Paul, & Sault Ste. Marie R.R.		Dr	24	24	8, 6			782	8.7	5- 5-60	In
23-156	SE SW	Zion Lutheran Church	1937	Dr	168	60	4	70-168	Ꞓ	878	37	5- -37	D
25-340	NE NE	McHugh Bros	1950	Dr	235	75	6	75-235	Ꞓ	896	71.1	7-10-59	D, S
26-375	NW NE	G. Retzlaff	1959	Dr	128	56	6	56-128	Ꞓ	873	44.5	8-16-59	D
30-318	SW SE	Silverfield Cheese Factory	1953	Dr	284	265	6	265-284	Ꞓ	755	+6	3- -53	In
34-337	NW NE	A. Tews	1900	Dr	277	277	3		Q	761	+17	1900	D, S
22/11/8-21	NE SW	Sheridan School	1958	Dr	59	54	6	54- 59	Q	961	22.2	5-26-58	D
21-37C	SW SE	R. Erickson	1957	Dr	46	31	30	31- 46	Q	921	10.1	7-21-58	Ir
-230	SE NW	R. Erickson, Jr		Dr	55	30	18	30- 55	Q	921	8.7	8-26-59	Ir
											8.5	10-28-59	
25-632	NW NE	F. Strebe	1958	Dr	176	129	6		pꞒ	908	35	4-18-58	D
29-29	SW SE	E. Huntoon	1954	Dr	80	26	12, 6	26- 80	Q	912	3	8- -54	Ir
											2.8	8-26-59	
35-108	NW SW	G. Johnson	1958	Dr	177	177	4		Q	896	7.4	6-24-58	D
-188	SE NW	F. Woolsey	1959	Dn	32	29	2	29- 32	Q	897	8	5- -59	D
											7.8	10-29-59	
											7.9	1- 4-60	
											7.7	5- 4-60	
-250	SE NW	do	1959	Dn	68	64	1¼	64- 68	Q	897	8.5	6-11-59	D
											8.5	10-29-59	
											8.4	1- 4-60	
22/12/6-505	NW SE	L. Kienert	1958	Dr	70	70	4		Q	931	40	6- -58	D, S
12-448	NE SE	W. Rasmussen	1958	Dr	178	112	4		pꞒ	850	20	8- -58	D, S
23-452	SE NE	G. W. Rodmann	1958	Dr	120	60	4		pꞒ	837	30	7- -58	D, S
28-45	NE NW	City of Waupaca	1957	Dr	88	92	4	92-102	Q	836	26	11- -57	U
											24.2	5-29-58	
-619	SW NE	Berwind Fuel Co	1959	Dr	80	75	6	75- 80	Q	832	18	12- -59	In
30-25	SE NE	City of Waupaca	1950	Dr	45	25	26	25- 45	Q	828	4.8	1- -50	P
-53	NE SE	do	1922	Du	34	34	36	28- 31	Q		13.5	19 50	P

22/13/5-444	NW	SE	C. Soffa	1958	J	140	140	2	-----	Q	803	+2	5- -58	D
												+2.1	8-12-59	
24-430	NW	NW	B. Bridges	1957	Dr	64	61	2	61- 64	Q	830	10	9- -57	D,
32-24	NE	SW	Waupaca County Hospital	1944	Dr	223	214	15, 10	214-223	Q	806	10.0	2-20-59	D
-36	NE	SW	do	1958	Dr	200	184	8	184-200	-----	795	+3	10- -58	D
												+2.9	8- 6-59	
22/14/1-10	SW	SE	City of New London	1940	Dr	118	75	16	75-118	Q	760	2	9- -52	D
-362	SW	SE	H. C. Schmallenberg	1959	Dr	138	128	6	128-138	Q	760	8.4	7-27-59	D
3-398	NE	SW	C. Soffa	1955	Dr	211	202	4	-----	p€	829	55	6- -55	D
8-73	SW	NW	Girl Scouts of America	1954	Dr	215	92	6	-----	p€	783	11.0	5-28-58	D
12-13	SW	NE	Green Bay and Western Railway	1949	Dr	203	190	10	190-203	Q	764	9.8	11- 7-58	U
13-11	NE	NW	City of New London	1937	Dr	128	108	16	108-128	Q	767	-----	-----	P
-12	NW	SE	do	1946	Dr	170	130	16	130-170	Q	799	29	1946	P
-28	SW	SE	do	1954	Dr	165	107	16	107-165	Q	810	43½	1954	P
25-413	NW	NW	A. Delzer	1900	Dr	102	40	4	-----	p€	811	20	1950	D, S
27-418	SE	NE	Huntley Bros	1945	Dr	175	139	4	139-145	€	784	5.6	8-10-59	D, S
35-383	SE	SE	C. Schadler	1942	Dr	132	104	4		Q	799	-----	-----	D
23/11/8-503	SW	SW	L. E. Leppen	1955	Dr	55	55	4	-----	Q	1,001	42.6	8-25-59	D, S
22-348	NE	NE	Scandinavia Creamery Co	1959	Dr	52	48	6	48- 52	Q	926	30	-----	In
25-69	NE	NE	Elm Valley School	1955	Dr	34	31	2	31- 34	Q	887	6.4	8-25-59	D
30-501	SE	NW	R. Bergen	1957	Dr	212	207	6	207-212	Q	1,089	112	11- -57	D, S
23/12/1-611	SW	SW	D. Kosmerchock	1957	Dr	70	70	6	-----	Q	886	30	6- -57	D, S
13-613	SW	NE	P. Hansen and Son	1954	Dr	206	89	6	129-206	p€	875	40	3- -54	D, S
												26.4	10- 1-59	
35-626	SW	SW	H. Abrahamson	1954	Dr	106	102	6	102-106	Q	-----	70	9- -54	D, S
23/13/3-630	SE	SE	R. Fahser	1956	Dr	127	124	6	124-127	p€	849	35	5- -56	D, S
8-589	NW	SW	A. Buchholz	1960	Dr	309	97	6	285-309	p€	863	19	12- 8-59	D, S
-590	NE	SE	L. Ferg	1957	Dr	150	144	6	144-150	Q	864	27.5	9-29-59	D, S
13-628	NW	NW	T. Bonikowske	1959	Dr	70	33	6	33- 70	€	962	21	5- -59	D, S
16-27	NE	SE	City of Manawa	1954	Dr	73	58	16	58- 73	Q	812	14.3	4-24-58	P,
25-595	NE	SW	Eder Bros	1957	Dr	115	115	4	-----	Q	812	2.9	9-29-59	D, S
23/14/1-577	NW	SW	E. Kronberg	1935	Dr	190	190	5	-----	Q	832	22.2	1- 6-60	D, S
-578	NW	SW	do	1910	Du	20	20	38	-----	Q	832	8.3	1- 6-60	D, S
10-573	SE	SW	C. Pirner	1955	Dr	317	154	6	282-317	p€	812	+1	12- -55	D, S
18-572	NW	NW	H. Griffin	1958	Dr	75	60	4	60- 75	€	891	30	10- -58	D, S
22-582	SE	NE	E. Moeller	1954	Dr	95	90	4	90- 95	Q	870	61.6	9-24-59	D, S
25-581	NE	NE	H. Prochnow	1954	Dr	103	98	6	98-103	Q	794	19.7	9-24-59	D, S
24/11/5-479	NE	SE	A. H. Amundson	1953	J	50	46	2	46- 50	Q	-----	34	1953	D, S
16-481	NW	SW	O. L. Twetan	1956	Dn	22	19	1¼	19- 22	Q	981	9	1956	D, S
31-490	SW	SW	H. Wallen	1957	Dr	142	138	4	138-142	Q	1,150	116	6- -57	D, S
35-498	NW	SE	S. Cleaves	1959	Dr	35	32	2	32- 35	Q	965	20	8- -59	D
36-140	SW	SE	H. Jensen	1958	Dn	11	10	1¼	10- 11	Q	949	2.9	12- 2-59	U
24/12/1-119	NE	SE	Shady Grove School	1938	Dr	43	43	4	-----	Q	909	38.6	7-14-58	D
												37.1	12- 2-59	
24-157	NE	NE	Sidehill View Cheese Factory	1950	Dr	44	40	4	40- 44	Q	890	19	1950	In
31-384	SE	SE	P. Wasrud	1959	Dr	143	68	4	-----	p€	964	40.0	7-22-59	D, S
33-606	SE	NE	B. F. LaStofka	1956	Dr	82	77	6	77- 82	Q	930	48	3- -56	D, S

TABLE 3.—*Records of repesentative wells in Waupaca County, Wis.*—Continued

Well Wp-	Quarter sections	Owner	Year completed	Type of well	Depth of well (feet)	Depth of casing (feet)	Diameter of well (inches)	Depth of screen (feet)	Geologic source of water	Altitude of land surface (feet)	Water level: Above (+) or below land surface (feet)	Water level: Date of measurement	Use
24/13/11-603	NW SW	L. Prill	1952	Dr	120	120	4	----------	pꞒ	863	27	5- -52	D, S
											24.7	9-30-59	
12-602	NE NW	B. Kutchenriter	1954	Dr	73	73	4	----------	Q	889	37.5	9-30-59	D, S
16-339	SW NE	Stoney Ridge Farmers' Cheese Factory.	1960	Dr	350	--------	4	200-350	pꞒ	881	----------	----------	In
24-600	NE NW	F. Rasmussen	1954	Dr	85	85	6	----------	Q	878	25	7- -54	D, S
											26.7	9-30-59	
36-599	NW SW	L. Jaeger	1957	Dr	316	80	6	308-316	pꞒ	921	58	1- -57	D, S
											74.1	9-30-59	
24/14/2-104	SE SE	Town of Bear Creek	--------	Dr	153	--------	6	----------	Q	840	17.5	6-23-58	D
											16.0	12- 2-59	
20-565	NE NE	Mrs. N. Flannery	1954	Dr	247	164	6	----------	pꞒ	880	27	10- -54	D, S
25-569	NE NW	Bear Creek Corners Cheese Factory.	1955	Dr	153	145	6	145-153	Q	857	26	11- -55	D, S
											32.4	9-23-59	
31-571	SW NE	D. Johnson	1959	Dr	91	91	6	----------	Q	843	8	----------	D, S
25/11/5-126	NW SE	A. Stanislawski and Sons	1958	Dr	44	20	18	20- 44	Q	1,091	6.3	12- 2-59	Ir
18-130	SE SW	E. Ferg	1958	Dr	141	43	6	128-141	pꞒ	1,202	40	4- -58	D, S
24-510	NE NE	J. Nitke	1957	Dn	20	17	1¼	17- 20	Q	1,008	5	1957	D, S
28-472	SE SW	A. Bergen	1955	Dr	52	38	5	38- 52	Ꞓ	1,021	20	8- -55	D, S
-475	SW SE	R. Lashua	1955	Dr	64	53	6	----------	pꞒ	1,015	15.2	8-20-59	D, S
30-125	NE NW	H. Halverson	1935	Dr	112	110	4	----------	Q	1,163	84.8	7-15-58	U
											84.4	12- 2-59	
25/12/2-518	NE NW	H. Seefeldt	1935	Dr	87	87	5	----------	Q	974	21.7	9- 9-59	D, S
24-145	SW NW	F. Anklam	--------	Dr	59	60	4	----------	Q	943	37.3	7-29-58	D, S
											35.5	12- 2-59	
25-513	SE SE	P. McKay and Sons	1959	Dr	178	43	7	150-178	pꞒ	899	35	1- -59	D, S
											48.7	9-10-59	
28-509	NE SE	R. Moericke	1958	Dr	62	40	6	----------	pꞒ	944	26.7	9- 3-59	D, S
25/13/2-22	NW NE	City of Marion	1935	Dr	97	50	12	50- 97	Q	859	12.2	7-16-58	P
-35	NW NE	do	1955	Dr	76	40	16	36- 76	Q	859	12.4	7-16-58	P
6-517	SE NW	A. Portnoy	1920	Dr	34	34	6	----------	Q	913	17	1950	D, S
											19.7	9- 9-59	
13-538	SE NE	H. Moericke	1910	Dr	60	57	3	57- 60	Q	881	----------	----------	D, S
17-525	NE NE	Maple Valley School	1959	Dr	62	40	6	40- 62	pꞒ	927	26.9	9-10-59	D
25-536	NW SW	C. Piehl	1956	Dr	66	66	6	----------	Q	872	13.4	9-17-59	D

25/14/5-540	SE	NE	Maple Grove Cheese Co	1958	Dr	170	170	6	----------	Q	941	70	9- -58	In
												94.6	9-17-59	
10-541	NW	SW	H. Lang	1958	Dr	156	136	6	136-156	p€	867	21	4- -58	D, S
												20.6	9-22-59	
23-15	SW	SE	City of Clintonville	1951	Dr	46	36	26	36- 46	Q	813	16	4- -51	P
-39	NE	NE	do	1957	Dr	172	147	12	147-172	Q	850	28	7- -57	P
24-19	SW	SW	Four-Wheel Drive Auto Co	1945	Dr	75	55	12	55- 75	Q	798	3	8- -45	In
												4.1	6-23-58	
-50	SW	SW	City of Clintonville	1921	Du	32	32	360	----------	Q	805	8	1921	P
												6.6	4-24-58	
-166	SW	SE	do	1932	Dr	124	--------	24, 16, 12	40-124	Q	813	+6.8	1935	P
												+4	6-23-58	
24-167	NE	SW	do	1930	Dr	168	148	16	148-168	Q	817	----------	----------	U
26-16	NE	SW	do	1946	Dr	144	69	16	69-144	Q	843	26.4	4-24-58	P
-109	NE	NW	Kuehl & Seering Co	1938	Dr	72	35	20	35- 72	Q	816	13.8	6-25-58	In
												13.7	9-22-59	
25/15/5-647	NW	SW	E. Lemke	1957	Dr	158	142	4	142-158	p€	832	18	12- -57	D
-664	SE	SW	Village of Embarrass	1960	Dr	80	50	10	50- 80	Q	814	18.5	2-24-60	P
												16.4	3- 9-60	
11-107	NE	NE	L. Bussian	1958	J	120	116	2	116-120	Q	846	54	6-23-58	D, S
22-555	SW	SW	C. Lundt	1952	Dn	62	59	1¼	59- 62	Q	795	20	1952	D

The hydrographs of wells Wp–24/14/2–104, Wp–25/11/30–125, Wp–25/12/24–145, and Wp–24/11/36–140 show that, in general, water levels declined during 1958 and into the spring of 1959 when snowmelt and above-average rainfall caused a rapid rise in water level. Continued average or above-average precipitation resulted in a continued rise in the water table during the remainder of 1959 and spring of 1960.

The rising trend in water levels shown by these hydrographs was preceded by a 3- or 4-year period of declining water levels. This decline in water levels was reflected by the corresponding decline in stages of lakes in the western part of Waupaca County. The hydrograph of well Pt–24/10/28–15 shows that the water level declined in the fall and winter of 1950, rose in 1951 and remained high through 1953, declined in 1953 and 1954, rose in 1954 and stayed at a high level until the summer of 1956. From 1956 to the summer of 1959, the water level declined because of below-average precipitation. In the fall of 1959 and during 1960, precipitation was average or above average and the water level rose in the well.

The amount of change in water levels shown by observation wells is dependent on several factors including (1) the amount, intensity, and frequency of precipitation, (2) the location of the well in respect to areas of natural discharge, (3) the character of the soil and its permeability (affecting recharge), and (4) the porosity of the aquifer (affecting movement of water within the aquifer). Water-level changes in wells near areas of natural discharge, such as streams, are not as great as in wells farther from points of natural discharge.

UTILIZATION OF WATER

Withdrawal of ground water in Waupaca County in 1959 was estimated to be 4 mgd, of which about 50 percent was for public supply, 35 percent for rural domestic and stock supply (including residences in villages without municipal systems), 10 percent for industry, and 5 percent for irrigation.

Average annual pumpage of ground water for public supply which was about 2.1 mgd in 1959, by the municipalities that provide water service and by the Waupaca County Hospital is listed in table 4. The village of Iola has had two test holes drilled preliminary to developing a public supply. The village of Embarrass has two wells that were drilled during early 1960 and will be in use when the distribution system is completed. The water supply for the Wisconsin State Veterans Home at King is obtained from Rainbow Lake.

In 1959, about 1.5 mgd of ground water was pumped for domestic and stock use. Domestic use includes villages not having water systems.

The use of water by industry for 1959 was estimated at about 0.4 mgd. This water is used mainly in the processing of dairy products and for cooling. Daily requirements for water related to the dairy industry are relatively constant. Daily requirements for industrial cooling vary greatly as they depend upon daily mean temperature.

Water for irrigation was originally obtained from lakes and streams in Waupaca County, but in the late 1940's dug pits became the main source of water. In 1953, drilled wells began to replace the dug pits as a source of water for irrigation. By midsummer of 1959, there were 16 drilled wells and at least 23 dug pits, of which 15 wells and 12 pits were in use. Because the frequency and quantity of precipitation varies, pumpage for irrigation is seasonal and varies annually.

In 1957, about 40 million gallons of ground water were used on about 500 acres; in 1958 about 105 million gallons were used on 1,190 acres. The large increase is attributed to below-average precipitation and soil moisture in the summer of 1958. In 1959, about 110 million gallons were used on 900 acres; in 1960 about 80 million gallons were used on 900 acres. Pumpage in 1960 decreased because of above-average precipitation and soil moisture.

TABLE 4.—*Pumpage for public water supply in Waupaca County, Wis.*

Public water supply	Population (1950)	Number of wells [1]	Average annual pumpage [2] (million gallons)
Municipalities:			
Clintonville	4,657	6	181.6
Manawa	990	2	45.8
Marion	1,118	2	36.8
New London	[3] 4,922	5	216.5
Waupaca	3,921	2	207.4
Weyauwega	1,207	2	81.6
County hospital	[4] 187	2	12.3
Total		21	781.9

[1] June 1, 1960.
[2] Calendar years 1958 and 1959.
[3] Waupaca County, 3,738.
[4] Average first-of-the-month population in 1959.

AQUIFER TESTS

An aquifer test consists of measuring water-level changes that occur in an aquifer in response to pumping a well at a given rate of discharge. Measurements are made periodically in the well being pumped and in as many additional wells within the cone of depression as possible. The measurements are used to determine the ability of an aquifer to transmit water and to release water from storage. The coefficient of transmissibility is the amount of water in gallons that will pass through a vertical strip of the aquifer 1 foot wide and extending the full thickness of the aquifer in 1 day under a unit hydraulic gradient (1 foot per foot). The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

The computations to determine the coefficients of transmissibility and storage assume (1) that an aquifer is fully penetrated, (2) that the aquifer is infinite in areal extent, (3) that the aquifer is of uniform material in all directions, (4) that the aquifer releases water from storage instantaneously in response to a decline in water levels, and (5) that the hydraulic characteristics of the aquifer do not change over a period of time. These conditions are rarely satisfied in nature, but they may be approximated closely enough to provided a basis for a general measure of the ability of an aquifer to store and transmit water.

TEST AT WELL WP-21/11/9-38

An aquifer test was conducted for 93.5 hours in May 1959 at well Wp-21/11/9-38, which is owned by Red Dot Foods, Inc. The average rate of pumping was 640 gpm, measured with a Parshal flume. Water-level measurements were made in wells Wp-21/11/9-38, 184, 186, and Wp-21/11/16-185 by means of a steel tape. Measurements were obtained at well Wp-21/11/9-63 by use of an automatic water-level recording gage supplemented by tape measurements. The distances of the observation wells from the pumped well and maximum drawdown during the test are given in the following table.

Well	Distance from Wp-21/11/9-38 (feet)	Maximum drawdown (feet)
Wp-21/11/9-38	0	15.6
-63	995	.2
-184	12.5	7.1
-186	657	.5
16-185	315	1.3

The hydrographs in figure 7 show the decline and recovery in the four observation wells and the drawdown and recovery in the pumped well.

The pumped well and observation wells are in outwash deposits of sand and gravel. At the beginning of the test, well Wp-21/11/9-184 was 32 feet in depth, about 3.2 feet below the prepumping water level; on the third day of the test, it was driven to a depth of 47.5 feet. This well was deepened during the latter part of the test because the local watertable had declined to below the bottom of the well after the test well was pumped about 1¼ hours. The late drawdown and the recovery measurements were obtained from this deepened well.

The computed coefficient of transmissibility is 100,000 ± 20,000 gpd (gallons per day) per ft; the permeability is about 1,000 gpd per sq ft; the coefficient of storage is 0.2±.07; and the specific capacity is 41 gpm per ft of drawdown.

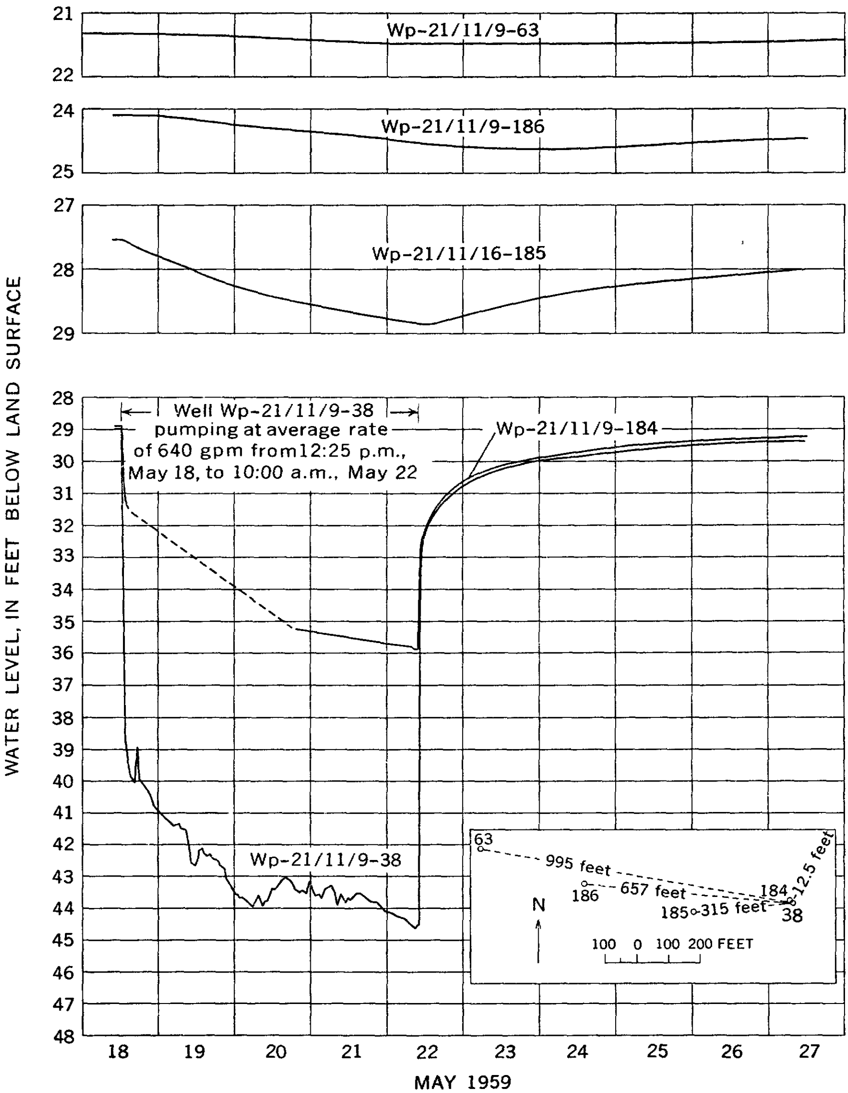

FIGURE 7.—Effect on water levels in observation wells caused by pumping well Wp-21/11/9-38, May 18-22, 1959.

Two short-term tests of wells in lacustrine deposits were conducted at wells Wp–22/13/32–36 and Wp–22/14/1–362. Geologic and hydrologic data were not adequate for reliable interpretation. However, the test of well Wp–22/13/32–36 and specific capacities of other wells (table 3) indicate that aquifers in lacustrine deposits locally may yield as much as 500 gpm.

SPECIFIC CAPACITIES OF WELLS

The specific capacities of 64 wells in the county are listed in table 5. The information was compiled from drillers' records and short-term pumping tests and is thought to be valid. Specific capacity of a well is the yield in gallons per minute for each foot of drawdown at a given pumping rate. The specific capacity is an indication of the permeability of the water-bearing materials within the area of influence of the well; therefore, if the pumping rate changes or if the duration of pumping changes, the area of influence of the well may change and the specific capacity of the well may change. In Waupaca County, the specific capacity for wells in fluvial deposits is generally greater than 10. The specific capacity for wells in till or lacustrine deposits and sandstone is less than 10, and wells in rocks of Precambrian age generally have a specific capacity of less than 1.

The specific capacity of wells is controlled by two factors; construction and development of the well and the characteristics of the aquifer. A well that is not fully developed or is equipped with a screen not suited to the aquifer materials will have a specific capacity less than might be anticipated.

TABLE 5.—*Specific capacity data for wells in Waupaca County, Wis.*

[Compiled from drillers' records and short-term pumping tests]

Well Wp–	Length of perforated casing, screen, or open hole (feet)	Draw-down (feet)	Duration of pumping (hours)	Rate (gpm)	Specific capacity (gpm per ft of drawdown)
Glaciofluvial deposits					
21/11/7–60	18	32	8	700	22
8–86	71	74	3	800	11
20–252	20	22	3	580	26
27–47	39	22	8	800	36
32–42	25	16	8	600	38
21/12/18–85	72	21	6	800	24
22/11/21–37C	15	10	3	900	90
–230	25	5	5	800	160
29–29	54	14	5	400	29
22/12/30–25	20	29	24	820	28
22/14/13–28	58	11	24	1,065	97
24/13/24–600	------------	2	2	25	13
25/11/5–126	24	29	14	575	20
25/13/2–22	47	21	48	600	29
–35	40	15	48	450	30
25/14/23–15	10	15	10	350	23
–39	25	33	48	300	9

TABLE 5.—*Specific capacity data for wells in Waupaca County, Wis.*—Continued

Well Wp-	Length of perforated casing, screen, or open hole (feet)	Draw-down (feet)	Duration of pumping (hours)	Rate (gpm)	Specific capacity (gpm per ft of drawdown)
Glaciofluvial deposits—Continued					
25/14/24-19	20	22	8	300	14
-50	------	22	7	400	18
26-16	75	36	12	400	11
-109	37	10	10	840	84
Glaciolacustrine or other Pleistocene deposits					
21/13/4-44	105	39	10	350	8
-54	20	31	2	410	13
22/12/28-45	10	17	9	50	3
-619	4	60	24	60	1
22/13/32-24	24	60	8	600	10
-36	16	59	2	470	8
22/14/1-10	43	50	------	250	5
-362	10	60	24	60	1
12-13	13	78	30	313	4
-396	------	11	8	80	7
13-11	20	48	------	350	7
-12	40	30	12	500	17
23/13/16-27	15	49	24	195	4
23/14/22-582	5	10	4	48	5
24/14/25-569	8	10	2	50	5
25/14/24-166	34	115	------	230	2
-167	20	110	------	110	1
25/15/5-664	30	38	22	75	2
Sandstone of Cambrian age					
21/13/15-306	3	12	3	12	1
16-314	9	12	2	35	3
17-292	5	15	4	30	2
21-308	14	21	3	47	2
35-311	58	17	3	17	1
21/14/4-371	20	7	2	21	3
8-154	72	150	------	250	2
9-372	30	6	2	65	11
23-156	98	4	7	20	5
26-375	72	1	4	9	9
30-318	19	23	4	45	2
23/13/13-628	37	5	2	15	3
23/14/18-572	15	5	2	10	2
Rocks Precambrian age					
22/14/3-398	9	25	2	100	4
8-73	123	110	10	12	<1
23/12/13-613	117	15	8	10	<1
23/13/8-589	212	126	3	7	<1
23/14/10-573	35	80	2	14	<1
24/13/11-603	------	37	8	5	<1
25/11/18-130	108	77	2	9	<1
25/12/25-513	135	65	6	30	<1
28-509	22	8	2	15	2
25/13/17-525	22	5	6	15	3
25/14/10-541	20	4	10	50	13
25/15/5-647	16	102	36	5	<1

CHEMICAL QUALITY

Ground water contains materials dissolved from the atmosphere and the earth. Chemical constituents and physical characteristics of ground water determine its suitability for industrial and domestic use. The chemistry of natural water is described by Hem (1959), and standards of chemical quality for domestic, industrial, and irrigation use are available (California State Water Pollution Control Board, 1952; Wilcox, 1948; Hopkins and Gullans, 1960, p. 1161–1168; U.S. Public Health Service, 1961).

Chemical analyses were made of 104 samples of water from 66 wells and 1 lake. The results of 46 analyses from representative wells are given in table 6. In general, the water from wells in Waupaca County is good for most uses, but it is very hard and may contain iron. Except for iron (plus manganese) in several samples and nitrate in one sample, the chemical constituents in the water sampled were within the requirements for potable water as recommended by the U.S. Public Health Service (1961). Ground water from each of the several water-yielding units in Waupaca County is roughly similar in chemical quality.

IRON

Iron is one of the most abundant constituents of rock and soil and is common in natural water (Hem, 1959, p. 58–66). Of the 87 samples of water tested for iron, 56 percent had less than 0.3 ppm (parts per million) of iron, 29 percent had concentrations between 0.3 and 1.0 ppm, and 15 percent had concentrations greater than 1.0 ppm. In this last group, one sample had a concentration of 32 ppm, four samples had concentrations between 2 and 2.6 ppm, and eight had concentrations between 1 and 2 ppm. The highest concentrations of iron in gound water are generally in areas of poor drainage such as swamps and marshes. The U.S. Public Health Service (1961) recommends that iron should not exceed 0.3 ppm. Excessive iron, although it stains porcelain fixtures and has an objectionable taste, does not cause health problems.

MANGANESE

The U.S. Public Health Service (1961) recommends that manganese concentration in drinking water should not exceed 0.05 ppm. Of the 87 water samples from Waupaca County tested for manganese, a concentration of 0.1 ppm was reported in eight of the samples, and one sample had a concentration of 1.0 ppm. The remaining 78 samples were reported to be free of manganese. Because of the method used to test for manganese, the results were reported to only the nearest 0.1 ppm. The eight samples reported as having 0.1 ppm may have actual concentrations ranging between 0.05 and 0.15 ppm.

TABLE 6.—*Chemical analyses of water from representative wells and a lake in Waupaca County, Wis.*

[Results in parts per million except pH. Agency making analysis: WSLH, Wisconsin State Laboratory of Hygiene; USGS, U.S. Geological Survey; NAC, National Aluminate Corp.; KPI, Klenzade Products, Inc.]

Well Wp-	Date of collection	Depth of well (feet)	Agency making analysis	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids [1]	Hardness as $CaCO_3$	pH
21/11/9-38	5-22-59	85	WSLH	---	0.0	30	15	132	9.0	2.5	<0.1	180	136	7.7
-184	5- 6-59	32	WSLH	0.1	.0	40	17	139	22	4.5	<.1	216	170	7.8
-186	5- 6-59	41	WSLH	---	.0	46	22	229	10	1.5	.1	226	206	8.2
16-185	5- 5-59	42	WSLH	---	.0	29	14	144	8.0	1.5	.1	162	134	8.2
21/12/2-249	6- 5-59	240	WSLH	.1	---	---	---	---	---	---	---	238	218	8.1
3-248	6- 5-59	25	WSLH	---	---	---	---	---	---	---	---	488	323	7.8
13-276	9-31-59	113	WSLH	32	---	---	---	304	---	---	---	---	302	7.2
16-244	6- 5-59	100	WSLH	.1	---	---	---	---	---	---	---	200	173	8.0
26-277	6-29-59	---	WSLH	---	---	---	---	---	---	---	---	230	209	7.6
21/13/4-44	1-28-58	168	WSLH	---	.0	61	37	317	18	3.0	<.1	292	282	7.6
-54	4- 9-57	85	WSLH	.0	.0	66	35	361	6.0	3.0	<.1	326	312	7.6
21/13/5-55	6-29-59	140	WSLH	---	---	---	---	---	---	---	---	160	39	6.9
21/14/26-375	1- 6-60	128	USGS	.1	.1	---	---	236	9.8	2.0	.1	---	216	7.6
22/11/34-L24	2- 7-57	---	WSLH	.0	.0	31	21	198	6.0	3.0	.2	194	166	7.6
35-108	6- 4-59	177	WSLH	.7	---	---	---	---	---	---	---	204	190	8.0
-188	6- 4-59	32	WSLH	2.2	---	---	---	---	---	---	---	230	183	7.2
-250	6-10-59	68	WSLH	.8	---	---	---	---	---	---	---	230	196	7.8
22/12/30-25	5-19-55	45	WSLH	.0	.0	62	30	312	20	6.0	.2	328	288	7.3
-53	1-28-58	34	WSLH	.5	.1	55	30	278	18	9.0	.2	266	244	7.6
22/13/32-24	7-17-57	---	WSLH	2.2	.0	65	46	434	5.0	2.5	.2	368	354	7.6
-36	7-17-57	---	WSLH	2.0	.0	68	46	449	5.5	1.5	.2	378	368	7.6
22/14/1-10	2- 5-58	118	WSLH	.1	.0	24	21	185	11	6.0	1	206	132	8.2
-362	7-27-59	138	WSLH	---	---	---	---	---	---	---	---	204	150	8.0
12-13	9-11-43	203	NAC	.0	---	---	---	188	13	18	---	194	134	8.1
13-11	2- 5-58	129	WSLH	.4	.0	45	36	276	29	3.0	.2	258	244	7.8
22/14/13-12	12-16-54	170	WSLH	.1	.0	55	30	276	25	4.0	<.1	270	258	7.7
-28	2- 5-58	165	WSLH	.1	.0	54	30	262	22	5.0	<.1	266	244	7.7
23/11/30-501	9- 4-59	212	WSLH	---	.0	49	23	236	8.0	1.0	---	242	217	8.0
23/13/8-590	5- 2-58	150	KPI	.3	---	---	---	305	0	8.8	---	---	298	7.8
16-27	2- 5-58	73	WSLH	---	.0	52	42	351	13	11	.6	314	280	7.8
23/14/1-577	1- 6-60	190	USGS	.1	.1	---	---	142	3.2	2.0	1.2	---	41	7.7
-578	1- 6-60	20	USGS	.1	.1	---	---	342	57	53	.0	---	417	7.9
24/12/33-606	1- 8-60	82	USGS	.1	.0	---	---	412	15	15	.2	---	450	8.0
24/13/12-602	1- 8-60	73	USGS	.4	.1	---	---	288	12	1.0	.9	---	240	7.7
25/11/18-130	9- 4-59	141	WSLH	---	.0	58	26	308	9.0	2.0	---	288	258	7.6
24-510	9- 3-59	20	WSLH	---	.0	54	27	293	14	1.5	---	260	250	7.9
25/12/28-509	9- 4-59	62	WSLH	---	.0	58	27	300	8.0	2.0	---	276	262	7.8
25/13/2-22	5-10-55	97	WSLH	.0	.0	66	32	349	8.0	4.0	.5	318	302	7.5
-35	9-13-57	76	WSLH	---	.0	67	30	352	14	4.0	.6	326	303	7.4
25/14/23-15	8- 6-58	46	WSLH	.0	.0	61	34	295	26	13	.2	326	270	7.8
-39	8- 6-58	172	WSLH	.1	.0	62	40	359	17	3.0	.4	310	296	8.0
24-50	1-12-55	33	WSLH	.0	.0	59	32	312	18	7.5	.3	308	281	7.5
-166	1935	124	WSLH	.4	0	---	---	312	7	3	---	287	293	---
-167	1935	168	WSLH	2.4	.1	---	---	264	6	3	---	248	216	---
26-16	8- 6-58	144	WSLH	.4	.0	61	39	356	15	3.0	.9	310	293	7.9
25/15/ 5-664	2-26-60	80	WSLH	---	.1	26	11	159	1.0	1.0	1.0	156	112	7.8

[1] Residue on evaporation at 105°C, WSLH; residue on evaporation at 180°C, USGS; temperature for other analyses unknown.

FLUORIDE

Fluoride was determined in 60 samples of water from Waupaca County. A fluoride concentration of about 1.3 ppm in water is reported to lessen greatly the dental caries in the teeth of children (Dean, 1943). One sample contained no fluoride. The average fluoride content is about 0.4 ppm; about one half of the samples have a concentration of less than 0.2 ppm fluoride. The maximum fluoride content, 1.2 ppm, is below the limit (1.5 ppm at 55°F) recommended by the U.S. Public Health Service (1961).

HARDNESS

Hardness determined in 103 samples from Waupaca County ranged from 39 to 450 ppm (table 6). The average, 224 ppm, is very hard and is probably representative of ground water in the county. Water having a hardness greater than 180 ppm is considered to be very hard. Hardness of the water represents the effects principally of calcium and magnesium. Excessive hardness is recognized by the large quantity of soap required to produce lather. The constituents causing hardness may also contribute to incrustation.

SUMMARY AND CONCLUSIONS

Waupaca County is underlain by crystalline rocks of Precambrian age. Overlying this basement complex in part of the county are sandstone beds of Cambrian age and dolomite of the Prairie du Chien Group of Ordovician age. Sediments of Pleistocene age mantle nearly all the county.

Glaciofluvial deposits of sand and gravel are the principal aquifers in Waupaca County. These deposits, occurring generally in the western and central parts of the county, may yield large quantities (500 to 1,500 gpm) of water to wells. Till, occurring in most areas of the county, and glaciolacustrine deposits, occurring in the eastern and southern parts of the county, generally yield small to moderate (50 gpm) quantities of water to wells. The Prairie du Chien Group, although water-yielding, has small areal extent and is not important as an aquifer. Sandstone of Cambrian age, occurring in the southern part of the county, may yield large quantities of water to wells. Precambrian crystalline rocks are not considered to be an aquifer where overlain by thick deposits of sand and gravel or sandstone. Crystalline rock may be a source of water where overlying deposits are thin or absent.

Average daily precipitation in Waupaca County is about 1,000 mgd. About 400 mgd runs off in streams and about 600 mgd is lost by evapotranspiration. Total pumpage is about 4 mgd. Use of water from wells has caused no regional decline of water levels; the general decline in water levels from 1955–58 was caused by below-average precipitation.

Supply problems will continue in those areas where the granite is the only source of water or where the ground moraine, lying on granite, is relatively impermeable. In the remainder of the county, water supply from wells should be no problem. Continued collection of drillers' logs, water-level data, and pumpage records would aid greatly in determining geology, occurrence of ground water, and the effects of pumpage on water levels.

The chemical quality of the ground water is good, although the water is generally hard and in some areas the iron content is reportedly too great for many industrial or domestic uses.

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