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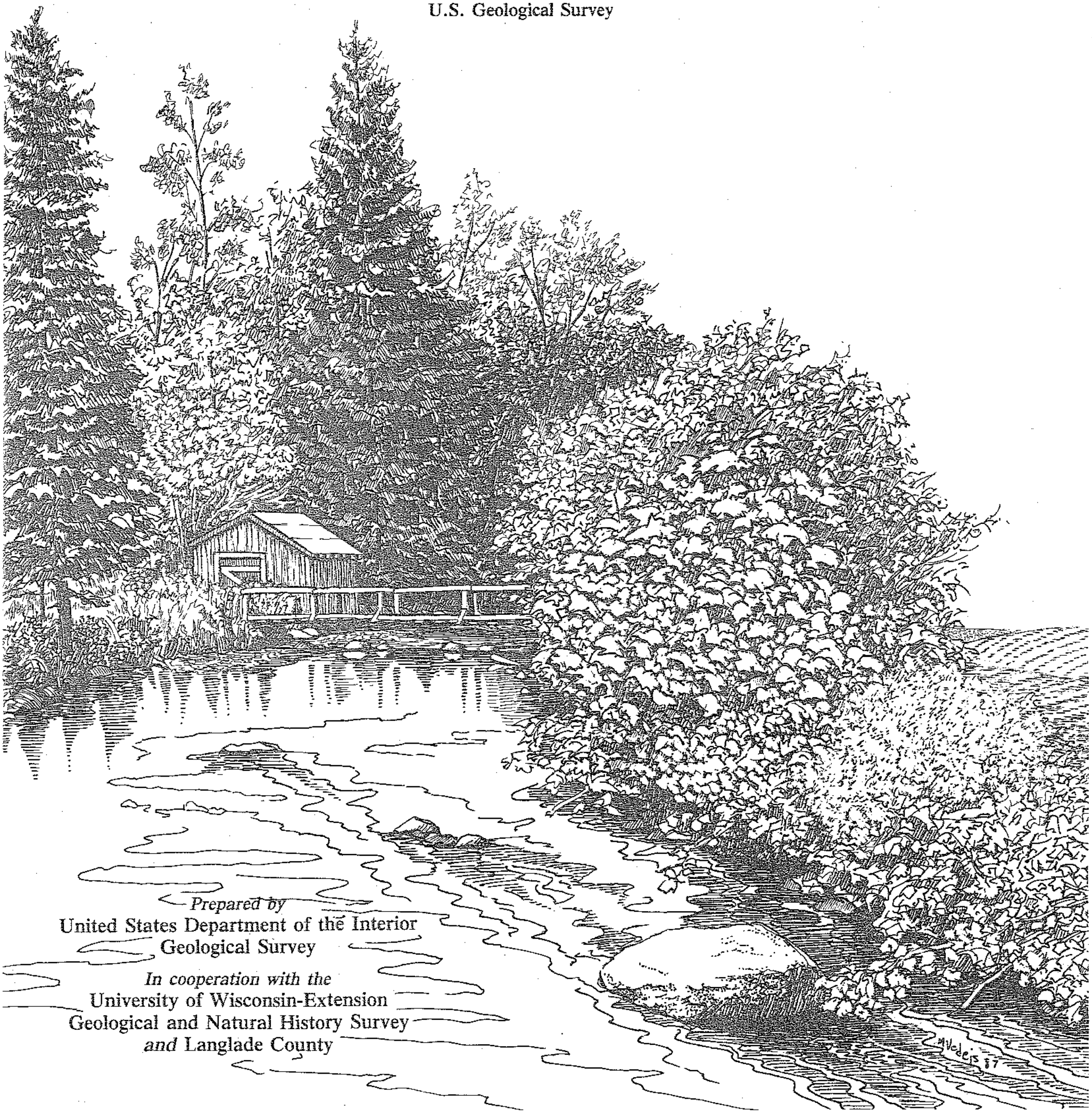
Water Resources of Langlade County, Wisconsin

By
W. G. Batten
U.S. Geological Survey



Prepared by
United States Department of the Interior
Geological Survey
In cooperation with the
University of Wisconsin-Extension
Geological and Natural History Survey
and Langlade County

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M. E. Ostrom, Director and State Geologist,
and
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This report is a product of the U.S. Geological Survey Water-Resources Division and the University of Wisconsin-Extension Geological and Natural History Survey.

The Wisconsin Geological and Natural History Survey Water Resources Program includes: systematic collection, analysis, and cataloging of basic water data; impartial research and investigation of Wisconsin's water resources and water problems; publication of technical and popular reports and maps; and public service and information. This report for the Survey's Water Resources Program is accomplished through state-federal cooperative cost sharing with the U.S. Geological Survey's Water Resources Division.

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

The stratigraphic nomenclature used in this report is that of the Wisconsin Geological and Natural History Survey and does not necessarily follow usage of the U.S. Geological Survey.

Water Resources of Langlade County, Wisconsin

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ABSTRACT

Langlade County depends almost exclusively on ground water pumped from the glacial sand and gravel deposits for its water needs. Well yields of 10 to 20 gallons per minute can be obtained from these deposits throughout most of the county. Yields of 500 to 1,000 gallons per minute are obtained for irrigation of crops from glacial outwash deposits in some areas of the county and particularly in the extensive 125-square-mile outwash plain in south-central Langlade County. Very low yields of less than 5 gallons per minute are obtainable for private domestic use from Precambrian crystalline rocks in areas of the county where overlying glacial material is thin. Glacial deposits are more than 400 feet thick in glacial moraine areas of east-central Langlade County; saturated thicknesses exceed 250 feet in the north-central part of the county.

Horizontal hydraulic conductivity values of glacial material range from less than 1 foot per day in fine-grained glacial tills in western parts of the county to approximately 145 feet per day in outwash deposits. The transmissivity of glacial deposits ranges from essentially zero in areas of unsaturated glacial material to more than 40,000 feet squared per day in the outwash plain of south-central Langlade County.

Most surface and ground water originates from precipitation falling within the county. Streams and ground water flow into the county only in areas along its northern edge. Ground water supplies about 70 percent of the annual streamflow.

Ground-water composition in Langlade County is similar to most ground water in the State and is of suitable quality for most uses. It is a calcium magnesium bicarbonate type. Concentrations of total dissolved solids are relatively low and range from 71 to 369 milligrams per liter, with a median value of 144 milligrams per liter. Dissolved iron and manganese concentrations exceeded secondary (aesthetic) standards in about 30 percent of all ground-water analyses. Values for total hardness as calcium carbonate ranged from 48 to 280 milligrams per liter for all samples. Ground water classified as very hard was confined to the southern part of the county where glacial deposits are higher in carbonate mineral content.

An average of about 4.7 million gallons of water was pumped daily in Langlade County in 1983. Irrigation and fish rearing are the major ground-water uses in the county. An average of about 4.2 million gallons per day was pumped for irrigation during the months of June, July, and August. Results of this study show that present irrigation pumpage rates have little effect on ground-water levels in the Antigo Flats area.

INTRODUCTION

Settlers first came to the Langlade County area in the 1860's to harvest the enormous stands of white pine that covered much of the area. While some settlers logged the timber, others began farming the cleared land to provide food. These two businesses, along with wholesale and retail trade, account for most of the county's present economy.

The county is not densely populated; the population has remained essentially constant at about 21,000 people since 1930. It is forecast to remain near that number through the year 2000 (Robert Naylor, State of Wisconsin Census Data, oral commun., 1984). Almost half of the population lives in Antigo, the only city in the county with a permanent population over 1,000. Overall population increases somewhat during the summer when tourists take advantage of the area's lakes, streams, and forests for recreation.

Purpose and Scope

The purpose of this report is to describe the ground-water and surface-water resources in Langlade County.

Hydrologic, geologic, and water-quality data were collected, compiled, and analyzed; results of analyses were mapped to show areal variations in the hydrology, water quality, and geology of the area. Well-construction, aquifer-test, and test-hole data were used to determine water-table conditions, ground-water movement, aquifer characteristics, and geology. Wells and streams were sampled to define chemical characteristics of water in the county. Precipitation, lake-level fluctuation, and ground-water data were analyzed to determine the relationship between ground water and surface water.

Description of Study Area

Location and Land Use

Langlade County is located in the Northern Highland Province of northeastern Wisconsin (Martin, 1916). Antigo, the county seat, is about 80 mi northwest of the city of Green Bay (fig. 1).

About 15 percent of the county's 875-mi^2 area is agricultural cropland; much of it is irrigated and used to grow seed potatoes. About 70 percent of the county is covered by secondary growth forest. Half of this forested area is National and County Forest land, particularly the glacial upland terrain that is unsuitable for other agricultural purposes.

Acknowledgments

Thanks are given to the many county officials, State agencies, and landowners for providing well and water information. Thanks are also given to the many well owners who allowed access to their wells for water-level measurement and for collection of water samples. The Wisconsin Department of Natural Resources supplied well and pumpage records. Special acknowledgment is made to Joseph Jopek and Francis Gilson, Langlade County Resource and Agricultural Agents, respectively, who pointed out areas of interest for this study and helped gain access to private lands for data collection.

GEOLOGIC SETTING

Precambrian Bedrock Geology

Glacial deposits are underlain by Precambrian bedrock throughout the entire county. The Precambrian bedrock is approximately 1,500 million years old and consists primarily of granite, monzonite, and metamorphosed sedimentary and volcanic rocks (Greenberg and Brown, 1983).

The Precambrian bedrock surface, once rugged and mountainous, had been leveled by erosional processes prior to deposition of overlying glacial deposits. Well logs, outcrop information, and seismic data were used to map the altitude of the Precambrian bedrock surface (fig. 2). Altitudes of the Precambrian bedrock surface range from over 1,500 ft above sea level in western, northern, and northeastern parts of the county to less than 1,100 ft above sea level in the extreme southeastern part of the county. In general, the regional slope of the bedrock surface is toward the southeast at a rate of 10 to 15 ft/mi. Bedrock data were not available for the central and northwestern parts of the county.

Glacial Geology

The unconsolidated deposits overlying the Precambrian bedrock are predominantly Quaternary glacial sediments. Holocene or recent marsh deposits and alluvium occur in low-lying wetlands and in areas adjacent to lakes and streams. The distribution and texture of these deposits and associated landforms affect the movement, availability, and chemical characteristics of surface water and ground water in the county.

Mickelson describes, in detail, the distribution, origin, and lithology of glacial deposits in Langlade County (Mickelson, 1987). Much of the following summarizes his findings pertinent to understanding the hydrology of the county.

The thickness of glacial deposits ranges from less than 20 ft in the western and northeastern parts of the county to more than 500 ft in east-central Langlade County. Thicknesses are generally greatest in end moraine areas and thinnest in areas of high Precambrian bedrock. The thicknesses of unconsolidated deposits are shown in figure 3.

Five major divisions or units of glacial deposits, based on characteristics such as grain size, color, and mineral composition, have been identified by Mickelson (1987). The general distribution of each unit within the county and the type of glacial landforms associated with it are shown in figure 4.

Glacial deposits in the county are typically coarse-textured; that is, they contain a large percentage of sand-sized and gravel-sized particles. Most glacial material in the county is sand, gravel, or till. Till is a poorly sorted material deposited directly by glacial ice; it contains clay- to boulder-sized material. The Wausau and Merrill till units in the extreme western and southwestern parts of the county contain considerably more fine-grained material (silt and clay) than the other three units and will be referred to as fine-grained tills throughout this report. These are thin units that may be less than 20 ft thick. These two units were probably deposited under glacial ice as ground moraine. This type of till deposition is

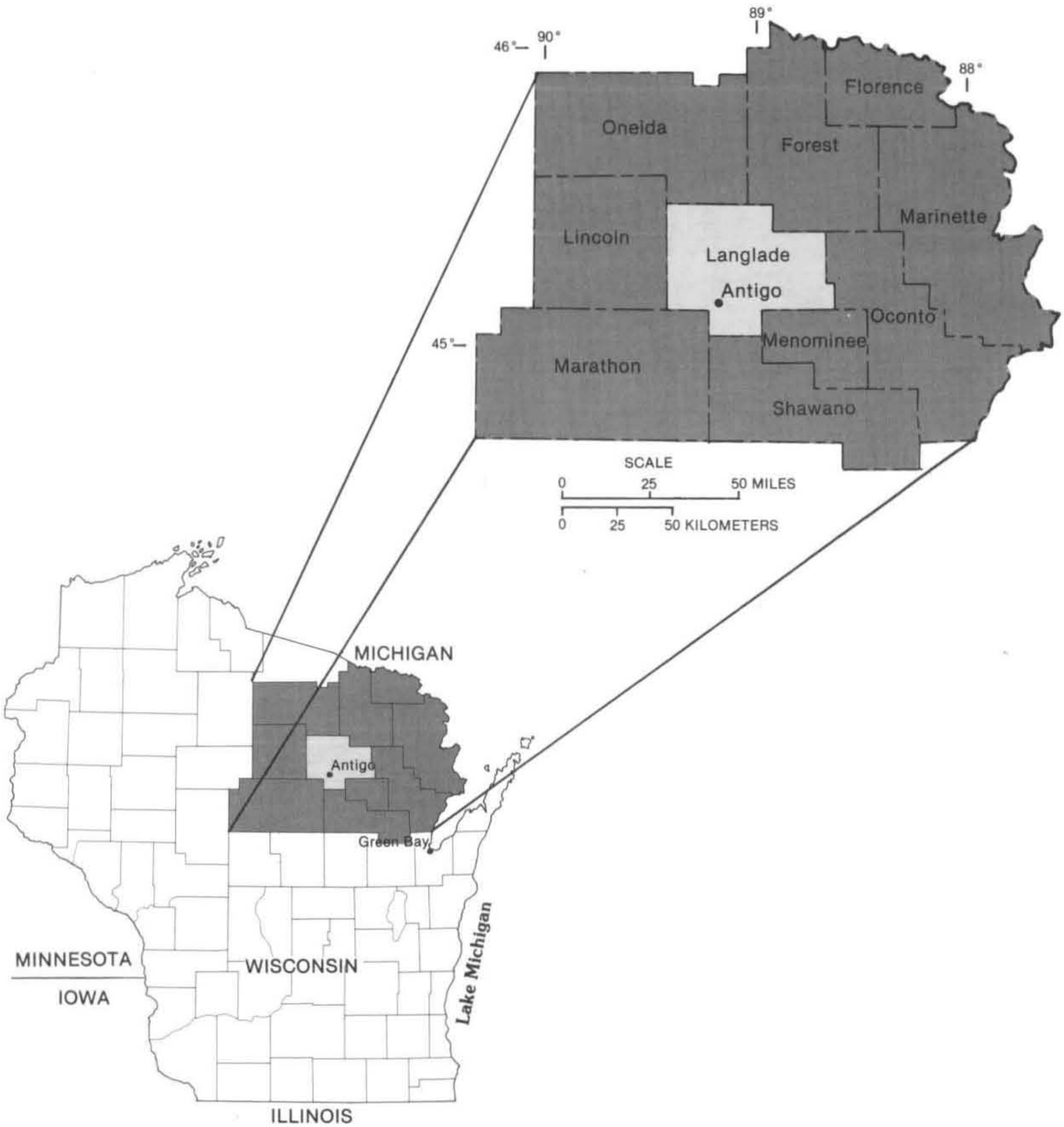

Figure 1. Location of Langlade County in Wisconsin.

characterized by undulating, gently sloping topography.

The northern and northeastern parts of the county are underlain by the Nashville till unit and associated sand and gravel deposits (fig. 4). The southern and southeastern areas are underlain by the Mapleview till and similar sand and gravel deposits. Both tills have a very coarse-grained texture and contain about 80 percent sand-sized particles by weight. Both units contain silt and clay lenses that are not extensive.

Similar glacial landforms are associated with both the Nashville and Mapleview tills. End moraines, which are hummocky ridge systems composed of till deposited at the melting ice margin, are present in each till area (fig. 4). Behind each moraine ridge system are broad areas of outwash sand and gravel deposited by glacial meltwater flowing from receding glacial ice. These outwash deposits typically form level to gently sloping topography that surrounds ridges and hills of ground moraine. Distinct glacial ice-contact features such as eskers or kame terraces may also be found in the area.

Some differences do exist between the Mapleview and Nashville tills. Glacial ice that deposited the Mapleview till advanced into the county from the southeast. This ice flowed across

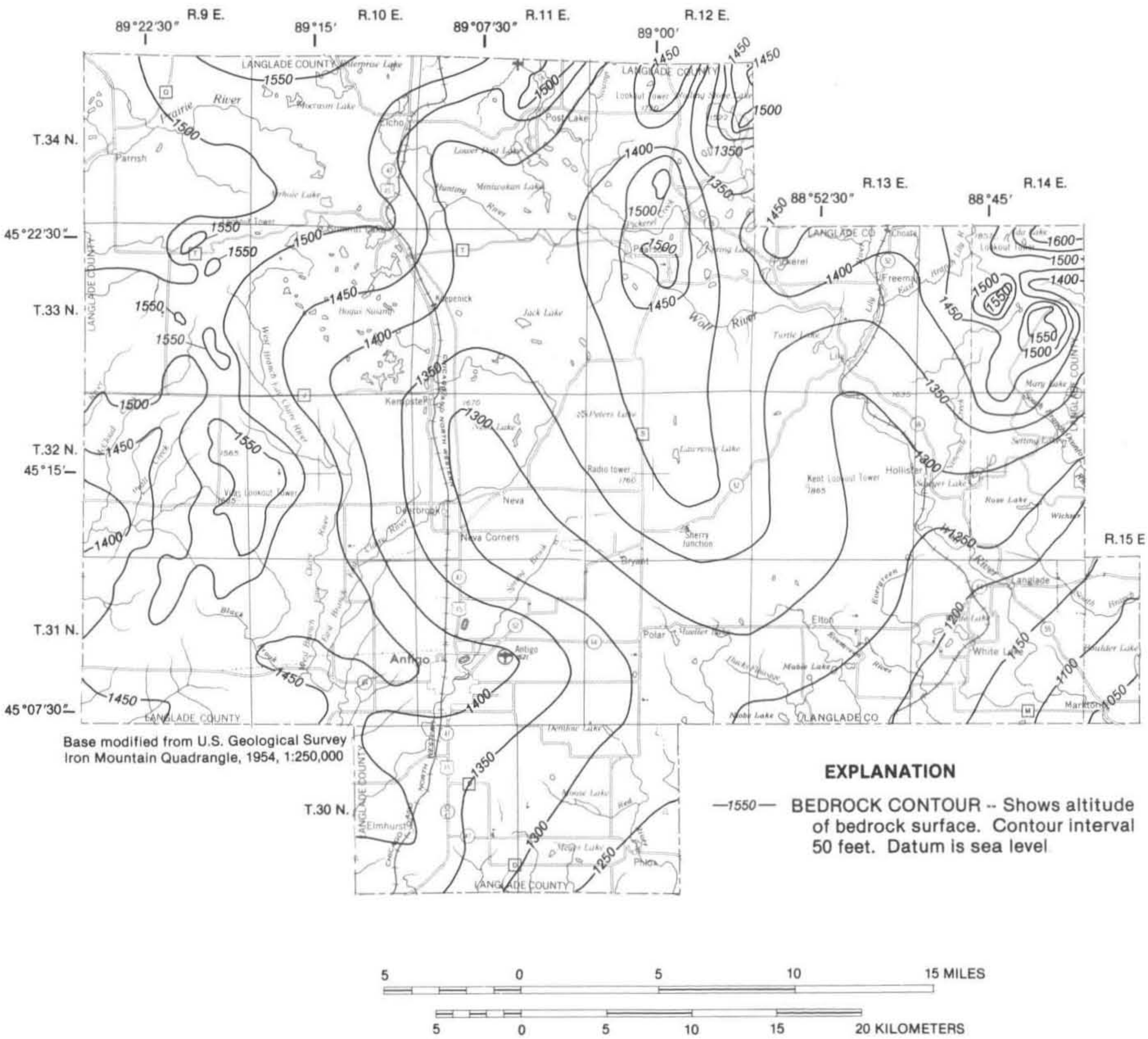

Figure 2. Altitude of Precambrian bedrock surface in Langlade County.

Paleozoic carbonate and sandstone rocks. Glacial ice that deposited the Nashville till advanced from the northeast by flowing over Precambrian igneous and metamorphic rocks. Mickelson (1987) found that about 25 percent of pebble-sized material in the Mapleview till is carbonate rock (dolomite) compared to less than 6 percent in the Nashville till. In general, the Mapleview till is more sandy and has less associated silt- and clay-sized deposits than the Nashville till.

The fifth major glacial unit recognized by Mickelson (1987) consists of outwash sand and gravel deposited by meltwater flowing out from the moraines of both the Nashville and Mapleview tills. He calls these deposits the Antigo unit. This unit forms the gently sloping outwash plain in the area surrounding Antigo referred to as the "Antigo Flats" (fig. 4).

GROUND-WATER HYDROLOGY

Ground-Water Availability

Langlade County relies almost exclusively on ground water pumped from sand and gravel deposits for its water supply. Yields of 10 to 20 gal/min, which are sufficient for domestic purposes,

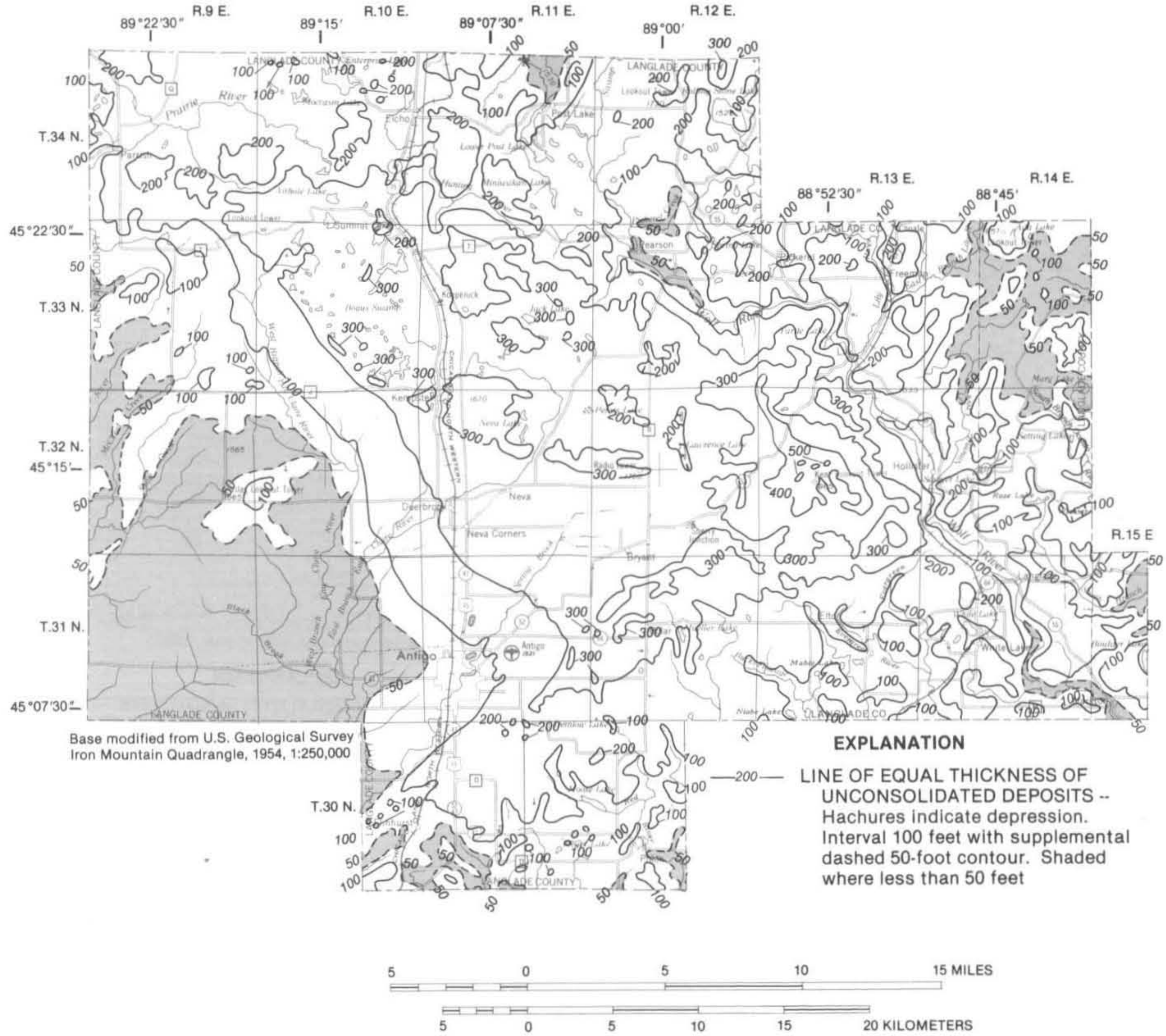

Figure 3. Thickness of unconsolidated deposits in Langlade County.

can be obtained almost everywhere in the county. Domestic wells are typically between 50 and 150 ft deep. Irrigation wells (80 to 150 ft deep) provide yields of 500 to 800 gal/min in the Antigo Flats area and in minor outwash deposits in other areas. The depths of wells completed in the Precambrian bedrock vary from 60 to 300 ft. These wells typically yield less than 5 gal/min and are therefore limited to domestic use.

Ground-Water Occurrence and Movement

Movement of ground water in Langlade County can be best described by referring to plate 1, a map of the water table. A water-table map is a contour map that depicts the altitude above sea level of the top of the saturated zone. Within the saturated zone, all interconnected openings (pore spaces) in the glacial material or bedrock are filled by water.

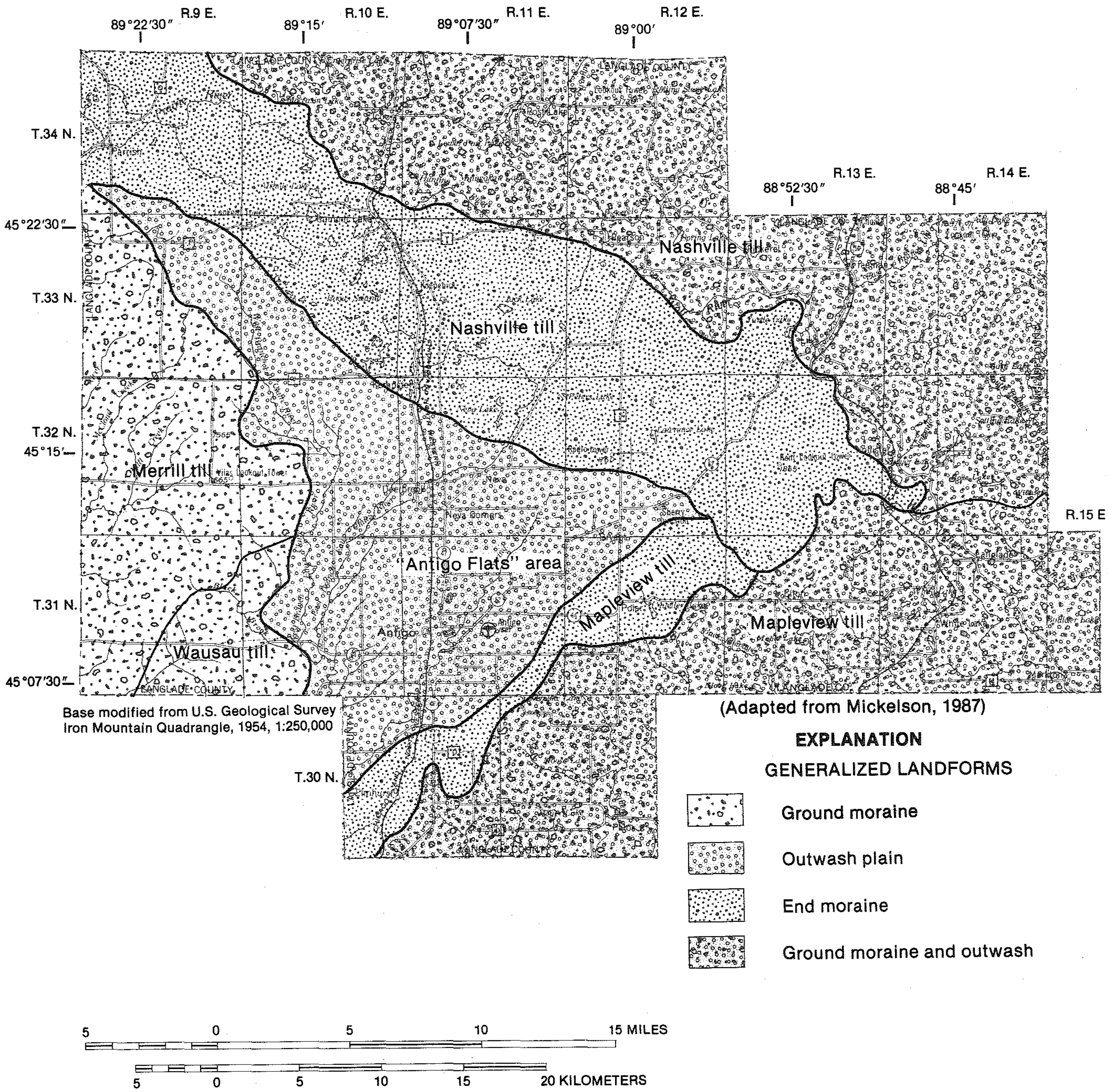

Figure 4. Generalized landforms and associated glacial units in Langlade County.

Contour lines on plate 1 connect points of equal water-table altitude (feet above sea level). The map is based on altitudes of static water levels in wells and elevations of streams, lakes, and wetlands during the summer of 1983, and on interpretation of topographic information. The altitude of the water table ranges from more than 1,700 ft in northwest Langlade County to less than 1,080 ft in the extreme southeastern corner of the county.

The water table is a subdued replica of the land surface. The altitude of the water table is usually higher under topographic highs such as the glacial end moraine that extends from northwest to southeast through the central part of the county. It is usually lower but closer to land surface in topographically low areas such as the Wolf River valley and in areas adjacent to other streams or rivers.

Lakes, rivers, streams, and wetlands normally occur in these lower areas where the water table "intersects" the land surface. Exceptions to this situation are perched lakes or wetlands that occur in depressions in topographically high areas. Perched lakes are formed when fine-grained silt and clay-sized material is transported by rain and meltwater into the depression. These impermeable deposits form a seal that allows the lake or wetland to develop above the regional water table. Noboken Lake (T. 33 N., R. 11 E., sec. 20, pl. 1) is an example of a perched lake. Water levels in nearby wells that reflect the altitude of the regional water table are 40 to 50 ft below the water level of this lake. True water levels were estimated on plate 1 where water-level data were not available and perched water-table conditions were suspected.

Ground water moves from high water-table altitudes toward areas of low altitude where it discharges to springs, streams, rivers, and lakes. Some generalized flow paths (depicted by arrows on plate 1) indicate flow at approximately right angles to the water-table contours. Most ground water moves less than 5 mi from the point where it recharges the water-table aquifer to the point where it is discharged. An exception to this generalization is shown by the two long arrows on plate 1 just east of the city of Antigo. Here, ground water moves from its recharge area 8 to 10 mi southeastward under the Antigo Flats and is discharged into the many streams and spring ponds that occur in minor depressions in southeastern Langlade County. Surface-water outlets from these spring ponds serve as the headwaters for streams that flow southeastward out of the county.

All ground water occurring in Langlade County is discharged into streams that leave the county or moves along flow paths leaving the county along the entire eastern, southern, and western edge of the county. However, ground water moves into the county from the north in extreme northwestern and northeastern Langlade County, particularly in T. 34 N., R. 9 E., and T. 34 N., R. 12 E. This is shown by the arrows on plate 1. In T. 34 N., R. 9 E., ground water is discharged into the Prairie River. In T. 34 N., R. 12 E., it is discharged into Swamp Creek and Pickerel Creek, tributaries of the Wolf River.

Ground-Water Recharge

The sources of ground-water recharge in Langlade County are precipitation and snowmelt that infiltrate the land surface and move downward into the ground water. The rate of recharge varies from year to year and depends on the amount and distribution of precipitation, land use, soil type, air temperature, and depth to the water table. The major recharge period occurs in the spring during snowmelt; a minor recharge period occurs in the fall because of rain. The resultant rise in ground-water levels during these periods is illustrated by water-level hydrographs for observation wells La–1240 and La–1241 (fig. 5). The locations of observation wells are shown in figure 6. Water levels in these two wells decline in the summer months. This is due to evapotranspiration, the combined effect of evaporation of soil moisture and water intake by plants during the warm growing season. Evapotranspiration has a pronounced effect in areas where the depth to water is less than 20 ft. The depth to water in observation wells La–1242 and La–1243 (fig. 5) is greater than 40 ft and is less susceptible to the effects of both precipitation and evapotranspiration. Water-level changes in wells La–1242 and La–1243 are more subdued and only show long-term trends.

Annual recharge was estimated for the Antigo Flats area by multiplying the cumulative water-level rise in wells La–1240 and La–1241 by the specific yield of the aquifer. Estimated recharge rates at wells La–1240 and La–1241 were 14.0 and 7.3 in/yr, respectively. An estimate of about 5.4 in/yr for the Antigo Flats area was previously calclulated by Harder and Drescher (1954). In a somewhat more detailed study of a similar area in the central sand plain of Wisconsin, Weeks and Stangland (1971, p. 53) determined recharge rates ranging from 9.5 to 14.3 in/yr.

Another method of estimating recharge is to assume that the amount of ground water discharged to a stream is approximately equal to ground-water recharge within the ground-water basin for that stream. By dividing the total ground-water contribution to streamflow by the area of the ground-water basin for the stream, ground-water recharge can be estimated. Calculated ground-water recharge rates for the Eau Claire River basin in southwestern Langlade County and the Wolf River basin in eastern Langlade County were 6.1 and 10.8 in/yr, respectively. The lower recharge rate for the Eau Claire River basin is probably due to lower permeability and infiltration rates of the tight, finer-grained Wausau and Merrill tills that cover the western part of the basin.

In general, the infiltration and recharge rates in Langlade County are relatively high due to the coarse texture of surficial materials. From data collected in this study and previous studies (Harder

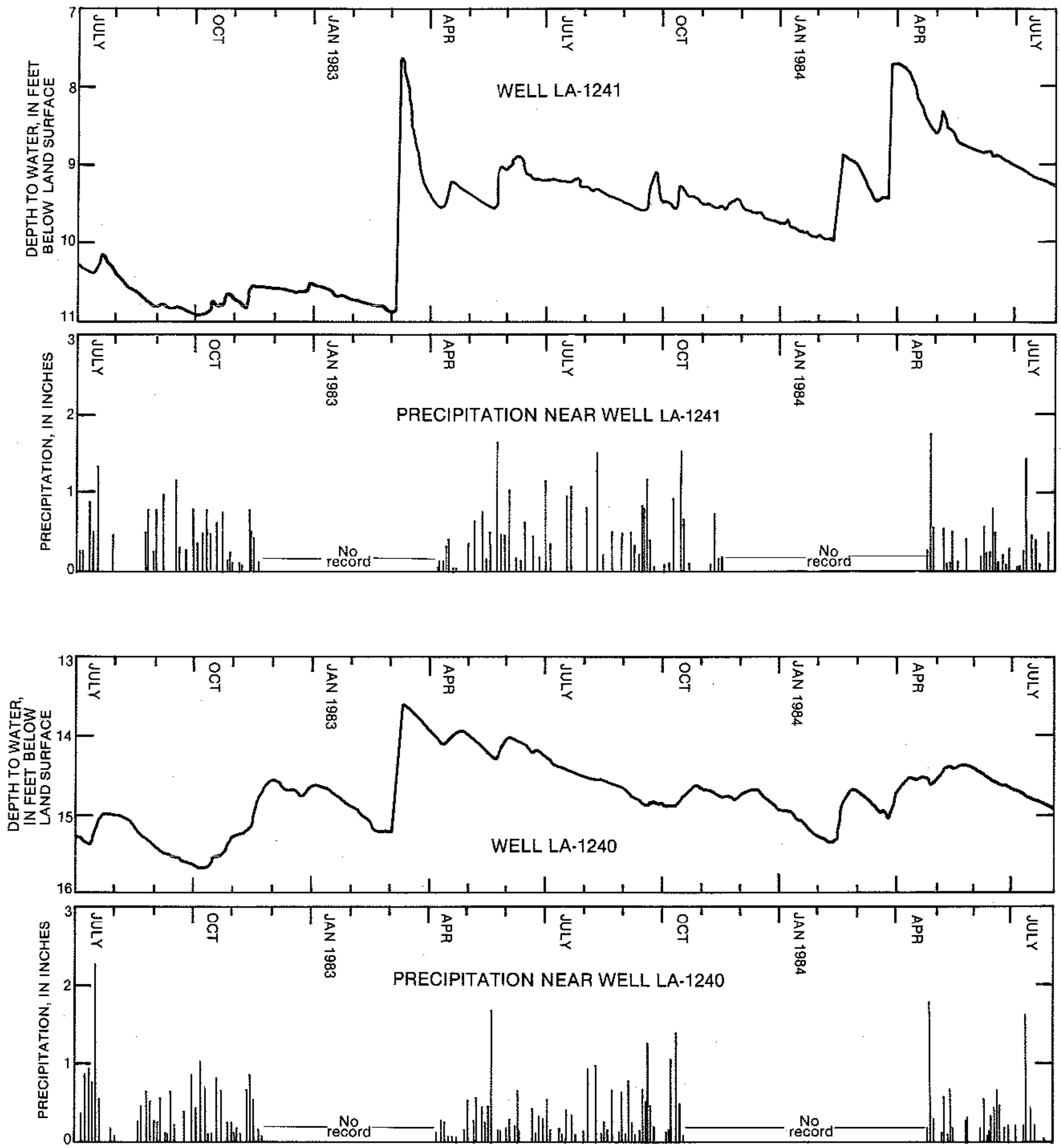

Figure 5. Hydrographs comparing ground-water levels, lake stage, and precipitation.

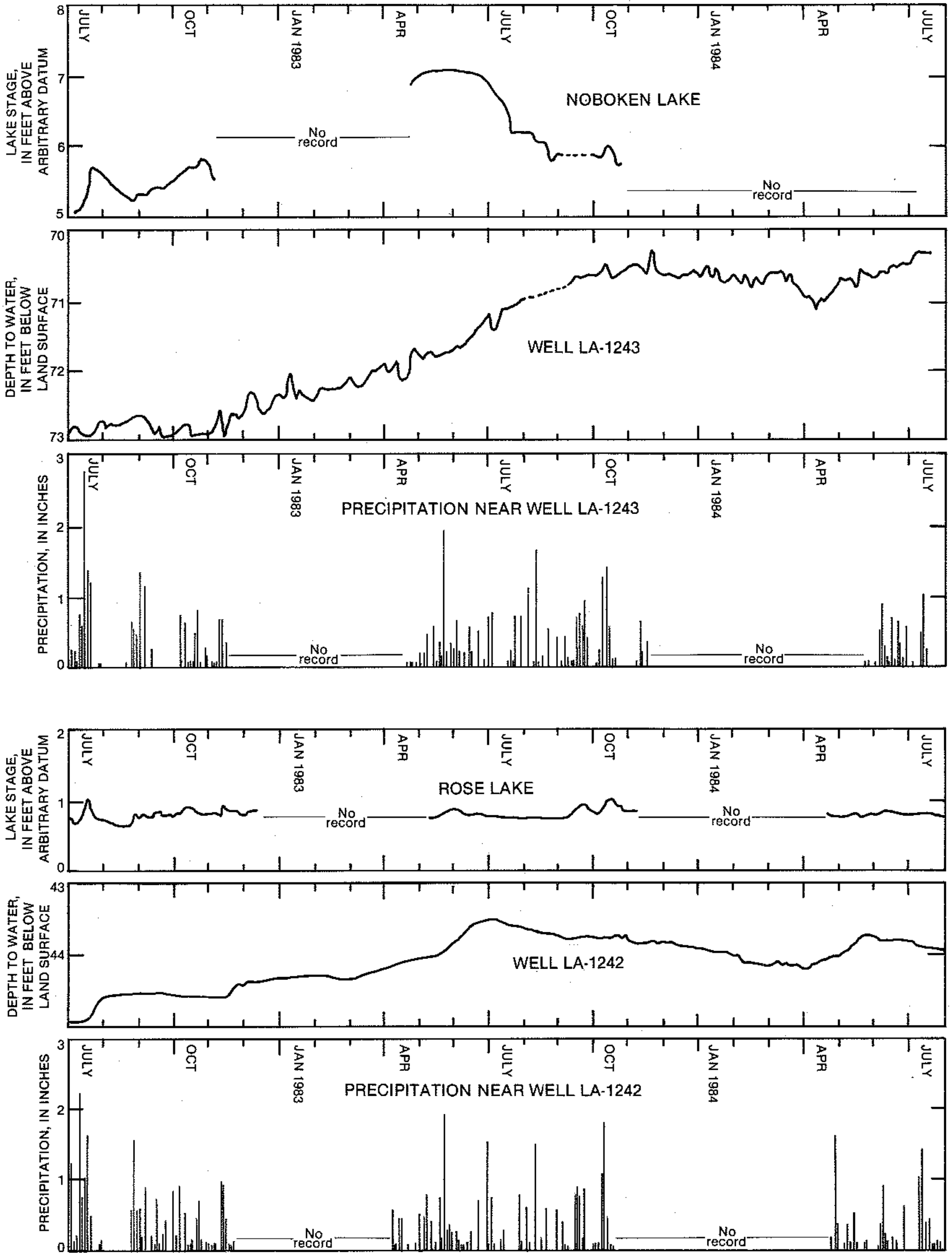

Figure 5. Hydrographs comparing ground-water levels, lake stage, and precipitation—Continued.

and Drescher, 1954; Weeks and Stangland, 1971), ground-water recharge rates of about 8 to 12 in/yr are reasonable estimates over most of the county.

Sand-and-Gravel Aquifer

The sand-and-gravel aquifer consists of saturated glacial sand-and-gravel. The areal extent, thickness, and hydraulic properties of these deposits control the occurrence, movement, and availability of ground water.

Thickness and Areal Extent

The thickness of saturated glacial deposits generally ranges from 50 to 250 ft (fig. 7). Areas where the saturated thickness is less than 50 ft are shaded in figure 7. Saturated sand and gravel deposits suitable for well development are present at depths less than 150 ft throughout much of the county.

Major water-bearing sand and gravel deposits occur as continuous glacial outwash or as discon-

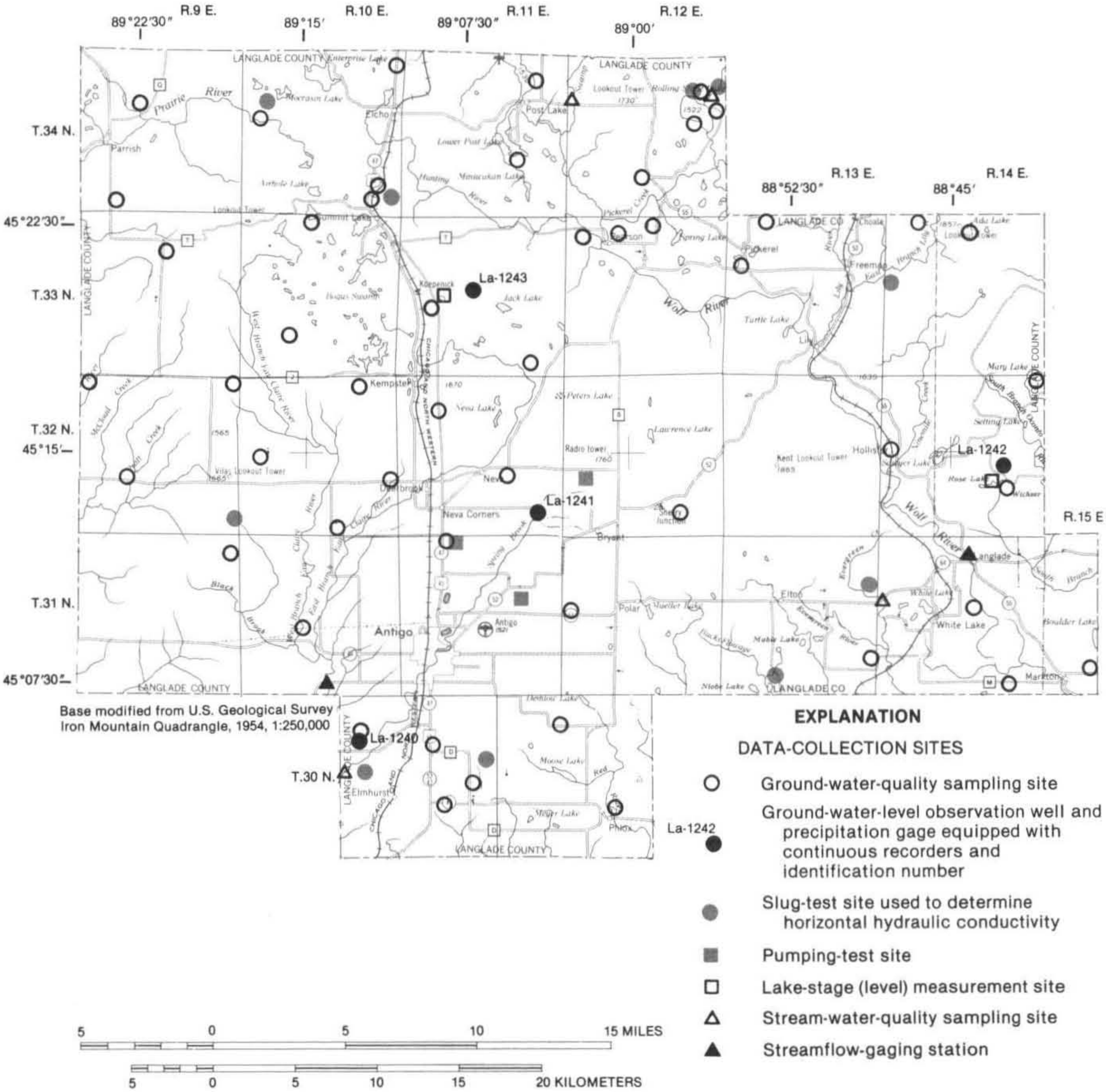

Figure 6. Locations of data-collection sites in Langlade County.

tinuous buried layers or lenses. Outwash deposits are present at land surface in much of Langlade County and often extend to considerable depths. For example, in the Antigo Flats area saturated outwash deposits are more than 100 ft thick. Most land surfaces with a gentle slope and significant areal extent are underlain by such deposits. These deposits are commonly capable of sustained well yields of 400 gal/min or more.

The Nashville and Mapleview tills (fig. 4) that cover most of northern, eastern, and southern Langlade County are generally very sandy and lack significant lenses of fine-grained, silt- and clay-sized material. Discontinuous layers of sand and gravel are also present throughout these areas. However, their occurrence is variable both areally and with depth. The total saturated thickness of these tills and associated sand and gravel deposits effectively forms a single aquifer capable of providing sufficient well yields for domestic purposes (10 to 20 gal/min). Greater yields may be possible in parts of these areas.

Saturated sand and gravel deposits are generally absent in areas where saturated thicknesses are less than 50 ft (fig. 7). This is particularly true in the Wausau and Merrill till subareas of western Langlade County (fig. 4). These deposits are both thin and fine-grained. Bedrock

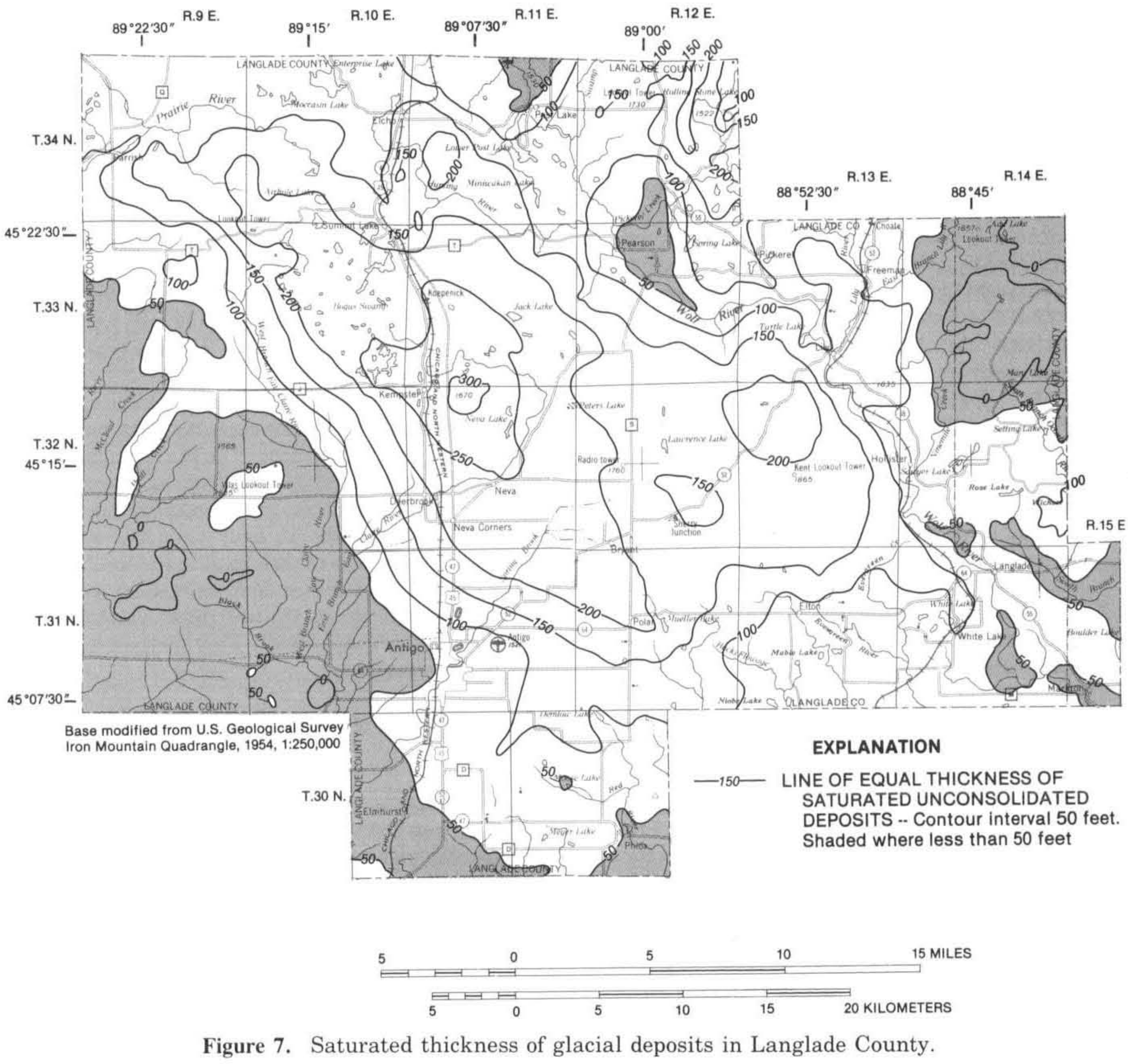

Figure 7. Saturated thickness of glacial deposits in Langlade County.

is at or near land surface in other areas of the county where saturated glacial deposits are less than 50 ft thick. In these areas, wells are likely to be finished in the bedrock.

Hydraulic Properties

Slug-test, pumping-test, and well-construction data were analyzed to determine the horizontal hydraulic conductivity and transmissivity values for the glacial sand-and-gravel aquifer. Hydraulic conductivity is a measure of the ability of an aquifer to transmit water and is defined as the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The hydraulic conductivity is high for materials with large, well-connected pore spaces such as sand and gravel and low for those with poorly-connected pore spaces such as silt and clay.

Transmissivity is the rate at which water is transmitted through a unit width of the entire saturated thickness of the aquifer under a unit hydraulic gradient. Thus, transmissivity can be calculated by multiplying the horizontal hydraulic conductivity by the saturated thickness of the aquifer. Conversely, the horizontal hydraulic conductivity can be calculated by dividing the transmissivity by the saturated thickness of the aquifer. Highest transmissivity values will be associated with thick saturated deposits of coarse material while thin, saturated deposits or fine-grained deposits will have lower transmissivity values.

Slug tests were conducted in 1.5-in.-diameter test wells installed by the U.S. Geological Survey at 10 sites shown in figure 6. Horizontal hydraulic conductivity values were calculated from measurements of water-level recovery versus time after introducing a known volume of water into each well. Each type of glacial deposit in the county is represented and results are shown in table 1.

Results vary, as expected, according to the texture (proportion of sand-, silt-, and clay-sized particles) of each type of deposit. Hydraulic-conductivity values ranged from 0.7 to 24.1 ft/d in the Mapleview and Nashville tills. Values for the Nashville basal till in northern Langlade County agree with those of similar materials just north of this area, near Crandon, Wis. (J. T. Krohelski, U.S. Geological Survey, oral commun., 1984). Three slug tests were conducted in the Merrill and Wausau tills. Water-level recovery during two of these tests was too slow to measure and thus indicates the very low hydraulic conductivity expected in these two tills. The one value shown in table 1 is from a layer that has a coarser-grained texture than typical Merrill till.

The transmissivity and hydraulic conductivity of the outwash deposits underlying the Antigo Flats were also determined from pumping tests of three irrigation wells. Water-level declines were measured in observation wells near each irrigation well while the irrigation well was pumped at a steady rate over 24 to 30 hours. These measurements were plotted versus time and the data were analyzed to calculate the transmissivity of the aquifer at each site. Transmissivities calculated from the three pumping tests were 18,800, 23,900, and 33,200 ft^2/d, with an average of 25,300 ft^2/d. The average specific yield of the aquifer determined from the three pumping tests was 0.23. Specific yield is the volume of water that at an aquifer will yield to gravity divided by the total aquifer volume. This value of 0.23 is a ratio and can be multiplied by 100 and presented as a percentage (23 percent).

Hydraulic conductivities ranged from 95 to 220 ft/d with an average of 145 ft/d for the three tests (table 1). These values were calculated by dividing transmissivities determined from pumping test data by the total aquifer thickness at each test site. These large hydraulic conductivities are typical of glacial outwash deposits.

Hydraulic conductivities also were calculated from well drillers' specific-capacity data for 273 wells throughout the county. The specific capacity of a well is calculated by dividing the amount of well discharge (in gallons per minute) by the total water-level drawdown (in feet) when the well is pumped. The specific capacities of individual wells were converted to transmissivity values for the aquifer interval open to the well using a technique given by C. V. Theis (1963). This method makes use of the equation:

$$T' = Q/s\ (K - 264\ log_{10}\ 5S + 264\ log_{10}\ t)$$

where Q is the well discharge and s is the drawdown in the well after pumping t days. S is the specific yield of the aquifer and is defined as the ratio of the volume of water that the aquifer will yield by gravity drainage to its total volume of aquifer. Theis' method relates the T' value to the transmissivity (T) by the equation:

$$T' = T - \frac{264\ Q}{s}\ log_{10}\ (T \cdot 10^{-5})$$

K is a constant for a given well radius r (in feet) given by the equation:

$$K = -66 - 264\ log\ (3.74\ r^2 \times 10^{-6}).$$

The hydraulic conductivity is then obtained by dividing the calculated transmissivity by the length of each well open to the aquifer.

An average hydraulic conductivity was calculated for each type of glacial deposit based on the hydraulic conductivities determined from all wells in each type. A transmissivity map (fig. 8) was developed by contouring transmissivities calculated by taking the average hydraulic conductivity of each glacial type multiplied by its saturated thickness at hundreds of points throughout the county. This map is only a rough estimate of the transmissivity of the glacial sand-and-gravel aquifer because of the large range in hydraulic conductivity estimated from specific-capacity data. However, the map does show areas of relatively high and low transmissivity based on the texture and saturated thickness of the various glacial deposits. The areas of highest transmissivity are the areas of coarse-textured outwash deposits such as the Antigo Flats and areas of thick, saturated drift in the central part of the county. Areas of low transmissivity are in extreme western Langlade County and in T. 33 N., R. 14 E., where saturated glacial deposits are fine-textured and thin, or absent.

Transmissivity is directly related to well yield because it is a measure of the aquifer's ability to transmit water. Wells drilled in areas of high aquifer transmissivity are capable of higher production rates than those drilled in areas of low transmissivity. This is why well yields of more than 500 gal/min are common in the Antigo Flats area where transmissivity values are high (20,000–40,000 ft^2/d). In extreme southwestern

Table 1. Horizontal hydraulic conductivity of glacial deposits in Langlade County

Lithostratigraphic unit and location	Lithology	Hydraulic conductivity (ft/d)	Landform and remarks
Mapleview supraglacial till sec. 18, T. 30 N., R. 11 E.	Medium sand, trace silt and gravel lenses	14.4	Hummocky end moraine area
Mapleview supraglacial till sec. 13, T. 30 N., R. 11 E.	Medium sand, trace silt and gravel lenses	24.1	Hummocky end moraine area
Mapleview basal till sec. 33, T. 31 N., R. 13 E.	Very fine sand, silty	4.6	Streamlined ridge area
Mapleview basal till sec. 12, T. 31 N., R. 13 E.	Medium to coarse sand, very silty and some gravel	3.7	Streamlined ridge area
Nashville basal till sec. 7, T. 34 N., R. 10 E.	Mixed sand, very silty and some gravel	7.4	Streamlined ridge area
Nashville basal till sec. 25, T. 34 N., R. 10 E.	Mixed sand, very silty, and gravel, trace clay	1.0	Rolling topography
Nashville basal till sec. 18, T. 33 N., R. 14 E.	Mixed sand, very silty	1.2	Streamlined ridge area
Nashville basal till sec. 11, T. 34 N., R. 12 E.	Mixed sand, silty, and some gravel	.7	Streamlined ridge area
Merrill till sec. 36, T. 32 N., R. 9 E.	Mixed sand, silty, clay and some gravel	16.4	Rolling topography--tested permeable zone in Merrill till
Lacustrine sand in Nashville till area sec. 12, T. 34 N., R. 12 E.	Fine sand, very silty	4.2	Flat low-lying area adjacent to streamlined ridge
Antigo sand and gravel sec. 5, T. 31 N., R. 11 E. sec. 14, T. 31 N., R. 11 E. sec. 19, T. 32 N., R. 12 E.	Statified sand and gravel	145.0	Gently sloping glacial outwash plain--value is average of three pumping-test results

Langlade County, wells are drilled into the Precambrian bedrock because the transmissivity of glacial deposits is low (fig. 8).

Calculated Effects of Pumping in Antigo Flats

Knowledge of the hydraulic conductivity, transmissivity, thickness, and areal extent of the glacial aquifer provides a tool for predicting the effects of heavy pumping on water levels in the aquifer. The possibility of water-level decline in the Antigo Flats area due to pumpage for crop irrigation is of concern.

Transmissivity and specific yield values can be substituted into the following equation developed by Cooper and Jacob (1946) and applied to any number of situations to predict the water-level decline at various distances due to pumping a well at a given rate in gallons per minute. The equation:

$$s = \frac{264Q}{T}\left(\log_{10}\frac{0.3\ Tt}{r^2S}\right)$$

determines the drawdown (s) at a distance (r) from a well discharging water at the rate of (Q) in gallons per minute. T and S are transmissivity and specific yield, respectively, and (t) is time in days.

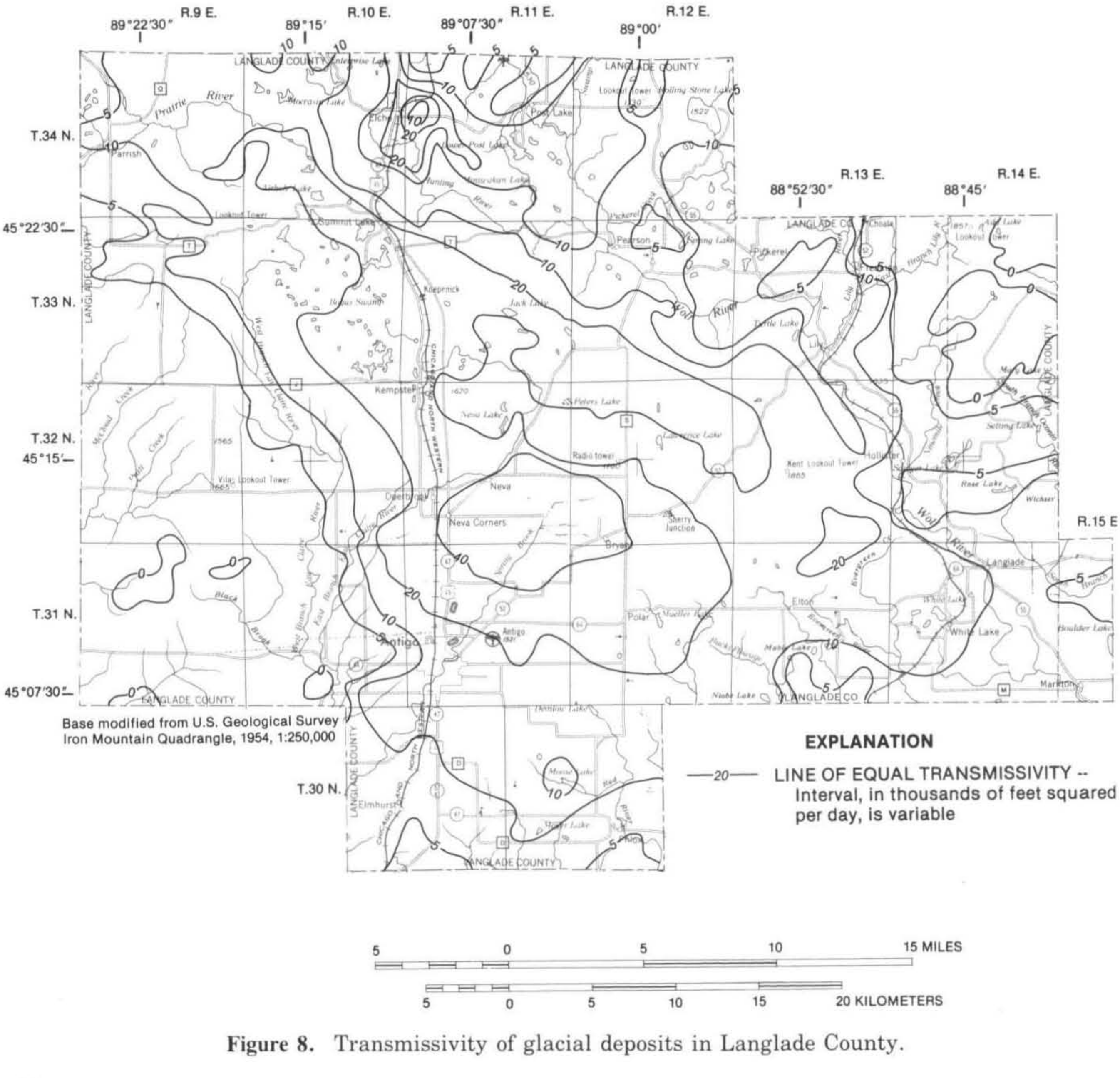

Figure 8. Transmissivity of glacial deposits in Langlade County.

To demonstrate the use of this method in the Antigo area, consider a typical section (1 mi^2) of cropland with one irrigation well located in the center of each quarter section. Each of these four wells is pumped continuously at 500 gal/min for 365 days. We want to know the effect of this large withdrawal (over 1 billion gallons in the 365 day period) on water levels in the aquifer at the point directly in the center of this 1-mi^2 section of land. Using the above equation, 0.98 ft of drawdown(s) was calculated at the center of the section resulting from pumping one well. This value is then multiplied by 4 to account for the effects of all four irrigation wells. This calculation shows a total water-level decline at the center of the 1-mi^2 section of slightly less than 4 ft due to pumpage of the four wells.

The above equation is based on the following assumptions: (1) The aquifer is of uniform thickness, (2) the aquifer has infinite areal extent, and (3) the aquifer receives no recharge from any source such as rainfall or ground water moving into the area. Nevertheless, the equation is reasonably accurate to show the extent of water-level decline due to irrigation in the Antigo Flats area. The above example is, by design, an extreme example in terms of both pumpage volume and well density. In the approximately 100-mi^2 rectangular area of the irrigated Antigo Flats, there are about 100 irrigation wells or a well density of about 1 well per square mile. The combined pumpage in 1983 for both irrigation and the city of Antigo was about 771 Mgal or about 73 percent of the total pumped by the four wells in the above example. This suggests that present pumpage rates for irrigation have minimal impact on water levels in the Antigo Flats area.

Precambrian Bedrock Aquifer

A relatively small number of domestic supply wells are finished in the Precambrian bedrock. They are drilled in the extreme western, eastern, and northeastern areas of the county where overlying glacial deposits are thin. These areas are generally shown as the shaded parts on figure 7.

Water generally enters wells in the Precambrian bedrock from one of two zones. The first is a permeable weathered zone in the uppermost 10 to 20 ft of rock. Natural weathering, due to near-surface chemical and mechanical forces, breaks down the dense rock to form interconnected pore spaces through which water can move. Secondly, water can enter these wells from large cracks or openings called fractures. Drillers report that these fractures are intersected during drilling at depths anywhere from 40 to 300 ft below land surface. The occurrence of these fractures characteristically decreases with depth. This results in two general types of wells finished in the Precambrian bedrock. Wells of the first type utilize the shallow weathered zone and are less than 150 ft depending on the depth to the rock. These wells commonly have less than 20 ft of borehole open to the well. The second type of construction takes advantage of the water derived from the deeper fractures. These wells are commonly 200 to 350 ft deep and typically have 200 to 300 ft of borehole open to the well.

Drillers' specific-capacity data from 55 wells finished in Precambrian bedrock were analyzed to determine the hydraulic conductivity in the same manner as data from wells in the glacial sand-and-gravel aquifer. Values ranged from less than 0.00001 to 34.6 ft/d for all wells. The average hydraulic conductivity for all 55 wells in Precambrian bedrock was 3.7 ft/d. In computing these values, the equation assumes that the entire borehole open to the well yields water to the well. In fact, the water enters the well only along fractures or through the upper weathered zone. However, it was not possible to determine how many, or at what depths, fractures intersected the borehole. The results do show that the hydraulic conductivity of the weathered, near-surface Precambrian rock is substantially higher than that of the deeper, fractured rock. The average hydraulic conductivity of the near-surface (upper 20 ft) weathered material was about 9.7 ft/d and the average of the deeper fractured (below 150 ft) rock was about 0.05 ft/d.

SURFACE-WATER HYDROLOGY

As in most of northern Wisconsin, the streams and lakes of Langlade County provide recreation for local residents and tourists. Almost all lakes and streams provide good to excellent habitat for game fish. Dense hardwood and conifer forests also provide scenic surroundings for lakes and streams. The Wolf River is one of the country's top white-water canoeing rivers.

Streams

Two major drainage systems—the Eau Claire and Wolf Rivers—dominate surface-water drainage in the county (fig. 9). The Eau Claire River and its tributaries drain most of central Langlade County including the Antigo Flats area. The Wolf River drains much of northern and eastern Langlade County. The remaining drainage areas are divided into three groups. Headwaters of the Prairie River and small tributaries to the Pine River (not shown on fig. 9) form in the western part of the area and flow westward out of the county. Headwaters of the south branch of the Oconto River and several small tributary streams originating in extreme eastern Langlade County flow southward and eastward out of the county. Several small streams in the south-central part of the county were grouped to form another basin referred to here as Spring Pond–Wolf River tributaries. These streams are somewhat unique because they form as surface-water outlets of spring-fed ponds that occur in kettle-shaped depressions in this area.

It is significant to note that the major drainage divide (fig. 9) separates streamflow toward the Gulf of Mexico from streamflow toward the Atlantic. Streamflow in the Eau Claire, Prairie, and Pine Rivers empties into the upper Mississippi River basin and eventually flows into the Gulf of Mexico. Streamflow in the Wolf and Oconto Rivers empties into Green Bay and ultimately reaches the Atlantic Ocean via the St. Lawrence River.

Streamflow has been measured continuously at the U.S. Geological Survey gaging station on the Wolf River at Langlade (fig. 6) since March 1966. Streamflow was also measured on the Eau Claire

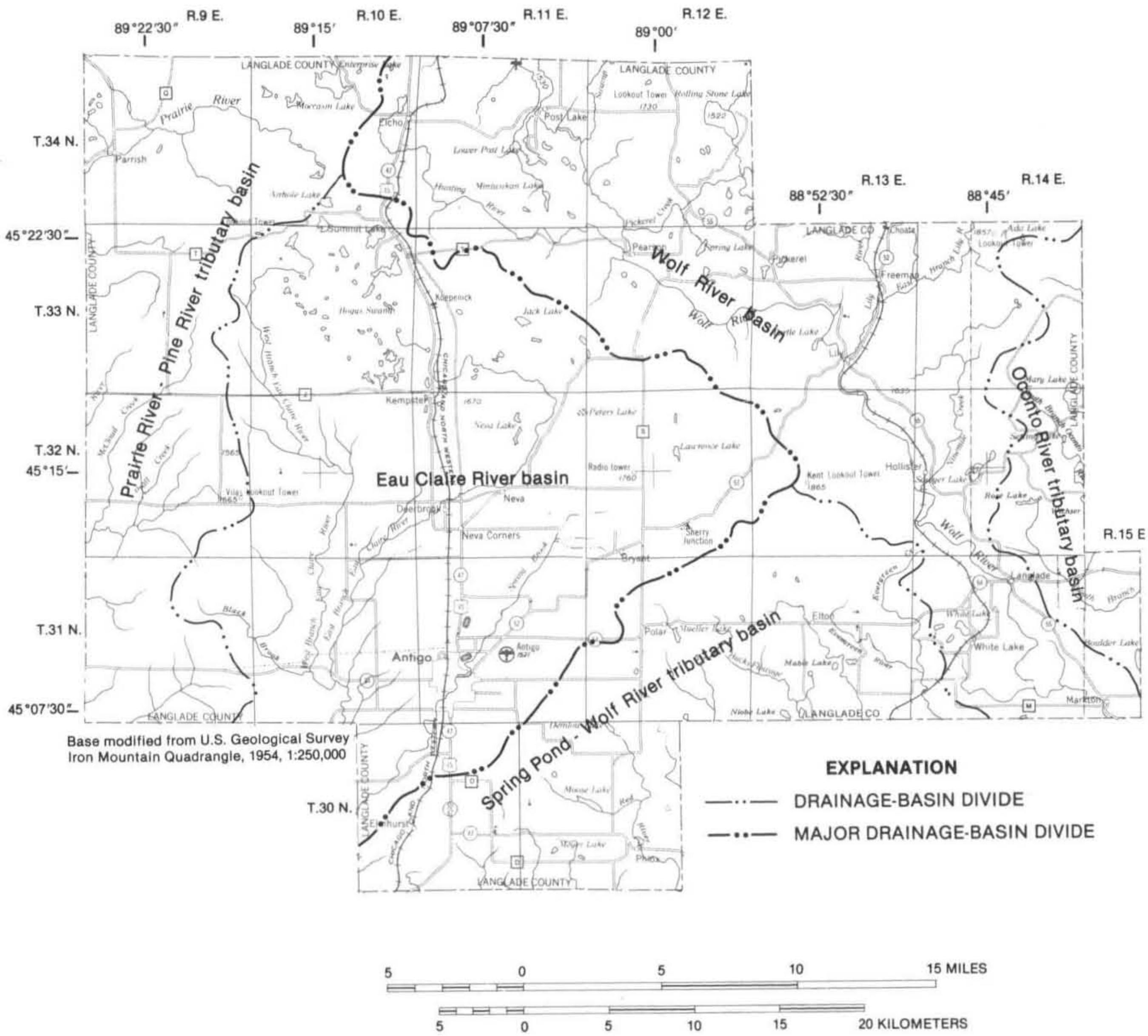

Figure 9. Surface-water-drainage systems in Langlade County.

River near Antigo (fig. 6) for the period October 1974 to September 1981. Table 2 is a brief summary of streamflow in these two rivers. The average discharge in the Wolf River at Langlade for the period March 1966 through September 1983 is 461 ft^3/s, which compares to an average of 146 ft^3/s for the Eau Claire River near Antigo for the period of record. Maximum instantaneous discharges for the periods of record were 2,200 ft^3/s on March 15, 1973, for the Wolf River at Langlade and 1,840 ft^3/s on April 24, 1975, for the Eau Claire River near Antigo. Minimum instantaneous discharges were 119 ft^3/s on November 8, 1976, for the Wolf River and 18 ft^3/s on November 6, 1976, for the Eau Claire River. The average discharge for the Wolf River is equivalent to a runoff rate of 13.5 in/yr spread over the 463-mi^2 drainage basin. The average discharge of 146 ft^3/s for the Eau Claire River represents about 9.9 in/yr drained from the entire 200-mi^2 drainage basin upstream from the gaging station near Antigo. This compares to the average rate of precipitation of about 30 in/yr (30.6 in/yr at Antigo) in Langlade County.

Another method for comparing the Wolf River and Eau Claire River basins is the flow-duration curve (fig. 10). A flow-duration curve is a cumulative frequency curve that shows the percentage of time that a specified discharge was equaled or exceeded during the period of record. For example, figure 10 shows that streamflow in the Wolf River at Langlade equaled or exceeded 300 ft^3/s for 70 percent of the time over the 18 years of record. Similarly, streamflow in the Eau Claire River near Antigo equaled or exceeded 53 ft^3/s for 70 percent of the time. This does not mean that streamflow in the Wolf River at Langlade equals or exceeds 300 ft^3/s for 70 percent of the time each year. Instead, the flow-duration curve shows that on the average, streamflow can be expected to equal or exceed 300 ft^3/s for 70 percent of the time.

The steeper slope of the curve for the Eau Claire River indicates that its flow is more variable. This is related to the fine-grained Wausau and Merrill tills that cover much of the western part of the Eau Claire River drainage basin; the low permeability of these deposits restricts infiltration of rainfall and snowmelt and thus causes more direct storm and snowmelt runoff to run into streams in the basin. The increasingly flat slope at the lower end (low discharge) of each curve, particularly for the Wolf River curve, is caused by the large ground-water contribution. This tends to maintain streamflow during low-flow conditions when precipitation is sparse or evapotranspiration is occurring.

Lakes

There are 843 lakes in Langlade County (Wisconsin Department of Natural Resources, 1977). Most lakes are located in the moraine areas of the northern and southeastern parts of the county. Only 37 lakes are over 40 acres; most lakes (762) in the county have surface areas of less than 20 acres.

Many of the small lakes are spring ponds, the ground-water fed bodies of water with outlets that form headwaters for streams. Water levels in these ponds are maintained by ground-water seepage. Most lakes in the northern part of the county have no streams flowing into or out of them. In a current study of four such lakes (no inflowing or outflowing streams) in northern Wisconsin, data show that direct precipitation is the major source of water entering this type of lake. Precipitation

Table 2. Summary of streamflow for the Eau Claire River near Antigo, Wisconsin, and the Wolf River near Langlade, Wisconsin

	Drainage basin area (mi^2)	Average instantaneous discharge (ft^3/s)	Minimum instantaneous discharge (ft^3/s)	Maximum instantaneous discharge (ft^3/s)	Average annual rate of runoff (in/yr)
Eau Claire River near Antigo, Wisconsin (period of record 1974-81)	200	146	18	1,840	9.9
Wolf River near Langlade, Wisconsin (period of record 1966-present)	463	461	119	2,200	13.5

accounts for 83 to 98 percent of inflow into these lakes (Dennis A. Wentz, U.S. Geological Survey, oral commun., 1985).

Seasonal lake-level fluctuations in Langlade County are likely to be less than 2 ft and often less than 1 ft [based on data from two lakes monitored in this study and on the findings of House (1985)]. House developed equations to estimate average-annual lake-level fluctuations in ungaged lakes throughout the State. These equations were based on long-term records from 32 lakes in 4 geographic zones within the State. House's equation for lakes in the Langlade County area is as follows:

$$\text{Average-annual fluctuation } (AAF) = 0.0036(RD) - 0.52(SA) + 0.0195\ (MD)$$

where:

RD = the ratio of the square root of a lake's surface area to its maximum depth, in miles,

SA = the surface area of the lake, in square miles, and

MD = the maximum depth of the lake, in feet.

This equation has a correlation coefficient (R^2) of 0.92. That is, it provided a correct estimate of the average-annual fluctuation 92 percent of the time for lakes in his study. The average error of estimate was 27.9 percent, which is the average percentage difference between the actual average fluctuation and that calculated by the equation.

The above equation was applied to Rose Lake and Noboken Lake, two lakes whose stages were monitored during periods of open water during this study. Their locations are shown in figure 6. Calculated estimates of average-annual fluctuation were 0.79 ft and 1.08 ft for Rose Lake and Noboken Lake, respectively. These values compare reasonably well with the fluctuations of these two lakes measured during this study. Rose Lake fluc-

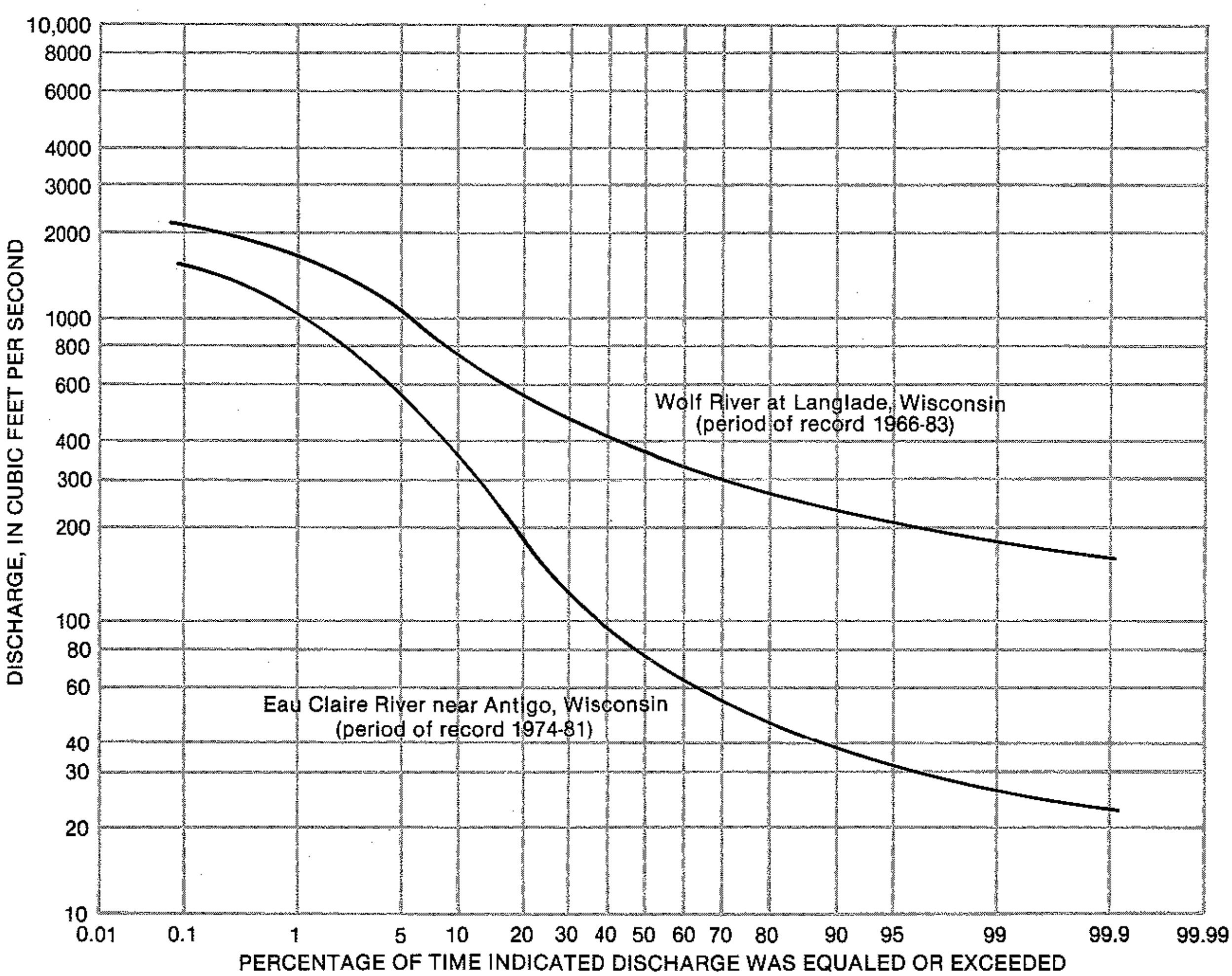

Figure 10. Flow-duration curves for the Wolf River at Langlade, Wisconsin, and the Eau Claire River near Antigo, Wisconsin.

tuated a total of about 0.3 ft and Noboken Lake fluctuated about 1.2 ft as shown in figure 5.

Lake levels appear to be relatively stable in Langlade County. This is significant in that lake cottage owners are not likely to be inconvenienced by rising lake levels that damage shorelines and structures or by falling lake levels that leave piers and docks high and dry.

GROUND-WATER/ SURFACE-WATER RELATIONS

The relation between ground water and surface water has been referred to in the previous sections on ground-water movement and estimation of ground-water recharge. In this section, this relation will be further presented in terms of ground-water/lake-level fluctuations. The areal variation in the ground-water component of streamflow will be determined from measurements of streamflow at low flow and by hydrograph separation.

Ground-Water/Lake Interactions

Hydrographs for observation wells La–1242 and La–1243, shown in figure 5, are compared with hydrographs of lake levels of nearby Rose Lake and Noboken Lake. Observation well La–1242 is located about 2,000 ft north of Rose Lake (fig. 6) and observation well La–1243 is located about 1.2 mi east of Noboken Lake. Most lake levels and nearby ground-water levels fluctuate together in a seasonal pattern—that is, levels rise due to snowmelt and spring precipitation and fall through the summer months due to evapotranspiration and less precipitation. However, neither observation-well/lake-level pair in figure 5 fluctuates according to this seasonal pattern.

Rose Lake is a ground-water discharge lake (Novitzki and Devaul, 1978). This type of lake has no inflow stream but has at least one outflow stream. Ground-water seepage into Rose Lake tends to stablize the lake level during the summer. Streamflow out of the lake increases with increased ground-water flow into the lake during the spring, thus reducing what might normally be a high lake level. The water level in Rose Lake does increase slightly (<0.2 ft) for a period of time after major rainstorms, as shown by the precipitation record in figure 5. Due to the relatively great depth to water and its proximity to the discharge area, the water level in observation well La–1242 shows only the subtle seasonal trends of rising during the spring recharge period and falling during the summer months.

There was no correlation between the lake-level fluctuation in Noboken Lake and ground-water fluctuation in observation well La–1243 (fig. 5). Noboken Lake is underlain by an impermeable clay layer that restricts downward ground-water movement. This causes the water level in Noboken Lake and adjacent wetlands to be "perched" about 50 ft above local ground-water levels. Unlike Rose Lake, the level of Noboken Lake is probably maintained by direct precipitation and, to a minor extent, by overland flow and ground-water seepage. The higher lake level in spring and early summer is caused by increased precipitation; the lake level declines throughout the summer due to evaporation. The lake level is able to rise higher than the level in Rose Lake, particularly in the spring, because Noboken Lake lacks a surface-water outlet.

Unlike Noboken Lake, the water level in nearby observation well La–1243 does not rise in direct response to periods of heavy precipitation. This slow response is caused by overlying impermeable material and a relatively great depth to water (>70 ft) in well La–1243. The hydrograph of well La–1243 does, however, show a trend of generally rising water levels throughout the monitoring period. In fact, wells throughout the State have exhibited rising levels for the past several years (Holmstrom and others, 1985).

Ground-Water/Stream Interactions

As discussed in the section "Ground-Water Occurrence and Movement," ground water is discharged into area streams. During extended periods of little or no precipitation, streamflow is maintained solely by ground-water runoff (seepage into the stream). Streamflow was measured during such a period (November 2–3, 1983) at 70 stream sites throughout Langlade County. Ground-water runoff rates were determined from these measurements for each of the 70 stream subbasins. Figure 11 shows runoff rates during this period in terms of streamflow per unit area of contributing surface-water basin.

The rate of ground-water runoff to a stream is largely determined by the type of surficial deposits drained by the stream. Runoff rates varied from 0.05 to 3.65 $(ft^3/s)/mi^2$ for individual subbasins. The majority of subbasins and areas had moderate runoff rates in the 0.50 to 1.50 $(ft^3/s)/mi^2$ range. This is due to the uniformity of the glacial deposits that cover most subbasins in the county. Less permeable deposits retard both infiltration of precipitation and ground-water movement. This accounts for the lower runoff rates [0–0.50 $(ft^3/s)/mi^2$] in the western part of the county where less permeable fine-grained Wausau and Merrill tills cover the entire subbasin areas.

The anomalously low runoff rate for the central part of the county and the very high runoff rates in several of the extreme southern subbasins of the county are interrelated. Although permeable outwash deposits underlie the Antigo Flats area of central Langlade County, the depth to the water table particularly in the eastern parts of the Antigo Flats area exceeds 50 ft or more. Streams draining this area are in relatively poor hydraulic connection with the water table. Much of the precipitation recharging this area infiltrates downward to the water table and moves out of the surface-water basin toward discharge areas south and east as shown in plate 1. These discharge areas, in particular, are the many spring ponds and

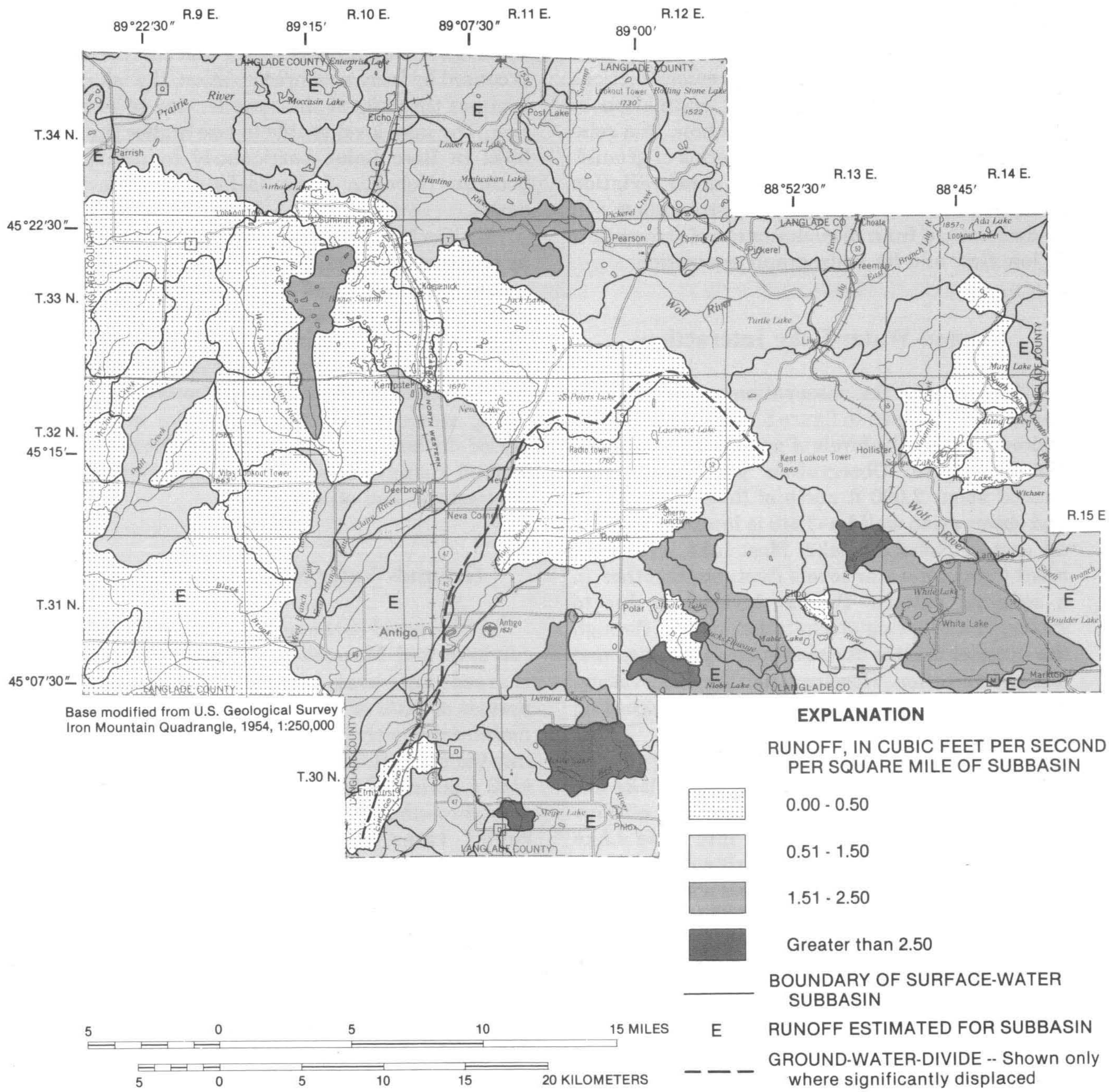

Figure 11. Low-flow runoff, November 2-3, 1983, in Langlade County.

streams referred to in previous sections. The anomalously high runoff rates in these subbasins are not due to more permeable surficial deposits, but rather to the displacement of the ground-water divide with respect to the surface-water subbasin divides in this area. This displacement (shown in fig. 11) creates larger ground-water basin areas and therefore larger runoff rates in southern surface-water basins. This displaced ground-water divide underlies the Antigo Flats area; its exact location probably changes seasonally with water-table fluctuations.

The ground-water contribution to streamflow in the Wolf and Eau Claire Rivers was also determined by the method of hydrograph separation (Linsley and others, 1975). Figure 12 shows hydrographs of average daily flows in each river for the 12-month period ending September 30, 1979, a period of above average precipitation. The streamflow has been separated empirically into its base-flow component (the contribution from ground water) and its surface-runoff component. The separation indicates that ground water contributed about 75 percent of the total 1.3×10^{11} gallons of water discharged past the Wolf River gaging station at Langlade during that period. About 55 percent of the total of 4.5×10^{10} gallons passing the Eau Claire River gaging station near Antigo was ground-water runoff. Ground water contributed about 70 percent of flow in the Wolf River and about 50 percent of flow in the Eau Claire River for the relatively dry 12-month period ending September 30, 1976 (hydrographs not shown). The difference in percentage of ground-water contribution for the two streams can be attributed to the less permeable surficial materials in the western drainage basin of the Eau Claire River.

In a previous study of spring ponds in southern Langlade County, Rose (1977, p. 6) determined that discharge in the Red River in southern Langlade County (pl. 1), was 97 percent ground-water runoff. The Red River is located in the major ground-water discharge area in southern Langlade County where contributing ground-water basin areas are con-

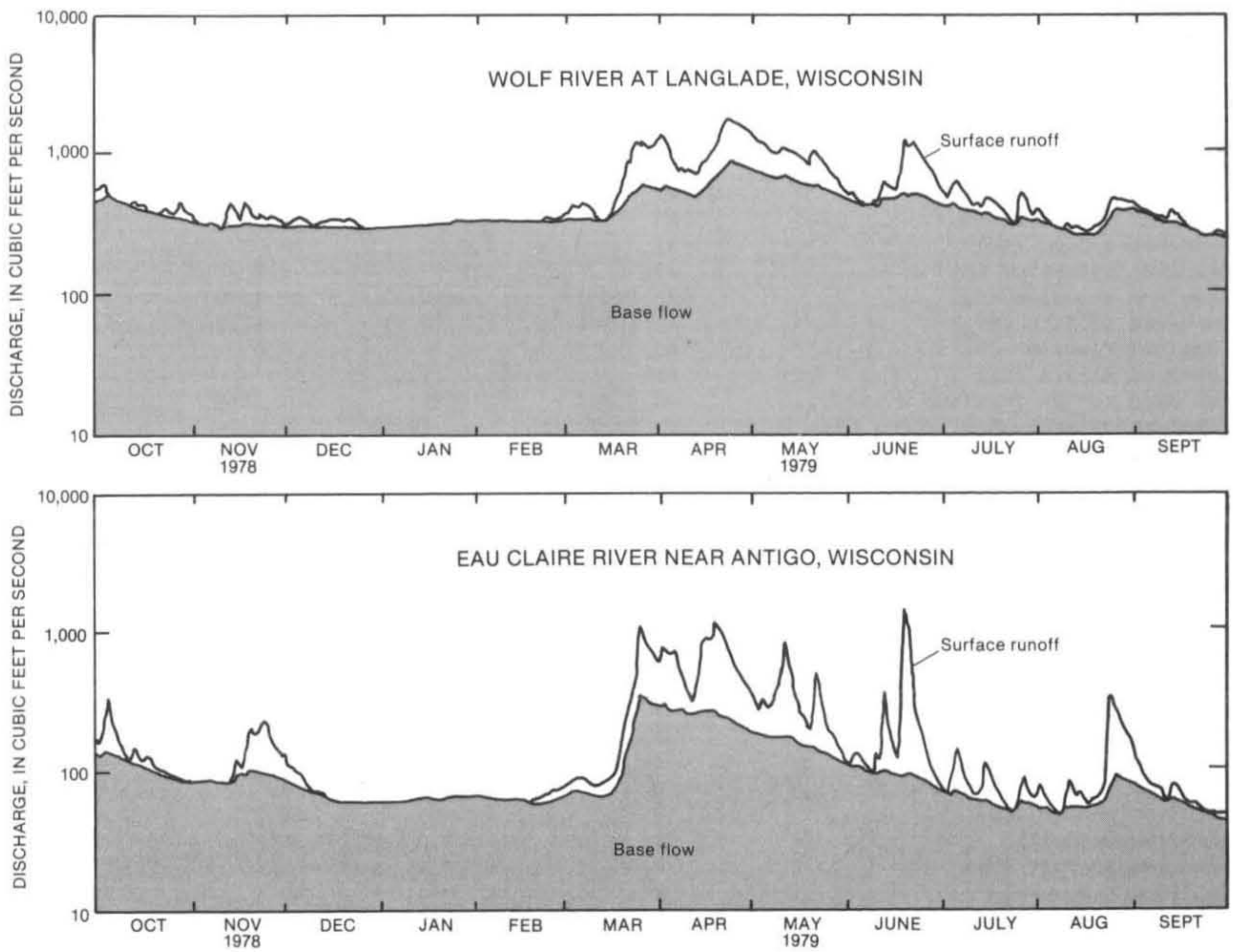

Figure 12. Hydrographs of base flow and surface runoff for the Wolf River and the Eau Claire River, 1979 water year.

siderably larger than the respective surface-water drainage basins.

WATER QUALITY

Ground-Water Quality

Ground-water composition in the county is a calcium magnesium bicarbonate type similar to most ground water in the State (Kammerer, 1984). The ground water is suitable for most water uses. Water samples from 41 wells in the sand-and-gravel aquifer and 12 wells in the Precambrian bedrock aquifer were analyzed to define the chemical character of the ground water. Sampling sites were selected in order to provide an even areal distribution of sites throughout the county (fig. 6).

Summaries of analyses for common cations and anions, nutrients, pH, dissolved solids, hardness, and trace constituents are shown in tables 3 and 4. Table 3 summarizes ground-water analyses from the sand-and-gravel aquifer and table 4 summarizes ground-water analyses from the Precambrian bedrock aquifer. Values shown in parentheses in tables 3 and 4 are taken from a summary of ground-water quality in Wisconsin by Kammerer (1984). Data for his summary were taken

Table 3. Summary of chemical analyses of water from the sand-and-gravel aquifer

Constituents	Number of analyses	Minimum value	Maximum value	Median value
Temperature (°C)	41	8.0	11.5	9.0
Specific conductance (microsiemens/cm @ 25°C)	41	100	630	260
pH (units)	41	5.6	8.5	7.5
CONCENTRATIONS IN MILLIGRAMS PER LITER				
Alkalinity (CO_3 + HCO_3)	41	30	259	130
Total hardness as $CaCO_3$	41	48	280	130
Noncarbonate hardness as $CaCO_3$	41	0	70	4
Dissolved calcium (Ca)	41	11	63	33
Dissolved magnesium (Mg)	41	4.3	30	13
Dissolved sodium (Na)	41	1.6	13	2.7
Dissolved potassium (K)	41	.1	1.6	.8
Dissolved chloride (Cl)	41 (166)*	.2 (0.0)	40 (190)	1.9 (2.2)
Dissolved sulfate (SO_4)	41 (166)	1.0 (0.5)	25 (149)	6.0 (7.2)
Dissolved fluoride (F)	41	.1	.6	.2
Dissolved silica (Si)	41	11	33	16
Dissolved solids (residue @ 180°C)	41 (165)	83 (28)	334 (940)	142 (146)
Dissolved nitrate as nitrogen (N)	41 (132)	<.10 (0.0)	9.9 (41)	.14 (0.20)
Dissolved ammonia as nitrogen (N)	41	<.01	.99	.02
Dissolved organic nitrogen as nitrogen (N)	41	<.01	2.06	<.1
Dissolved phosphorous (P)	41	<.01	1.10	.02
Dissolved organic carbon (C)	8	.90	2.10	1.25
CONCENTRATIONS IN MICROGRAMS PER LITER				
Dissolved iron (Fe)	41 (150)	3 (0)	11,000 (19,000)	16 (130)
Dissolved manganese (Mn)	41 (149)	1 (0)	1,100 (6,000)	14 (45)
Dissolved strontium (Sr)	41	19	110	40
Dissolved arsenic (As)	8	<1	7	<1
Dissolved barium (Ba)	8	12	31	23
Dissolved cadmium (Cd)	8	<1	2	<1
Dissolved chromium (Cr)	8	<1	3	<1
Dissolved copper (Cu)	8	2	29	5
Dissolved lead (Pb)	8	<1	5	2
Dissolved mercury (Hg)	8	<.1	<.1	<.1
Dissolved zinc (Zn)	8	14	140	76

*Numbers in parentheses represent values from summary of water-quality data by Kammerer (1984).

from analyses of water from 166 wells in the sand-and-gravel aquifer and 43 wells in Precambrian bedrock in a 20-county area in northeastern Wisconsin (including Langlade County) with a similar hydrologic and geologic setting. All maximum and minimum values in Langlade County analyses fall within those for the 20-county area with the exception of the maximum value for dissolved manganese in the Precambrian bedrock aquifer (table 4).

Elevated concentrations of dissolved solids, chloride, sulfate, iron, and manganese concentrations and trace inorganic constituents are generally recognized as indicators of poor quality water. Maximum recommended levels of these constituents in Wisconsin are shown in table 5. Primary standards are set to protect health; secondary standards are set for consideration of aesthetic effects.

Most of the inorganic constituents with primary standards (table 5) were analyzed in samples from eight wells in the sand-and-gravel aquifer and four wells in the Precambrian bedrock aquifer. No primary standards were exceeded in ground water from any of the sampled wells. Arsenic, barium, cadmium, chromium, copper, lead, mercury, and zinc are commonly referred to as trace inorganic constituents because they occur

Table 4. Summary of chemical analyses of water from the Precambrian aquifer

Constituents	Number of analyses	Minimum value	Maximum value	Median value
Temperature (°C)	12	5.0	12.5	9.0
Specific conductance (microsiemens/cm @ 25°C)	12	110	610	265
pH (units)	12	6.3	8.1	7.6
CONCENTRATIONS IN MILLIGRAMS PER LITER				
Alkalinity (CO_3 + HCO_3)	12	47	222	128
Total hardness as $CaCO_3$	12	50	260	125
Noncarbonate hardness as $CaCO_3$	12	0	57	2
Dissolved calcium (Ca)	12	11	66	32
Dissolved magnesium (Mg)	12	5.4	25	14
Dissolved sodium (Na)	12	1.5	12	4.2
Dissolved potassium (K)	12	.2	1.6	.8
Dissolved chloride (Cl)	12 (43)*	.2 (0.2)	32 (153)	1.5 (3.3)
Dissolved sulfate (SO_4)	12 (43)	2.0 (0.7)	21 (86)	8.0 (7.2)
Dissolved fluoride (F)	12	<.1	1.3	.2
Dissolved silica (Si)	12	11	32	17
Dissolved solids (residue @ 180°C)	12 (43)	71 (65)	369 (601)	146 (178)
Dissolved nitrate as nitrogen (N)	12 (25)	<.10 (0.0)	7.0 (21)	.18 (0.9)
Dissolved ammonia as nitrogen (N)	12	<.01	.08	.02
Dissolved organic nitrogen as nitrogen (N)	12	<.01	5.1	.18
Dissolved phosphorous (P)	12	<.01	.29	.02
Dissolved organic carbon (C)	4	.7	1.4	1.1
CONCENTRATIONS IN MICROGRAMS PER LITER				
Dissolved iron (Fe)	12 (44)	<3 (10)	480 (7,000)	20 (60)
Dissolved manganese (Mn)	12 (43)	1 (0)	2,400 (2,200)	18 (20)
Dissolved strontium (Sr)	12	14	210	60
Dissolved arsenic (As)	4	1	7	4
Dissolved barium (Ba)	4	10	42	26
Dissolved cadmium (Cd)	4	<1	2	<1
Dissolved chromium (Cr)	4	<1	1	<1
Dissolved copper (Cu)	3	4	5	4
Dissolved lead (Pb)	4	2	4	2
Dissolved mercury (Hg)	4	<.1	<.1	<.1
Dissolved zinc (Zn)	3	24	560	74

*Numbers in parentheses represent values from summary of water-quality data by Kammerer (1984).

in minute quantities in the earth's crust. Concentrations of these trace inorganic constituents in all water samples were either below detectable limits or below the drinking-water standards in Langlade County.

Iron and Manganese

There is a wide range in the concentrations of iron and manganese in Wisconsin ground water because of complex chemical and biological controls on their solubility (Kammerer, 1984). The concentration of dissolved iron exceeded established secondary standards in 13 of the 41 wells in the sand-and-gravel aquifer and in 1 well in the Precambrian bedrock aquifer. Dissolved manganese concentrations exceeded the standard in 17 of the 41 wells in the sand-and-gravel aquifer and in 3 of 12 wells in the Precambrian bedrock aquifer. Maximum concentrations found were 11,000 μg/L

Table 5. Summary of Wisconsin's drinking-water standards

Constituent	Maximum recommended level [all concentrations in milligrams per liter (micrograms per liter in parentheses) unless otherwise indicated] Primary (health) standard		Secondary (aesthetic) standard	
Inorganic chemicals:				
Arsenic	0.05	(50)		
Barium	1	(1000)		
Cadmium	0.01	(10)		
Chromium	0.05	(50)		
Fluoride	2.2	--		
Lead	0.05	(50)		
Mercury	0.002	(2)		
Nitrate (as N)	10	--		
Selenium	0.01	(10)		
Silver	0.05	(50)		
Chloride			250	
Color			15 units	
Foaming agents (MBAS)			0.5	
Hydrogen sulfide			not detectable	
Iron			0.3	(300)
Manganese			0.05	(50)
Odor			3 threshold number	
Sulfate			250	
Total residue			500	
Zinc			5	(5000)
Organic chemicals:				
Chlorinated hydrocarbons				
Endrin	0.0002	(0.2)		
Lindane	0.004	(4)		
Methoxychlor	0.1	(100)		
Toxaphene	0.005	(5)		
Chlorophenoxy herbicides				
2,4-D	0.1	(100)		
2,4,5-TP (Silvex)	0.01	(10)		

*From Wisconsin Department of Natural Resources (1978).

for iron and 2,400 μg/L for manganese. These higher concentrations of iron and manganese appear to be randomly distributed throughout the county, as is typical of much of the State. Elevated iron and manganese concentrations may cause objectionable stains to plumbing fixtures and fabrics. These concentrations, however, are not a health concern.

Hardness

The total hardness of water is primarily a measure of the combined concentrations of calcium and magnesium. Total hardness is expressed in terms of equivalent amount of calcium carbonate. Hardness of water from different sources can be compared by the following classification scheme (Durfor and Becker, 1964, p. 27).

Hardness range (mg/L of calcium carbonate)	Classification
0–60 mg/L	soft
60–120 mg/L	moderately hard
120–180 mg/L	hard
more than 180 mg/L	very hard

Values for total hardness (as calcium carbonate) ranged from 48 to 280 mg/L, with a median value of 130 mg/L. All 11 samples classified as very hard were from wells located in southern Langlade County. The higher percentage of carbonate material in the Mapleview till (fig. 4) underlying this part of the county is the probable source of the higher hardness in the ground water.

Surface-Water Quality

Water samples from four streams were analyzed for the same chemical constituents as ground water and the results are shown in table 6. Spring Creek near Antigo was sampled in section 18 of T. 30 N., R. 10 E. Evergreen Creek was sampled in section 18 of T. 31 N., R. 14 E. Swamp Creek was sampled in section 7 of T. 34 N., R. 12 E., and an unnamed tributary flowing into Rolling Stone Lake was sampled in section 12 of T. 34 N., R. 14 E. Stream sampling locations are shown in figure 6. Streams were sampled on May 5 and 6, 1983, during a period of medium flow when essentially all streamflow was ground-water runoff. This is shown by the similarity of chemical concentrations to those of ground water in each respective area. For example, the total hardness and total dissolved solids concentrations in Swamp Creek and in the unnamed tributary to Rolling Stone Lake are much less than those in Spring Brook and Evergreen Creek. Spring Brook and Evergreen Creek drain southern areas of the county where glacial materials contain carbonate minerals rich in calcium and magnesium.

Composite samples of stream-bottom material were collected at cross sections in Swamp Creek and the tributary to Rolling Stone Lake. Bottom material in Swamp Creek was mixed sand and some silt. Bottom material in the tributary to Rolling Stone Lake was silt and organic debris, with some sand. These samples were analyzed for trace inorganic metals in order to provide baseline data for comparison to future analyses if mining waste-disposal sites are placed in nearby areas. Concentrations of trace constituents in all samples were at or near the detection limits.

GROUND-WATER USE

A total of about 1.7 billion gallons of ground water was pumped from aquifers in Langlade County in 1983 (table 7). Only 3 Mgal of this total was pumped from domestic wells finished in Precambrian bedrock.

The city of Antigo, the village of White Lake, and Elcho Sanitary District are served by public-supply systems. Antigo pumped a total of 392 Mgal, Elcho 13.5 Mgal, and White Lake 9.5 Mgal in 1983. These totals include use by institutions such as schools and commercial and industrial customers served by these systems (Wisconsin Department of Natural Resource records).

All farms, rural residences, summer homes, and schools not served by these three systems have their own wells. Estimated total pumpage for 1983 for rural residences and farm stock was about 350 Mgal or about 1 Mgal/d. This pumpage is based on an average of 50 gal/d per person and standard consumptive values for farm animals; for example, 20 gal/d for a dairy cow (Lawrence and Ellefson, 1982).

Irrigation and fish hatcheries are the major uses of ground water in the county (table 7). Ground water for irrigation is pumped primarily during the months of June, July, and August. A pumpage of 379 Mgal of ground water for irrigation from 55 wells was reported to the Wisconsin Department of Natural Resource during the summer of 1983. This was approximately 22 percent of total pumpage for the county for that year. An additional 30 Mgal of water for irrigation was pumped from surface water.

Table 6. Chemical analyses of water and bottom material from Langlade County streams

Constituents Water-column analysis	Unnamed tributary to Rolling Stone Lake	Swamp Creek	Spring Brook	Evergreen Creek
Temperature (°C)	5.5	10.5	12.	11.5
Specific conductance (microsiemens/cm @ 25°C)	185	160	420	285
pH (units)	7.6	7.4	9.0	8.4
CONCENTRATIONS IN MILLIGRAMS PER LITER				
Alkalinity (CO_3 + HCO_3)	87	72	138	130
Total hardness as $CaCO_3$	93	79	180	150
Noncarbonate hardness as $CaCO_3$	6	7	45	8
Dissolved calcium (Ca)	21	18	42	34
Dissolved magnesium (Mg)	9.9	8.3	19	16
Dissolved sodium (Na)	2.2	2.5	18	2.4
Dissolved potassium (K)	.6	.8	3.2	1.3
Dissolved chloride (Cl)	.9	2.5	26	.9
Dissolved sulfate (SO_4)	10	10	31	10
Dissolved fluoride (F)	<.1	<.1	.2	.6
Dissolved silica (Si)	11	2.3	5.6	9.6
Dissolved solids (residue @ 180°C)	104	85	251	158
Dissolved nitrate as nitrogen (N)	.15	.11	3.7	<.10
Dissolved ammonia as nitrogen (N)	.02	.04	.03	.02
Dissolved organic nitrogen as nitrogen (N)	.18	.26	.27	.08
Dissolved phosphorous (P)	.02	.02	.56	.01
CONCENTRATIONS IN MICROGRAMS PER LITER				
Iron, total recoverable (Fe)	210	580	60	70
Manganese, total recoverable (Mn)	40	60	30	10
Arsenic, total recoverable (As)	1	1	1	1
Barium, total recoverable (Ba)	100	<100	<100	<100
Cadmium, total recoverable (Cd)	6	4	3	3
Chromium, total recoverable (Cr)	<10	20	20	<10
Copper, total recoverable (Cu)	3	3	5	3
Lead, total recoverable (Pb)	10	10	11	12
Mercury, total recoverable (Hg)	.1	.1	.2	.1
Zinc, total recoverable (Zn)	30	40	40	40
Nickel, total recoverable (Ni)	4	3	9	1
Silver, total recoverable (Ag)	<1	<1	<1	<1
Selenium, total recoverable (Se)	<1	<1	<1	<1

Constituents Bed-material analysis	Unnamed tributary to Rolling Stone Lake	Swamp Creek	Spring Brook	Evergreen Creek
CONCENTRATIONS IN MICROGRAMS PER GRAM				
Iron, total recoverable (Fe)	680	640		
Manganese, total recoverable (Mn)	100	96		
Arsenic, total recoverable (As)	<1	<1		
Cadmium, total recoverable (Cd)	3	2		
Chromium, total recoverable (Cr)	5	4		
Copper, total recoverable (Cu)	<10	<10		
Lead, total recoverable (Pb)	<10	<10		
Mercury, total recoverable (Hg)	.02	.01		
Zinc, total recoverable (Zn)	12	11		
Cobalt, total recoverable (Co)	<10	<10		
Nickel, total recoverable (Ni)	<10	<10		
Silver, total recoverable (Ag)	<1	<1		

Irrigation of cropland was started prior to 1950. At that time, dug open pits were used in areas of the Antigo Flats where the water table was less than 15 ft below land surface. By 1960, 15 wells had been drilled for agricultural irrigation purposes. Figure 13 shows the increase in the number of irrigation wells since 1960. The large increase in the number of wells during the period 1976–78 was due to the 1976–77 drought.

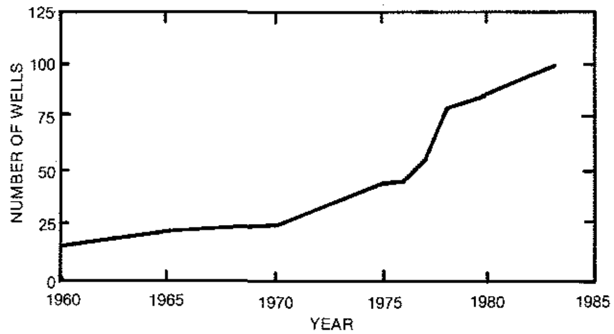

Figure 13. Number of agricultural irrigation wells in Langlade County, 1960–83.

SUMMARY

The glacial sand and gravel deposits underlying most of Langlade County provide essentially all water used for consumptive purposes. Characteristics of these deposits were determined from well and test-hole data. This information was used to map the thickness, areal extent, and hydraulic properties of the glacial deposits.

Saturated thicknesses of the sandy deposits underlying all but the extreme western, southwestern, and northeastern parts of the county are adequate for development of domestic supplies. Irrigation wells developed in outwash deposits commonly produce 500 to 800 gal/min. Precambrian bedrock provides limited amounts (less than 5 gal/min) of water for domestic purposes only in areas of few or no saturated sandy glacial deposits.

The horizontal hydraulic conductivity of glacial deposits ranges from 0.7 to 220.0 ft/d, based on specific-capacity data from slug-test and pumping-test data. Transmissivity of the glacial deposits was mapped using the hydraulic conductivities and saturated thicknesses; transmissivities range from zero for areas with unsaturated deposits to greater than 40,000 ft/d in the outwash deposits underlying the Antigo Flats area.

Ground-water fluctuations were seasonal; levels rose in the spring recharge periods and fell through the summer periods of high evapotranspiration and decreased rainfall. However, seasonal fluctuations were not as apparent in areas where the depth to water was greater and ground-water levels did not rise in direct response to individual storm events. Seasonal ground-water level declines caused by irrigation pumpage were determined to be minimal and of little significance to the Antigo Flats area.

Ground-water runoff contributes approximately 70 percent of annual streamflow to county streams and rivers. This large ground-water component of streamflow reflects the overall high permeability of glacial deposits in the county. Ground-water-runoff rates based on measurements of streamflow at 70 stream sites throughout the county varied from 0.05 to 3.65 $(ft^3/s)/mi^2$ for surface-water subbasins. Low streamflow rates were generally found in areas underlain by fine-grained, less permeable glacial deposits or in areas where the water table was deeper than 50 ft. High

Table 7. Ground-water pumpage by use, 1983

Use	Quantity used (Total in millions of gallons)	Percentage of total pumpage
Public supply	415	24
Private residential	192	11
Industrial	10	1
Irrigation	379	22
Stock watering	161	9
Fish hatchery [1]	563	33
Total	1,720	100

[1] 1982 figure.

streamflow rates were found where the contributing ground-water basin was larger than the surface-water basin.

Natural ground-water and surface-water quality is good throughout the entire county. Some elevated concentrations of iron and manganese and overall hard water result in aesthetic nuisances but are not harmful.

Total ground-water use in 1983 for all of Langlade County was 1.7 billion gallons or about 4.7 Mgal/d. Fish-hatchery facilities, public supply, and irrigation were the major uses.

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