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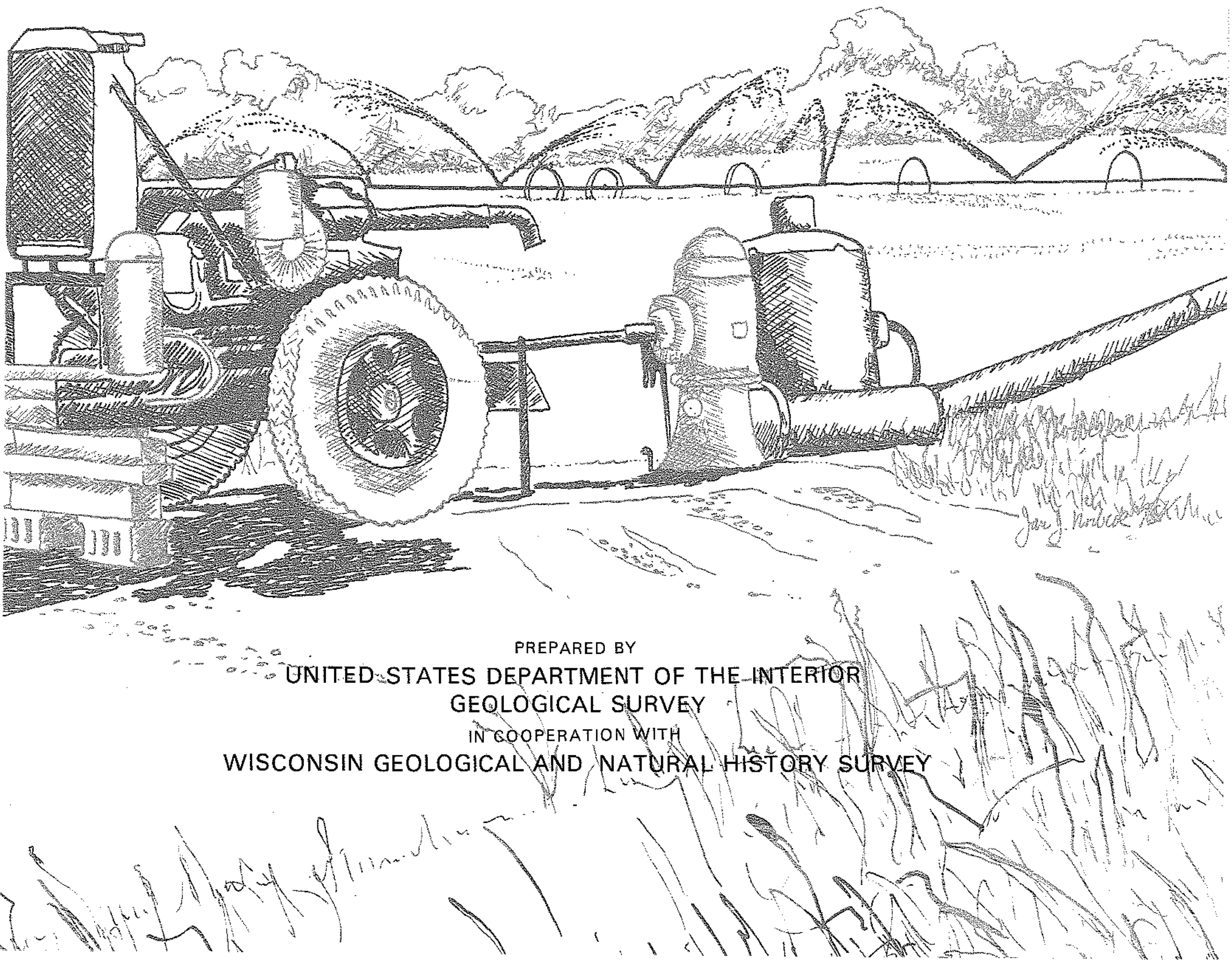
The Availability of Ground Water for Irrigation in the Rice Lake-Eau Claire Area, Wisconsin

by
E. A. Bell and S. M. Hindall
U.S. Geological Survey



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UNITED STATES DEPARTMENT OF THE INTERIOR
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This report is a product of the Geological and Natural History Survey Water Resources Program which includes: systematic collection, analysis, and cataloguing 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. Most of the work of the Survey's Water Resources Program is accomplished through state-federal cooperative cost sharing with the U.S. Geological Survey, Water Resources Division.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

and

UNIVERSITY OF WISCONSIN–EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
M. E. Ostrom, Director and State Geologist
Madison, Wisconsin
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Conversion Factors

Multiply English units	By	To obtain SI units
in (inches)	25.4	mm (millimetres)
ft (feet)	.3048	m (metres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)
gal (gallons)	3.785	l (litres)
gal/min (gallons per minute)	.06309	l/s (litres per second)
acres	.4047	ha (hectares)
acre-ft (acre-feet)	1233	m^3 (cubic metres)
ft/mi (feet per mile)	.1894	m/km (metres per kilometre)
ft^3/s (cubic feet per second)	.02832	m^3/s (cubic metres per second)
$(ft^3/s)/mi^2$ (cubic feet per second per square mile)	10.93	$(l/s)/km^2$ (litres per second per square kilometre)
(gal/d)/ft (gallons per day per foot)	12.42	(l/d)/m (litres per day per metre)
ft^2/d (feet squared per day)	.0929	m^2/d (metres squared per day)

Abstract

An abundance of ground water of excellent chemical quality for irrigating crops is available from glacial outwash sand and gravel and from the underlying sandstones in the Rice Lake-Eau Claire area.

Thick deposits of glacial outwash sand and gravel in the valleys of the Red Cedar and lower Chippewa Rivers yield more than 1,000 gallons per minute (63 litres per second) to many wells. Large tracts of irrigable soils, delineated in two subareas (Rice Lake and Cameron) in Barron County and one subarea (Menomonie) in Dunn County, lie within the outwash plains where ground water is available in large quantities. Yields are especially large in the Rice Lake and Cameron subareas where the sand and gravel is highly permeable and the thickness of saturated aquifer exceeds 250 feet (75 metres). Yields generally are less than 1,000 gallons per minute (63 litres per second) in the Menomonie subarea where large amounts of clay locally reduce the permeability of the aquifer and the thickness of saturated aquifer is less than 200 feet (60 metres).

Adequate water for irrigation is available also from sandstone underlying the glacial outwash plains. Because the two aquifers generally are connected hydraulically, wells penetrating the sandstone also withdraw water indirectly from the glacial drift. Most irrigation wells in Barron County withdraw water from glacial outwash; more than half the irrigation wells in Dunn County withdraw water from sandstone.

In most years, recharge to the ground-water reservoir is 6 to 8 inches (150 to 200 millimetres), which is more than ample to sustain pumping for irrigation without lowering the water table significantly.

Ground water in the area is a calcium bicarbonate water that ranges in dissolved-solids concentration from 35 to 330 milligrams per litre. Concentrations of sodium and boron are very low.

INTRODUCTION

The use of ground water for agricultural irrigation in the Rice Lake-Eau Claire area is well established. Few years have adequate rainfall at the right time for optimum crop production and the sandy well-drained soils retain water for only a short time. Crop moisture needs are supplemented by water pumped from glacial drift and sandstone bedrock, the two principal aquifers in the area.

Continued development of ground-water supplies for irrigation is likely in the area because conditions are favorable for expanded vegetable production. Large plots of sandy soil and generally abundant supplies of ground water give the area a good potential for cash crops (University of Wisconsin, Extension Service, College of Agriculture, 1964). The area is near large population centers and good markets for fresh and processed produce.

Purpose and Cooperation

The purpose of this report is to discuss the quantity and chemical quality of ground water available to irrigable lands in the area. It is intended to aid irrigators, water planners, and other users in the future management of the resource.

This study is a result of a cooperative project between the U.S. Geological Survey and the University of Wisconsin-Extension, Geological and Natural History Survey.

Scope

The report evaluates the ground-water resources of the Rice Lake-Eau Claire area with emphasis on use for irrigation. Three subareas in the Red Cedar River basin (fig. 1) were studied in detail. The three subareas, Rice Lake and Cameron subareas in Barron County and Menomonie subarea in Dunn County, include large tracts of irrigable soils on broad plains of glacial deposits in rural areas where large amounts of ground water are available. Although an abundance of water is available from the glacial drift in the Chippewa River valley in the Chippewa Falls-Eau Claire area, urbanization limits large-scale irrigation.

A series of maps of the entire project area and each of the three subareas show the geology; soils; and hydrology, water-yielding capability, and water quality of the glacial-drift and sandstone aquifers.

Many data on well logs, water levels, aquifer tests, precipitation, soil characteristics, crops irrigated, water use, chemical quality of water, and low flows of streams were collected and analyzed to compile the maps in this report. Most of the data relate to the glacial-drift aquifer and the sandstone aquifer of the irrigable lands in the three subareas.

Location and Extent of the Area

The Rice Lake-Eau Claire area (fig. 1) in this report includes the Red Cedar River basin and parts of the St. Croix and the lower Chippewa River basins.

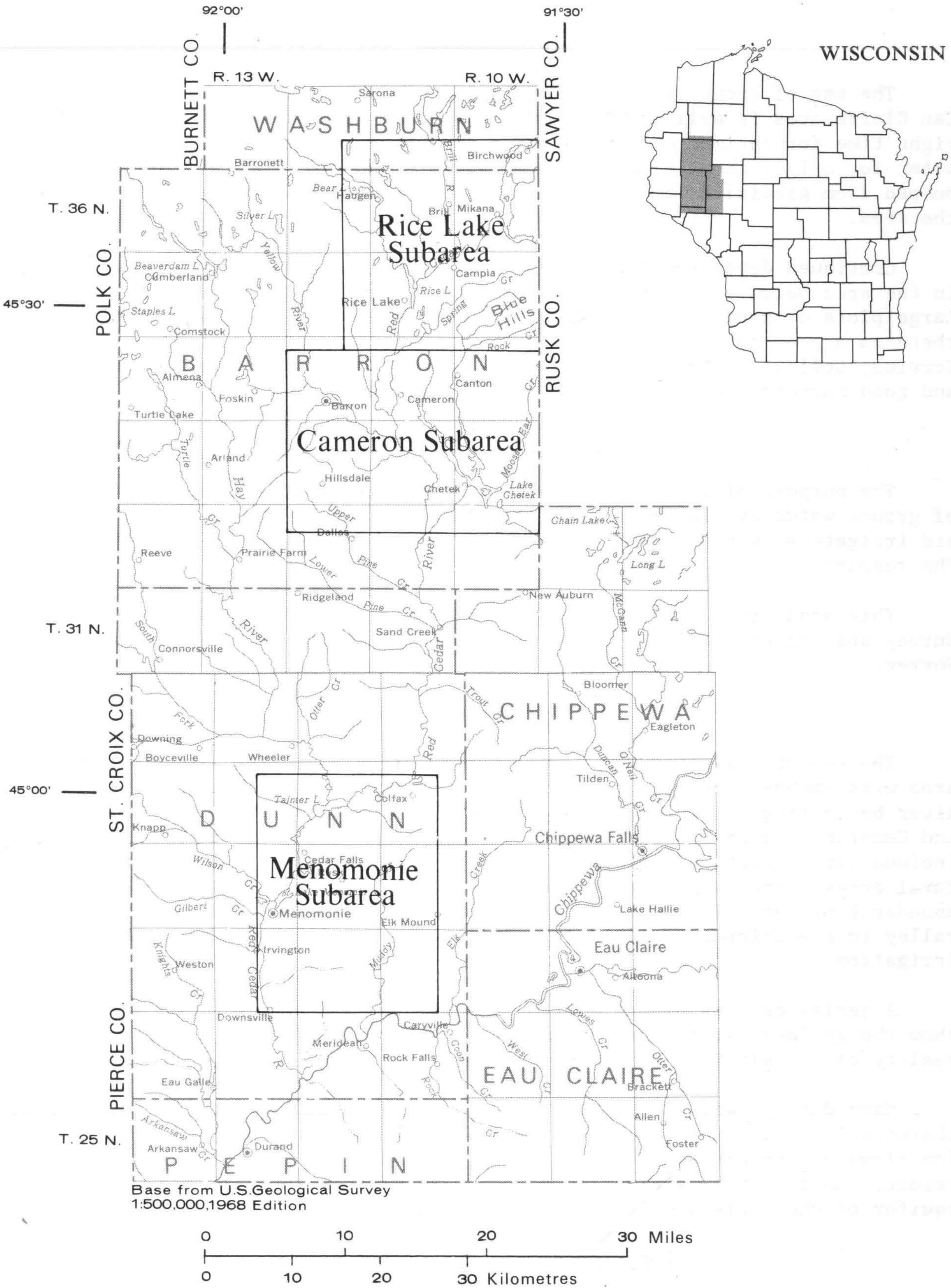


Figure 1. Location map of the Rice Lake-Eau Claire area.

The study area is about 3,000 mi^2 (7,800 km^2); it comprises all of Barron and Dunn Counties and parts of Pepin, Eau Claire, Chippewa, and Washburn Counties in northwestern Wisconsin.

The irrigable areas lie mostly in the valleys of the Chippewa and Red Cedar Rivers and their tributaries and adjoining outwash plains.

Irrigation

About 146,000,000 gal (550,000,000 l) or 450 acre-ft (555,000 m^3) of ground water was applied to about 5,000 acres (2,000 ha) during 1972. That amount of water is equivalent to 10 wells pumping at a rate of 1,000 gal/min (63 l/s) continuously for about 10 days. Two crops, peas followed by beans, were grown on about 3,000 of the 5,000 irrigated acres (1,200 of the 2,000 ha).

Irrigation water applied to crops during 1972 ranged from less than 0.5 to about 4 in (13 to 100 mm) and averaged about 1 in (25 mm). The supplemental application of 1 in (25 mm) of water during the wet summer of 1972 contrasts with nearly 8 in (200 mm) applied during the dry summer of 1969.

Supplemental irrigation in the Rice Lake-Eau Claire area is used chiefly for optimizing yields and control of quality vegetable crops. The acreages irrigated for the principal crops are tabulated below.

	Irrigated area (acres)		
Principal crops	1970	1971	1972
Potatoes- - - - - -	3,050	2,550	2,000
Other crops - - - -	3,100	4,600	3,050
Total - - - -	6,150	7,150	5,050

These crops include potatoes (particularly in Barron County), peas, beans, sweet corn, strawberries, and cucumbers. They are important cash crops in the area. Potatoes and strawberries are processed by the growers and marketed within west-central Wisconsin, southeastern Minnesota, and northeastern Iowa. Peas, beans, sweet corn, and cucumbers generally are grown under contract to major canneries and processed for nationwide distribution.

Irrigated crops of the area are raised on as much as 7,000 acres (2,830 ha), although the acreage varies annually. The acreage of irrigated crops is about 1 percent of the total harvested cropland (about 730,000 acres or 300,000 ha in 1971) in the study area. Nonirrigated crops are chiefly grains and hays to feed dairy cows and other livestock. Dairying is the principal agricultural industry in the area.

Climate

Warm, humid summers and cold, snowy winters are characteristic of the climate of the Rice Lake-Eau Claire area. The annual average temperature is 42°F (5.5°C). The seasonal average during June, July, and August is 67° (19°C).

The growing season averages 117 days, although the length of the season varies from year to year. In the northern part of Dunn County at Downing, the growing season ranges from 70 to 152 days. Latest killing frosts have occurred as early as April 30 and as late as June 14; earliest killing frosts have ranged from August 24 to October 14.

Of the 30-in (765-mm) average annual precipitation, about 20 in (518 mm) occurs during the spring and summer. June is the wettest month, with an average rainfall of 4.8 in (122 mm).

Previous Studies

The geology and hydrology of the Rice Lake-Eau Claire area have been described in regional and statewide reports. The general geology of the area was described by Chamberlin (1882a and b), Martin (1932), and Bean (1949). Glacial geology was outlined and mapped by Leverett (1929) and Thwaites (1956). Soils were classified by Hole and others (1968); soils of Barron County were described in detail by Robinson and Vessel (1958). Precambrian rocks have been described and mapped by Dutton and Bradley (1970). Information on water resources was compiled by Kirchoffer (1905), Weidman and Schultz (1915), and most recently by Young and Hindall (1972). An evaluation of the irrigation potential of Dunn County has been made in a preliminary report by Olcott and others (1967).

Acknowledgments

Many municipal and county officials, State and Federal agencies, consultants, drillers, and individual well owners assisted this study by providing well and water information. Many persons allowed access to their wells for water-level measurements or for collecting water samples for chemical analyses. Many others allowed test augering and the placing of observation wells on their land. Several irrigators pumped their wells for aquifer tests. The authors thank each of these persons for his contribution to the study. The authors also appreciate the assistance given by several persons who measured water levels and precipitation gages or serviced automatic water-level recorders for the duration of the study.

GEOLOGY

The rocks and soils that control the movement and storage of ground water in the Rice Lake-Eau Claire area include, in ascending order, basement rocks of Precambrian age, younger Cambrian and Ordovician sandstone and dolomite bedrock, unconsolidated glacial deposits of Quaternary age, and alluvial soil of Holocene age. The bedrock geology is shown in figure 2. It is overlain by glacial drift throughout most of the study area.

Precambrian Crystalline Rocks

Igneous and metamorphic basement rocks of Precambrian age underlie the entire area, are essentially impermeable, and their surface marks the lower limit of ground-water movement. These rocks form the bedrock surface in the Blue Hills area east of Rice Lake and in the Chippewa River valley around

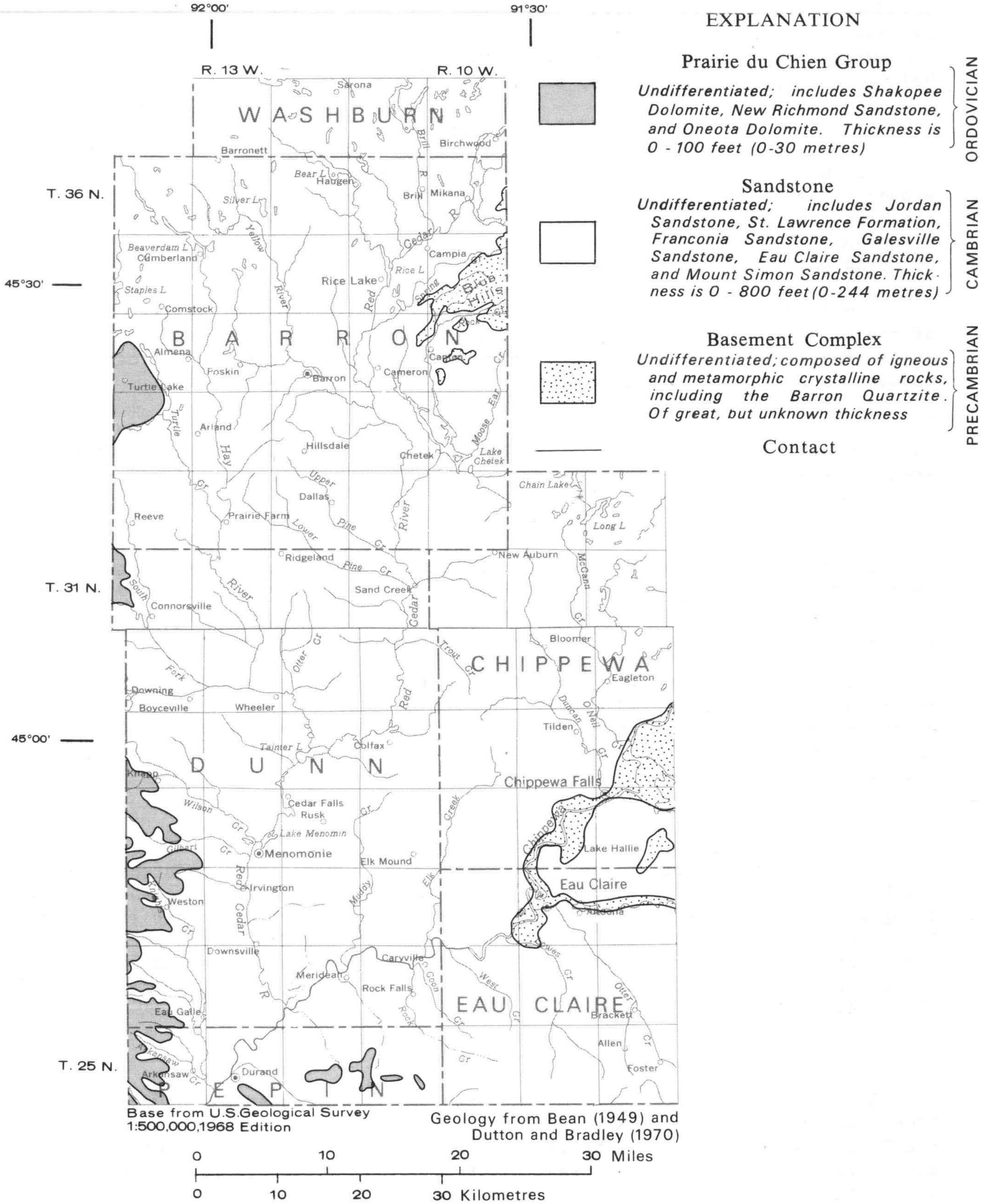


Figure 2. Bedrock geology of the Rice Lake-Eau Claire area.

Chippewa Falls and Eau Claire. Throughout the rest of the area they are overlain by sandstone. The eroded Precambrian crystalline rock surface generally slopes southwestward at about 15 ft/mi (2.8 m/km) and reaches a depth of 500 ft (150 m) below the Chippewa River valley floor near Durand.

Paleozoic Bedrock

The bedrock in nearly all the Rice Lake-Eau Claire area (fig. 2) is sandstone of Cambrian age, which is one of the two major aquifers. In this report the sandstone is undifferentiated, but it consists predominantly of the Mount Simon and Eau Claire Formations. Most wells penetrating bedrock in the area withdraw water from these units.

The sandstone thins from about 800 ft (240 m) in the southwestern part of the study area to zero in the Chippewa Falls-Eau Claire area and the Blue Hills area. The sandstone originally covered the entire area, but erosion has reduced it greatly, entirely removing it in some places.

As much as 100 ft (30 m) of dolomite of the Prairie du Chien Group overlie the Cambrian rocks and cap hills in the southwestern and western parts of the area. These Ordovician rocks are not within the areas of irrigation.

Bedrock Surface

The bedrock surface in the Rice Lake-Eau Claire area, as the land surface, is a series of valleys flanked by highlands. If all the unconsolidated material overlying the bedrock were removed, the valleys and hills would be evident. The valleys contain thick sections of water-yielding sand and gravel.

The bedrock valleys were probably preglacial watercourses that were enlarged by the action of glacial melt water. At the Blue Hills area, the hard quartzite diverted the melt water around the quartzite bluffs and eroded a deep valley in the soft sandstone. During later stages of glaciation the valley filled with outwash and the existing drainage system evolved.

Rice Lake Subarea

A "Y"-shaped buried valley system cut 250 ft (76 m) into sandstone, and the high, steep bluffs of quartzite in the Blue Hills area dominate the bedrock topography in the Rice Lake subarea (fig. 3). The deeper and longer limb of the "Y" trends southwestward from Birchwood through the Red Cedar Lake area along Red Cedar River and turns southward just east of Rice Lake. The smaller and shallower limb of the "Y" extends along Bear Creek to Rice Lake, where it joins the larger valley.

Cameron Subarea

A 200- to 300-ft (61 to 91-m) deep bedrock valley extends southward from Rice Lake into the Cameron subarea (fig. 4), where it turns southeastward along the Chetek chain of lakes. The valley narrows where it is restricted by the steep bluffs of quartzite northeast of Cameron. It widens southeast of Chetek and south of the Blue Hills area. A tributary bedrock valley extending from Barron to Cameron joins the main bedrock valley near Cameron.

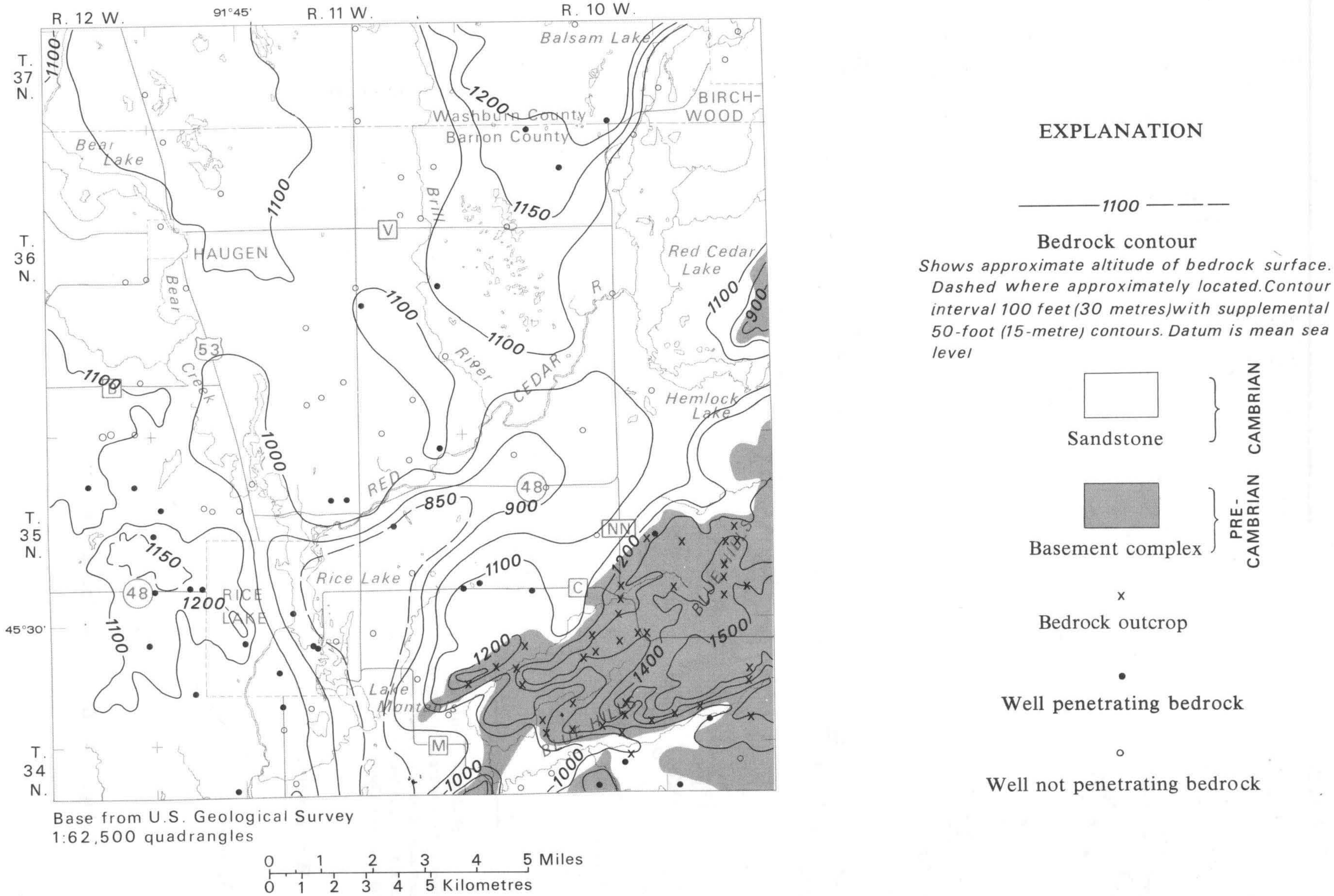


Figure 3. Bedrock geology and topography of the Rice Lake subarea.

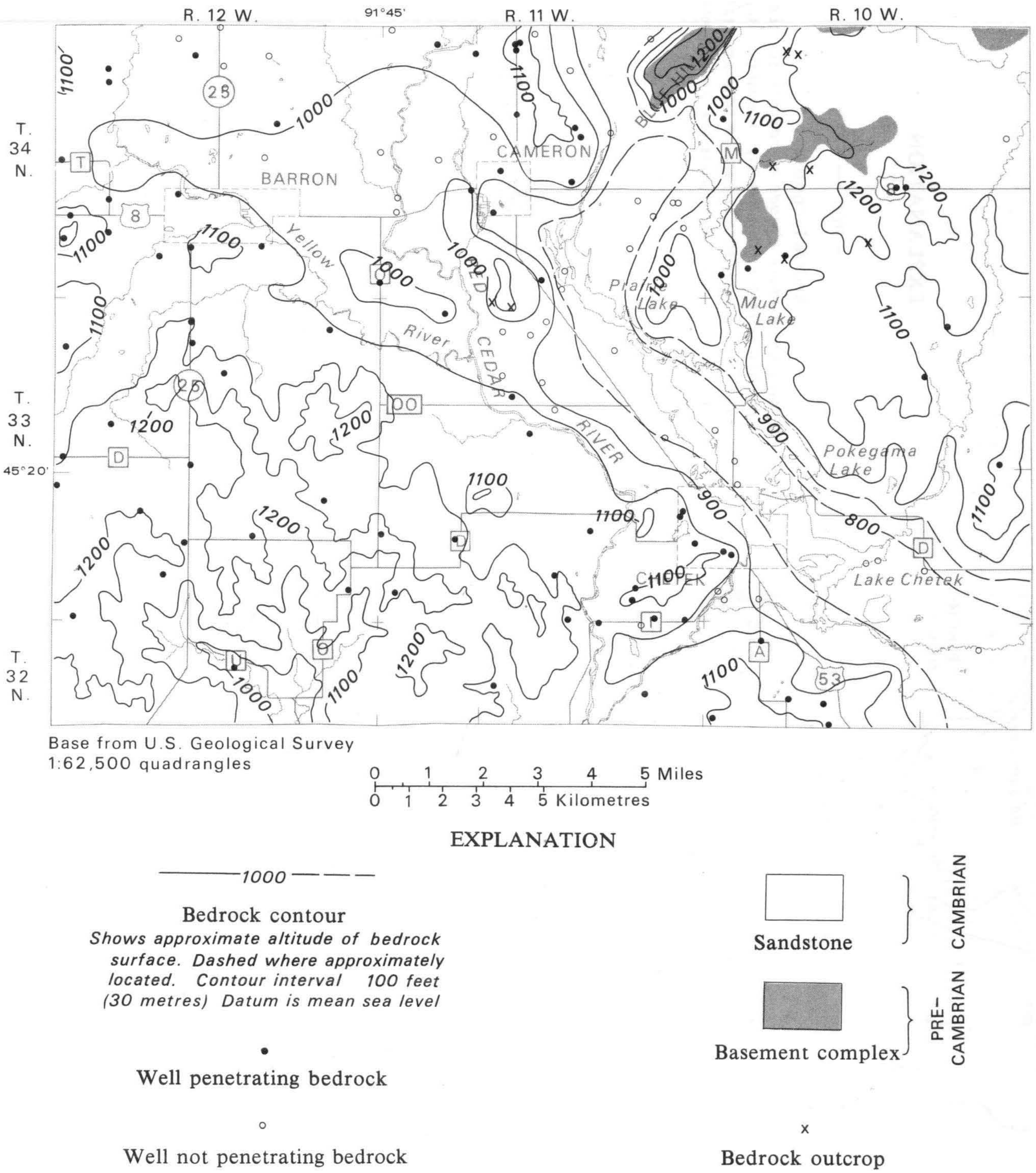


Figure 4. Bedrock geology and topography of the Cameron subarea.

The main bedrock valley extends southeastward from the Cameron subarea to the Chippewa River valley at Chippewa Falls as indicated by the glacial geology map of the area (fig. 6).

Menomonie Subarea

The bedrock surface in the Menomonie subarea (fig. 5) is Cambrian sandstone. A bedrock valley trends southwestward along Red Cedar River between Colfax and Menomonie and widens near Tainter Lake. East of Menomonie it turns southeastward and extends under the broad outwash plains to the irrigable land in the lower Chippewa River valley in the southeastern part of the subarea.

Quaternary Glacial Drift

Glacial drift forms an almost continuous mantle as thick as 375 ft (114 m) over the bedrock in the area. Drift is thickest in preglacial rock valleys (figs. 3, 4, and 5); it is thin to absent in the Blue Hills area east of Rice Lake. In general, the thinnest glacial deposits cover the hilltops and slopes of the area, and the thickest deposits fill bedrock valleys. A narrow area along the southern boundary is in the "Driftless Area" of Wisconsin that may not have been glaciated.

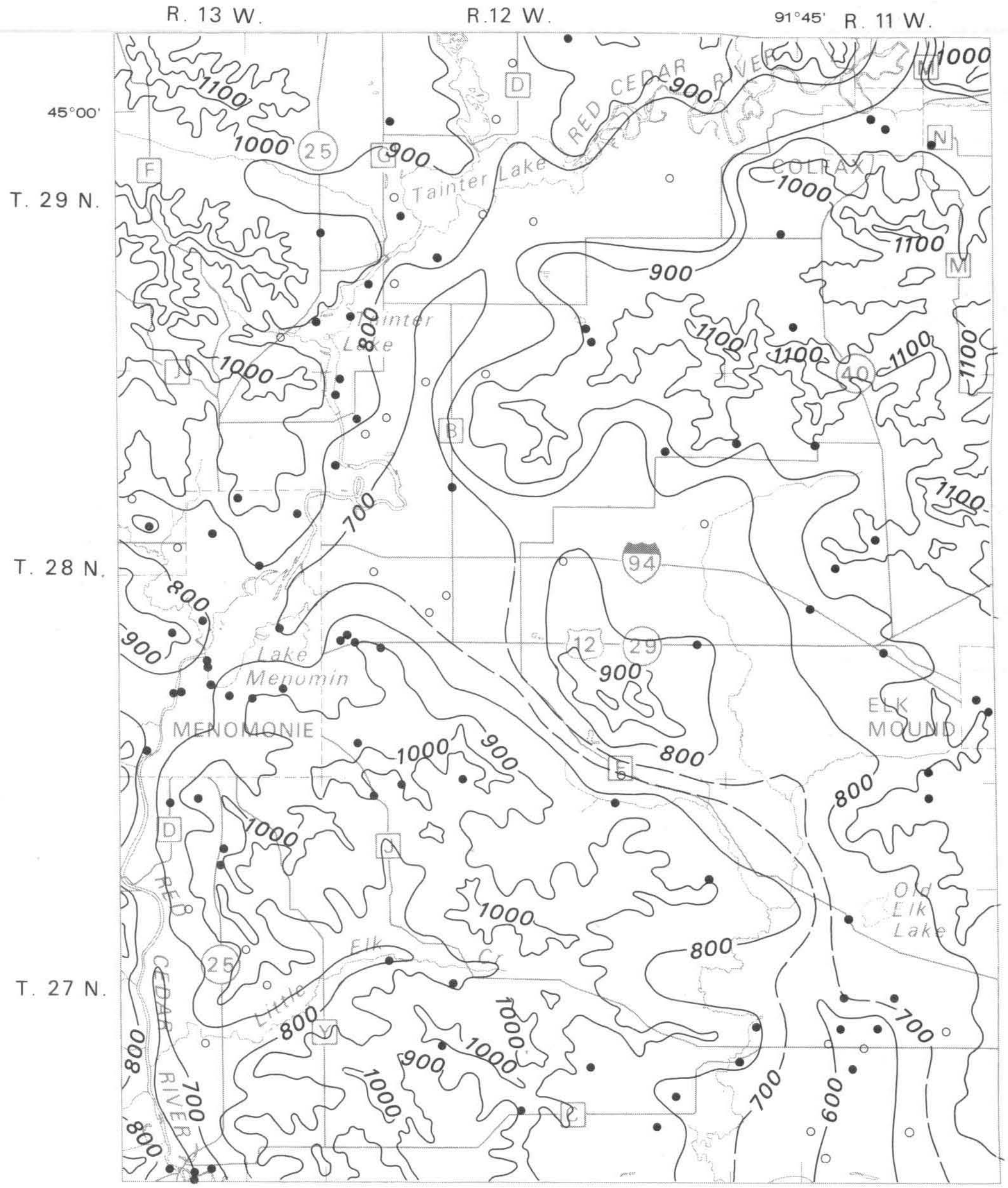
Drift in the study area is composed of ice-laid morainal deposits and water-laid outwash deposits (fig. 6). Ground moraine, consisting of till (an unsorted mixture of clay, silt, sand, gravel, and boulders), overlies most of the area. It is the least permeable type of drift in this area, especially where it contains much clay and silt. End moraines are ridges of till containing stratified outwash sand and gravel deposited at the edges of the glacier when the ice front was stationary. Outwash is stratified sand and gravel deposited by glacial streams as plains ahead of the ice front. Stratified sand and gravel is the most permeable drift and is a major aquifer in the area.

Mostly clean, well-sorted sand and gravel containing thin lenses of clay fills bedrock valleys in the Rice Lake and Cameron subareas. Although much clean sand and gravel fills the valleys in the Menomonie subarea, large amounts of clay locally reduce the permeability of the aquifer.

Windblown silt covers the study area and is the parent material for many of the soils. Its thickness ranges from 0.5 to 2 ft (0.2 to 0.6 m) in most of the area, although maximum depths of about 4 ft (1.2 m) occur in central Barron and southern Pepin Counties (Hole, 1950). Because its permeability generally is lower than that of the outwash deposits in the rock valleys, the silt limits the rate of downward percolation of water to much of the ground-water reservoir.

SOILS

Thirty-six major groups of soil associations in the Rice Lake-Eau Claire area are differentiated and related to suitability for irrigation by Hole and others (1968) (fig. 7 and table 1). The suitability for irrigation is rated on physical properties of the soils, the slope of the land, and depth to water; water availability, soil fertility, and air temperature are not included in the rating.



Base from U.S. Geological Survey
1:62,500 quadrangles

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

———— 800 — — —
Bedrock contour

Shows approximate altitude of bedrock surface. Dashed where approximately located. Contour interval 100 feet (30 metres) Datum is mean sea level

•
Well penetrating bedrock

○
Well not penetrating bedrock

Figure 5. Bedrock topography of the Menomonie subarea.

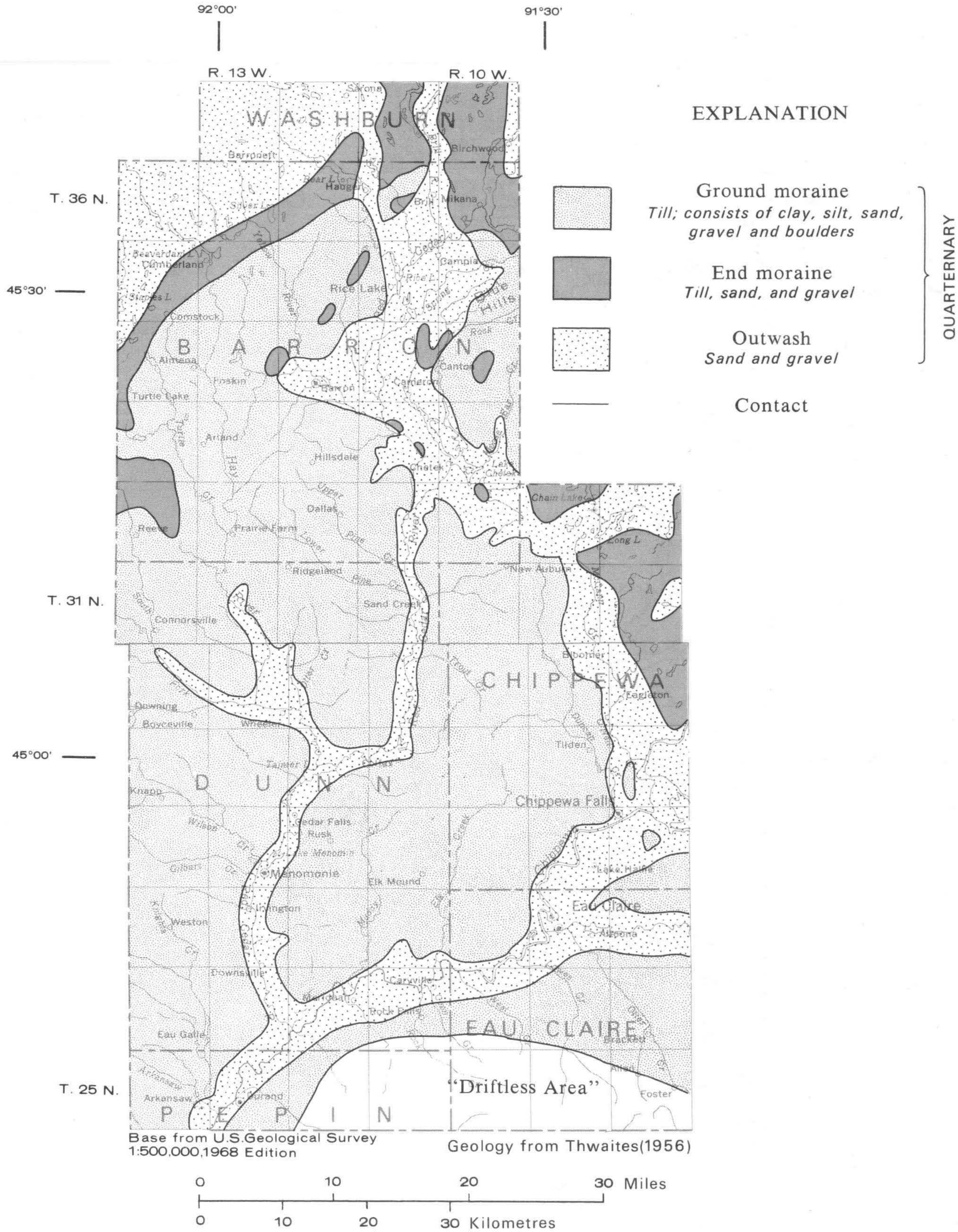


Figure 6. Glacial geology of the Rice Lake-Eau Claire area.

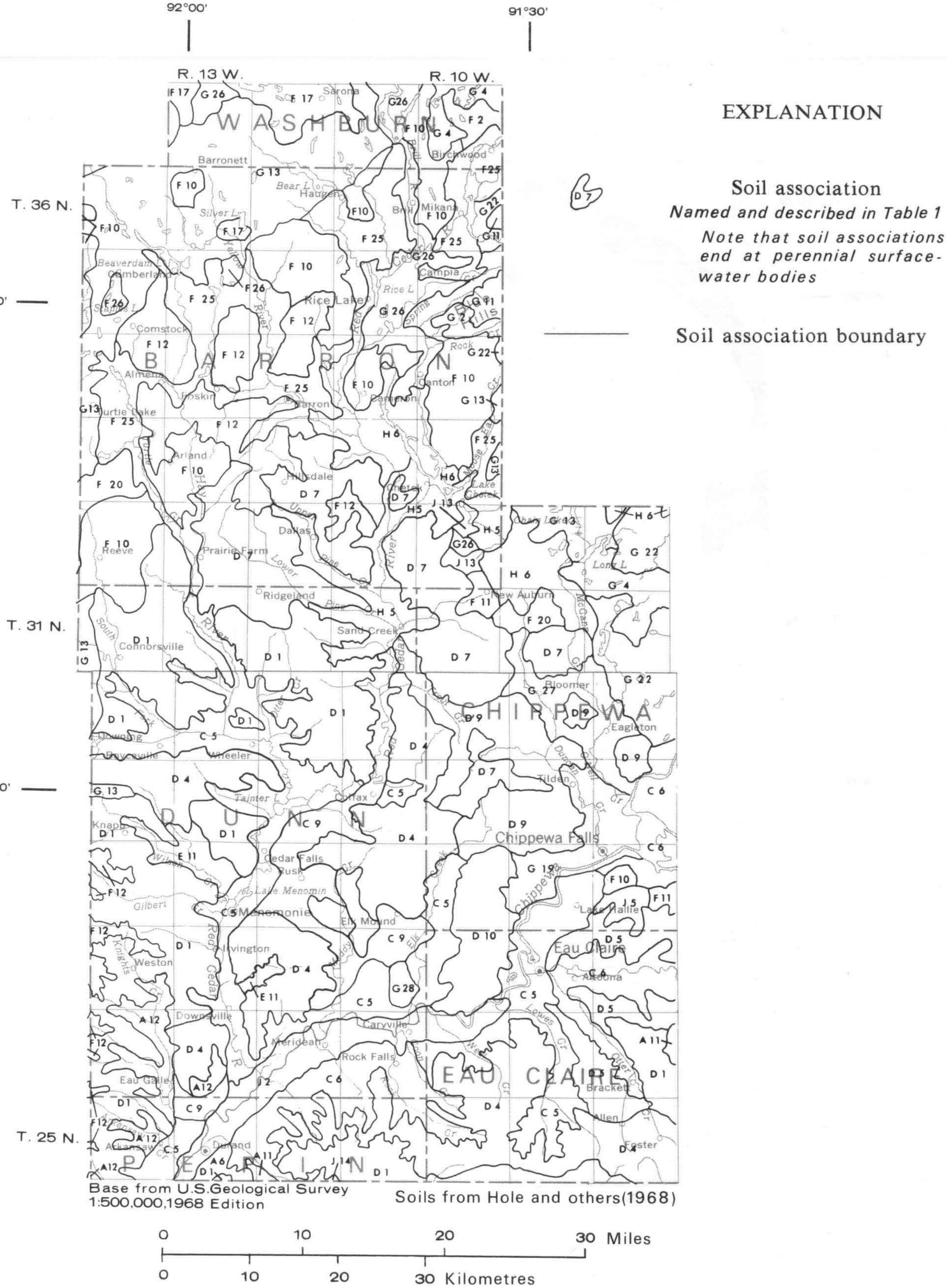


Figure 7. Soil groups of the Rice Lake-Eau Claire area.

Table 1.--Description of soils

Symbol	Soil association	Soil description	Irrigability
A-6	Palesgrove and associated silt loams	Silty soil mostly 30-50 in thick over clayey residuum on sloping uplands. Well drained.	Possible on level areas
A-11	Richwood and associated silt loams	Silt loam soil as much as 40 in thick over acid sand on nearly level terraces. Well drained.	Good
A-12	Bertrand soils and associated silt loams and loams	Silty soil as much as 40 in thick over acid sand on nearly level terraces. Well drained.	Good
C-5	Sparta and Plainfield soils and associated sands	Loamy sand soil 10-20 in thick over acid sand on nearly level terraces. Well drained.	Good
C-6	Plainfield soils and associated sands	Silt loam soil 10-20 in thick over silt and clay on nearly level, narrow outwash plains. Somewhat poorly drained.	Good
C-9	Dakota soils and associated loams and sandy loams	Loamy soil 20-40 in thick over acid sand on nearly level terraces. Well drained.	Good
D-1	Gale soils and associated loams	Silty and loamy soils 20-40 in thick over sandstone on sloping uplands. Well drained.	Not irrigable
D-4	Norden soils and associated loams	Loamy soil 20-40 in thick over glauconitic sandstone on sloping uplands. Well drained.	Not irrigable
D-5	Hixton soils and associated silt loams and sands	Loamy and silty loam soils, mostly 20-40 in thick over sandstone on sloping uplands. Well drained.	Not irrigable

Table 1.--Description of soils--Continued

Symbol	Soil association	Soil description	Irrigability
D-7	Hixton soils and associated silt loams	Loamy soil 20-40 in thick over sandstone on sloping uplands. Well drained.	Possible on level areas
D-9	Hixton soils and associated sandy loams and loams	Loamy and sand loam soils mostly 20-40 in thick over sandstone on sloping uplands. Well drained.	Possible on level areas
D-10	Hixton and associated loams	Loamy soil mostly 20-40 in thick over sandstone or acid sand on sloping uplands and some level terraces. Well drained.	Possible on level areas
E-11	Tustin and associated loams	Sand to silty loam soils 20-40 in thick over calcareous clay, silt, or sands on nearly level to sloping lake plains. Somewhat poorly drained.	Moderate
F-2	Santiago and associated silt loams	Loamy soil mostly 20-40 in thick over acid, sandy loam till on sloping to nearly level uplands. Somewhat poorly drained.	Not irrigable
F-10	Santiago soils and associated silt loams and peat	Silty loam soil 20-40 in thick over acid, sandy loam till on sloping to nearly level uplands. Some restricted drainage.	Moderate
F-11	Loyal and associated silt loams	Loamy soil 20-40 in thick over acid loamy till and sandstone on sloping uplands. Well drained.	Not irrigable
F-12	Spencer soils and associated silt loams	Silty soil 30-50 in thick over acid, sandy loam till on sloping to nearly level uplands. Somewhat poor drainage.	Not irrigable

Table 1.--Description of soils--Continued

Symbol	Soil association	Soil description	Irrigability
F-17	Antigo soils and associated silt loams	Silty and loamy soils 20-40 in thick over acid sand and gravel on nearly level terraces. Well drained.	Moderate
F-20	Freer and associated silt loams	Silty loam soil mostly 20-40 in thick over acid, sandy loam till on nearly level to sloping uplands. Somewhat poorly drained.	Moderate
F-25	Antigo soils and associated silt loams and loams	Silty soils 20-40 in thick over acid sand and gravel on nearly level terraces. Well drained.	Good
F-26	Poskin soils and associated silt loams and loams	Silty soil 20-40 in thick over acid sand and gravel on nearly level terraces. Some drainage restrictions.	Good where drained
G-2	Iron River and Pence soils and associated silt loams and peat	Loamy soil 12-40 in thick over acid, sandy loam till on sloping uplands and terraces. Well drained.	Not irrigable
G-4	Milaca soils and associated sandy loams, sands, and peat	Loamy soil mostly 12-36 in thick over acid, sandy loam till on nearly level to sloping uplands. Some restricted drainage.	Not irrigable
G-11	Iron River soils and associated loams, sand, and some peat	Loamy soil mostly 20-40 in thick over acid, sandy loamy till and sand and gravel on sloping upland. Well drained.	Possible on level areas
G-13	Cloquet soils and associated sand loams and loams with peat	Loamy soil mostly 20-36 in thick over acid, sandy loam till on nearly level to sloping uplands. Some restricted drainage.	Good only on drained level areas

Table 1.--Description of soils--Continued

Symbol	Soil association	Soil description	Irrigability
G-19	Onamia and associated loams	Loamy soil mostly 20-40 in thick over acid sand and gravel on nearly level terraces. Well drained.	Good
G-22	Milaca soils and associated silt loams and some peat	Loamy soils mostly 20-36 in thick over acid, sandy loamy till on sloping uplands. Well drained.	Possible on level areas
G-26	Onamia and Chetek soils and associated silt, loam, and peat soils	Loamy soil mostly 10-40 in thick over acid sand and gravel on nearly level terraces. Well drained.	Good
G-27	Pence sandy loams and associated sands, loams, and some peat	Sandy loam soil mostly 10-20 in thick over acid sand and gravel on sloping to nearly level terraces. Well drained.	Good
G-28	Onamia soils and associated loams and silt loams with some peat	Loamy soil mostly 10-40 in thick over acid sand and gravel on nearly level terraces. Well drained.	Good
H-5	Vilas soils and associated sands and sandy loams with some peat	Sandy soil mostly 10-20 in thick over acid sand on level to sloping terraces. Well drained.	Good
H-6	Omega and Vilas soils and associated sandy loam and some peat	Sandy soil mostly 10-30 in thick over acid sand on level to sloping terraces. Well drained.	Good
J-2	Wet alluvial soils	Loam soils nearly level. Poorly drained.	Not irrigable
J-5	Newton and associated loamy sand and sand with some peat	Sandy soil 10-30 in thick over acid sand on level to nearly level terraces. Poorly drained.	Possible if drained

Table 1.--Description of soils--Continued

Symbol	Soil association	Soil description	Irrigability
J-13	Raw acid sedge and woody peat soils and associated silt loam	Peat and muck soils, nearly level. Poorly drained.	Possible if drained
J-14	Acid sedge peat and muck and associated sands	Peat and muck and dark sands, nearly level. Poorly drained.	Possible if drained

Favorable conditions for irrigation are (1) level land, which allows use of sprinkler equipment and reduces surface runoff, (2) permeable soil, which allows water to infiltrate, and (3) depth to water of at least 4 ft (1.2 m), which allows plant roots to remain in the zone of aeration for good assimilation of oxygen and nutrients.

Soils on nearly one-half the 1.85 million acres (750,000 ha) of the study area are rated good and moderately good for irrigation. Large-scale maps (figs. 8, 9, and 10) show areas where soils are suitable for irrigation in each of the three subareas. These are mostly well-drained soils on level or nearly level outwash plains and where the water table is 4 ft (1.2) or more below land surface. Soils on about 40,000 acres (16,000 ha) chiefly in the east-central part of the area are conditionally suitable for irrigation; these include soils on sloping uplands that would be irrigable if level and peat soils in several wetlands that would be irrigable if drained. Poorly drained soils on steeply sloping uplands in about half the study area are not suitable for irrigation (fig. 7 and table 1).

Production of vegetables on sandy soils under irrigation has certain advantages over production on finer textured soils. Rainfall rapidly enters the soil and is less likely to delay planting and harvesting. This is particularly important in the Rice Lake-Eau Claire area where the growing season is short. The sandy soils also require less tillage to prepare them for planting.

Information on the characteristics, productivity ratings, and management recommendations for all soils is available from local county agricultural extension agents; the University of Wisconsin-Extension, Geological and Natural History Survey, Soil Survey Division; and the U.S. Department of Agriculture, Soil Conservation Service. A detailed description of soils in central Wisconsin is given in the University of Wisconsin-Extension report "Vegetable and Fruit Potential for Production and Processing in Central Wisconsin", December 1964.

Rice Lake and Cameron Subareas

Soils suitable for irrigation in the Rice Lake and Cameron subareas (figs. 8 and 9) are developed primarily on the outwash plains. The soils were classified by Robinson and Vessels (1958). Antigo silty soils and Onamia loamy soils on outwash plains are the major types of soil in the suitable areas of the Rice Lake subarea (fig. 8). Chetek loamy soils and Omega sandy soils, also on outwash plains, predominate in the suitable areas of the Cameron subarea (fig. 9). Some peat is associated with the Chetek soils.

These Antigo, Onamia, Chetek, and Omega soils are on level to gently undulating land with slopes ranging from 0 to 6 percent. The soils are permeable, well drained, and the water table is more than 4 ft (1.2 m) below land surface. Most of the suitable land in the two subareas is cleared and the wetland area is negligible.

The soils in the two subareas are suitable for growing potatoes and truck crops with or without irrigation. Although irrigation generally assures better control of quality and maximizes yields, crops may be produced without benefit of irrigation.

A detailed description of the soils of the two subareas is given in "Soil Survey, Barron County, Wisconsin" by Robinson and Vessels (1958), which is available from the Barron County Agricultural Agent, Barron, Wis., and from the University of Wisconsin-Extension, Geological and Natural History Survey, Madison.

Menomonie Subarea

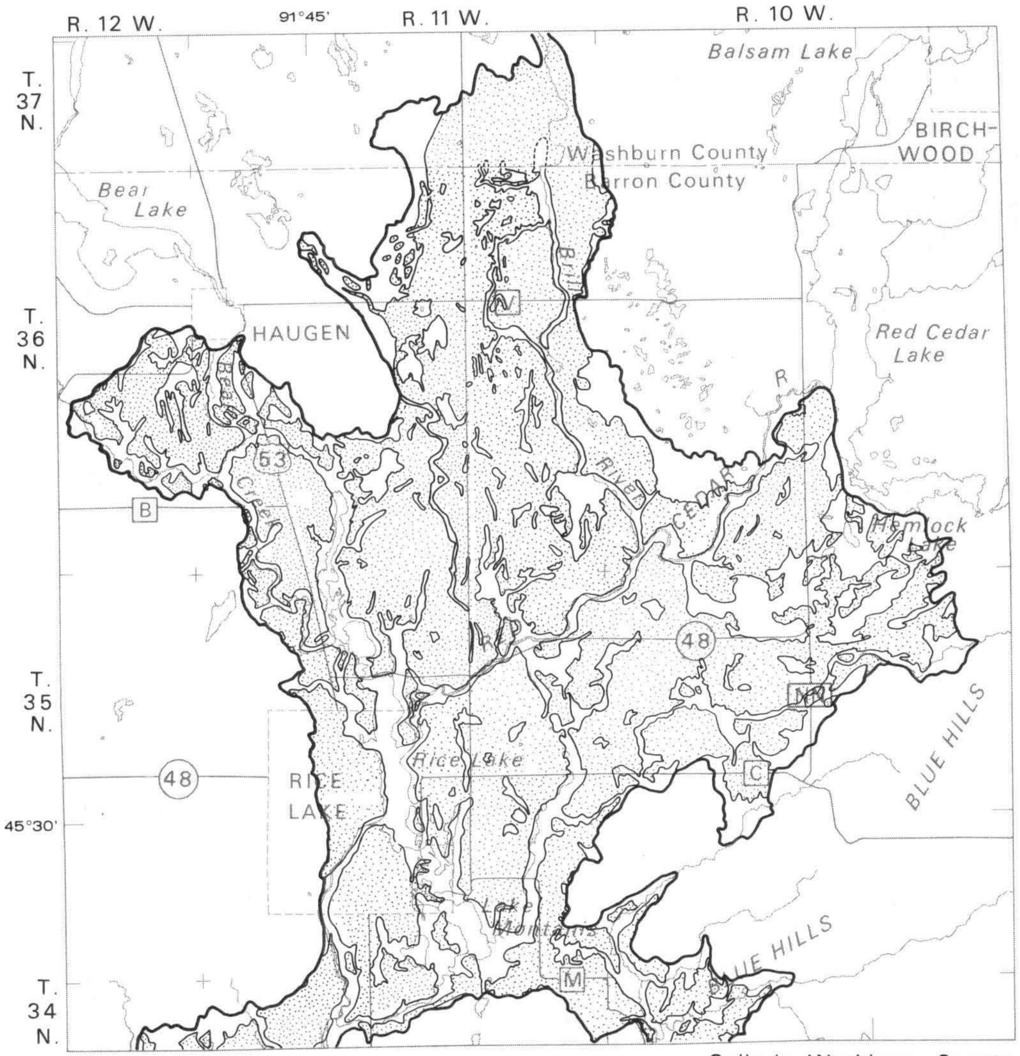
Soils suitable for irrigation in the Menomonie subarea (fig. 10), as in the Rice Lake and Cameron subareas, are developed primarily on the outwash plains. The soils (table 1 and fig. 7) were classified by Hole and others (1968).

Sparta and Plainfield loamy sand soils and Dakota loamy soils developed on nearly level glacial outwash plains are the principal soils in this subarea. They generally are in the Red Cedar River valley and on the adjacent broad glacial outwash plain in the southeastern part of the subarea. These soils are permeable, well drained, and the water table is more than 4 ft (1.2 m) below land surface. Most of the suitable land in the Menomonie subarea is cleared.

Tustin sand and silty loam in the Little Elk Creek valley and in the area northwest of Menomonie is "somewhat poorly drained" and is moderately suitable for irrigation. Poorly drained sedge peat and muck in the wetlands west of Elk Mound is potentially suitable if the soils were well drained.

GROUND-WATER HYDROLOGY

Recharge to the ground-water reservoir, movement of water through the aquifers, and discharge from the aquifer describe the ground-water phase of the hydrologic cycle.



Base from U.S. Geological Survey 1:62,500 quadrangles

Soils in Washburn County from Hole and others, 1968; soils in Barron County from Robinson and Vessel, 1958

0 1 2 3 4 5 Miles

0 1 2 3 4 5 Kilometres

Figure 8. Soils suitable for irrigation in the Rice Lake subarea.

EXPLANATION

Soils that are suitable for irrigation

Soil is level to gently undulating and is permeable; water table is more than 4 feet (1.2 metres) below land surface, and area is large enough to be irrigated economically

Soils that are not suitable for irrigation

Boundary of nearly level outwash plains and terraces

Contact

Base from U.S. Geological Survey
1:62,500 quadrangles

Soils from Robinson and Vessel, 1958

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

Soils that are suitable for irrigation

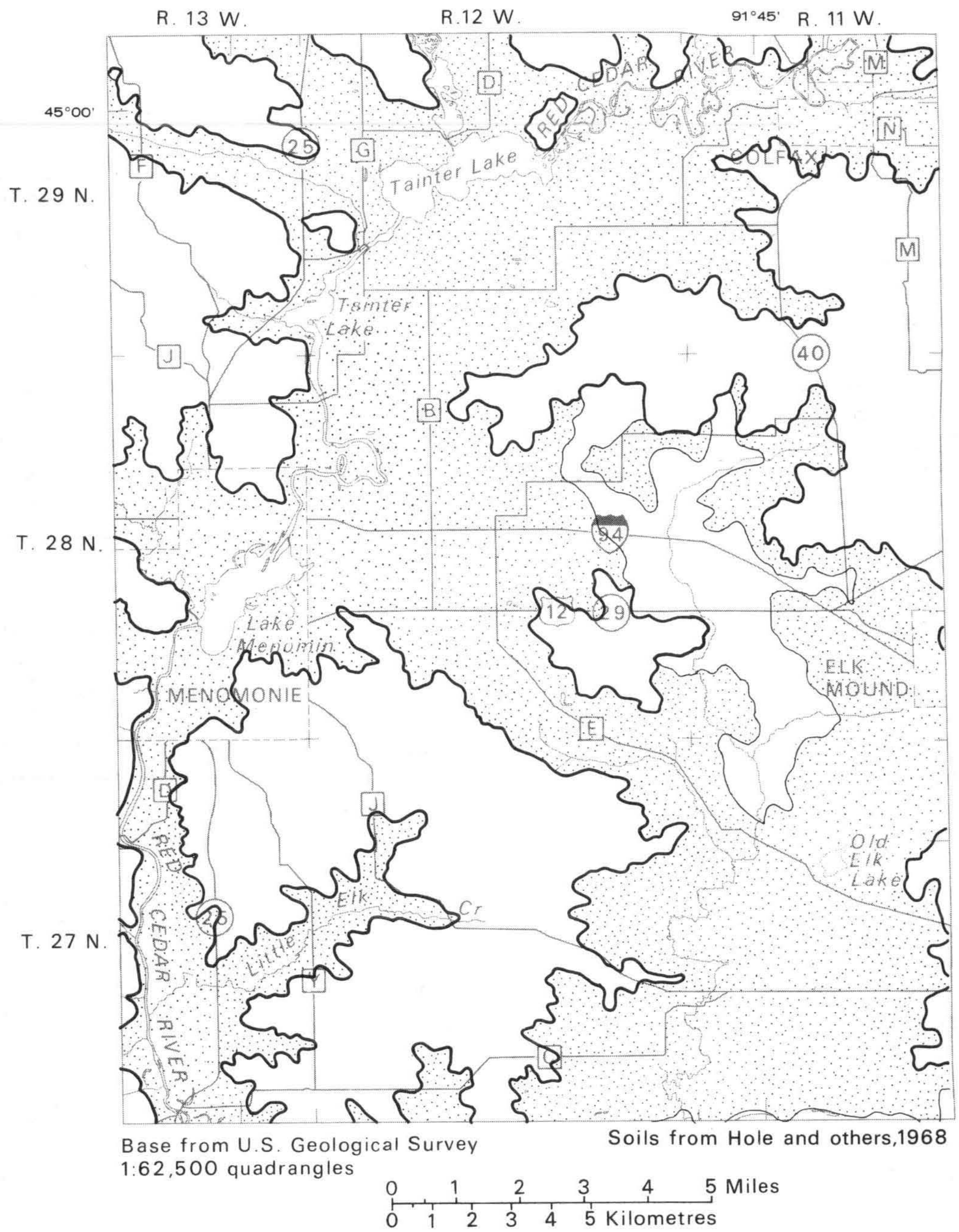
Soil is level to gently undulating and is permeable; water table is more than 4 feet (1.2 metres) below land surface, and area is large enough to be irrigated economically

Soils that are not suitable for irrigation

Boundary of nearly level outwash plains and terraces

Contact

Figure 9. Soils suitable for irrigation in the Cameron subarea.



EXPLANATION

Soils that are suitable for irrigation
Soil is level to gently undulating and is permeable, water table is more than 4 feet (1.2 metres) below land surface, and area is large enough to be irrigated economically

Soils that are not suitable for irrigation

Boundary of nearly level outwash plains and terraces

Contact

Figure 10. Soils suitable for irrigation in the Menomonie subarea.

Hydrologic Budget--Rice Lake Subarea

The amount of precipitation is the ultimate limit of water availability. It is the source that replenishes water losses and maintains an equilibrium on a long-term basis within the hydrologic system. This equilibrium can be expressed as a water budget which reflects the distribution of precipitation as phases of the hydrologic system and indicates available water as water in transit or in storage.

A generalized hydrologic budget accounts for quantities of water in various environments within the hydrologic cycle, and it indicates the relationships among the components of the cycle. The hydrologic budget is estimated by the equation: water gains = water losses, or P (precipitation) + I (surface-water inflow) + Q_I (ground-water inflow) = ET (evapotranspiration) + R (surface-water outflow) + Q_O (ground-water outflow $\pm$ S (change in storage).

The water budget of the study area is much like that of the Rice Lake subarea because the general hydrology and geology is similar in the area. Precipitation of 36.6 in (930 mm) at Rice Lake during 1972 is 5.1 in (130 mm) greater than the 31.5-in (800-mm) average for the period of record (1952-72) (U.S. Weather Bureau). The maximum annual precipitation recorded at Rice Lake is 46.9 in (1,190 mm), which occurred in 1968; the minimum recorded, 23.1 in (590 mm), occurred in 1952. Table 2 compares the annual (1972) and long-term (1952-72) hydrologic budgets for the Rice Lake subarea.

Runoff is that part of precipitation that appears in streams. It includes precipitation that runs overland directly to streams, and precipitation that percolates downward to the ground-water reservoir and later discharges to streams. The net runoff (stream inflow minus stream outflow) in the Rice Lake subarea during 1972 was 19.6 in (498 mm) or 304 ft^3/s (8.6 m^3/s), which is nearly 20 percent greater than the long-term average of 254 ft^3/s (7.2 m^3/s).

Although the net change in water storage over a long period may be assumed to be zero, yearly storage changes are common. Water in storage includes water in lakes, in streams, in wetlands, in the soil zone, and in the ground-water reservoir. Lake levels in the Rice Lake subarea did not change significantly during 1972; the average change in five lakes was less than 0.1 ft (0.03 m) between the beginning and the end of the year. The soil zone probably was saturated at the beginning and end of 1972 as a result of extremely wet summers and falls in 1971 and 1972. Therefore, the net change in storage in lakes and in the soil zone during 1972 is estimated to be zero. A net gain in ground-water storage of about 0.3 in (8 mm) during the year was estimated from the rise of water levels measured in the subarea.

Underflow (ground-water inflow and outflow) is water that enters or leaves the subarea underground, and its rate depends on the hydraulic gradient of the potentiometric surface (fig. 15) and the transmissivity of the aquifer. An estimated average of 0.1 in (3 mm) of underflow annually enters the Rice Lake subarea, most of it occurring in the Birchwood area; about 0.3 in (8 mm) of underflow leaves the subarea, mainly in the Red Cedar River valley south of Rice Lake. The estimated annual net loss (0.2 in or 5 mm) of underflow remains fairly constant except during extremely high or low ground-water levels and is balanced by infiltration of precipitation.

Table 2.--Comparison of 1972 and long-term hydrologic budgets in the Rice Lake subarea

Water item	Water quantity 1972 (inches)	Water quantity 1952-72 average (inches)
Water gains:		
Precipitation	36.6	31.5
Surface-water inflow	5.9	5.4
Ground-water inflow	.1	.1
Total	42.6	37.0
Water losses:		
Evapotranspiration	16.5	14.9
Surface-water outflow	25.5	21.8
Ground-water outflow	.3	.3
Change in storage:		
Surface water	.0	.0
Ground water	.3	.0
Soil moisture	.0	.0
Total	42.6	37.0

Evapotranspiration is the combined evaporation of water from all moist or wet surfaces and from shallow ground water, and transpiration of water by plants. Evapotranspiration, like precipitation, is greatest during the warm months. Although evapotranspiration is considered to be a water loss, much of that water may be used by beneficial plants. Evapotranspiration of 16.5 in (420 mm) in 1972 and an average of 14.9 in (378 mm) annually, 1952-72, was computed for the Rice Lake subarea by balancing the equation above.

Recharge

Recharge is precipitation that percolates downward to the ground-water reservoir. Most recharge in the Rice Lake-Eau Claire area occurs during two periods of each year. Melt water from snow, ice, and frost during the spring thaw quickly satisfies the soil-moisture deficiency, and large quantities of water move downward to the water table. When frost ends the growing season in the fall, evapotranspiration decreases, soil moisture is restored by precipitation, and recharge increases until the winter freeze.

The rate of recharge to the ground-water reservoir differs between parts of the recharge area. Recharge is generally zero or minimal where the water table is at surface (streams, lakes, and some wetlands) or in other ground-water discharge areas.

Elsewhere in the Rice Lake-Eau Claire area, annual recharge to the ground-water reservoir ranges from less than 1 in (25 mm) in the nearly impermeable Precambrian bedrock of the Blue Hills to about 10 in (250 mm) in the outwash plains of surficial sand. Average recharge is about 6 in (150 mm) over the entire area.

Recharge in the Rice Lake-Eau Claire area is greatest to the glacial outwash deposits in stream valleys, where the average is about 8 in (200 mm) annually. It is significantly less, however, in parts of the Menomonie subarea where large amounts of clay and silt in the valleys retard the downward seepage.

Annual recharge is greatest during wet years and least during dry years, although it is not directly proportional to annual precipitation. The range in annual recharge reflects variations in intensity and duration of precipitation and in the degree of soil-moisture depletion.

Rates of recharge within the three subareas were determined by a flow-net analysis (Harder and Drescher, 1954, p. 26). Recharge is represented by the difference in the amounts of water entering and leaving a small area, which is defined by limiting flow lines between selected contours of the potentiometric surface. The amount of recharge is computed by dividing this difference by the area. The method of analysis assumes a constant transmissivity and a static potentiometric surface. The small areas selected for analysis are unpumped areas free of streams.

The rates of recharge were calculated by the equation $Q = TIL$ (a form of Darcy's Law) where:

Q = rate of recharge (flow), in cubic feet per day,
T = transmissivity, in feet squared per day,
I = hydraulic gradient, in feet per foot, and
L = width across section of flow, in feet.

The values of I were scaled as the slope between contours of the water table (figs. 11, 12, and 13). The values of T were assumed as the product of hydraulic conductivity times the thickness of saturated aquifer. (See section on Transmissivity of Aquifers for a definition of transmissivity.) The hydraulic conductivity was estimated from a study of specific-capacity data and soil and rock descriptions in drillers' and sample logs of many wells.

Recharge values computed for the selected areas were extrapolated to apply to the three subareas (figs. 11, 12, and 13) based on hydrologic and geologic similarities.

Rice Lake Subarea

Recharge to the ground-water reservoir in the Rice Lake subarea differs with the hydraulic conductivity of the bedrock and overlying glacial drift. Recharge varies also in time because of differences in soil conditions and intensity and duration of precipitation.

Annual recharge (fig. 11) is less than 1 in (25 mm) in the Blue Hills, where surface runoff is rapid and relatively impermeable Precambrian bedrock stores water only in near-surface cracks and crevices. Annual recharge ranges from about 6 to 10 in (150 to 250 mm) in the permeable surficial outwash in the valleys in the Red Cedar River and its tributaries. Annual recharge through thin till overlying sandstone west of Rice Lake and through till in morainal areas surrounding the outwash plains ranges from 1 to 3 in (25 to 75 mm). Recharge to sandstone overlain by more permeable drift ranges from 3 to 6 in (75 to 150 mm). Recharge is zero or minimal in wetlands and in other ground-water discharge areas.

Cameron Subarea

The variation of recharge to the ground-water reservoir in the Cameron subarea (fig. 12) is similar to that in the Rice Lake subarea. Recharge is less than 1 in (25 mm) in the small part of the Blue Hills northeast of Cameron. The glacial drift overlying the sandstone in the uplands, except in the northeastern and northwestern parts of the subarea, is moderately permeable, and recharge of 3 in (75 mm) or more reaches the ground-water reservoir. The highest rate of recharge is to the outwash sand and gravel in the valleys of the Red Cedar River and its tributaries. Recharge is zero or minimal in wetlands and in other ground-water discharge areas.

Menomonie Subarea

The annual recharge to the ground-water reservoir in the Menomonie subarea (fig. 13) ranges from about 3 in (75 mm) in the uplands to 10 in (250 mm) in the flat plains of glacial outwash. The variation of recharge rates in this subarea is similar to that in the Rice Lake and Cameron subareas. Recharge to the glacial outwash in the central part of the subarea is about 6 to 10 in (150 to 250 mm) and averages about 8 in (200 mm) annually. Recharge is zero or minimal in wetlands and in other ground-water discharge areas.

Movement of Water

The general direction of ground-water flow is southward and southeastward toward the Chippewa River valley. Locally ground water discharges into the Red Cedar River, lakes, and smaller streams. The water table (fig. 14) generally is similar in shape to the land surface. Ground-water movement is generally perpendicular to water-table contours and conforms regionally to the direction of surface runoff.

Most ground water in the study area is unconfined; the water surface or water table is under atmospheric pressure. The water generally moves along shallow, short flow paths, usually traveling less than 4 mi (6.4 km) from points of recharge to points of discharge.

Artesian (confined) water occurs at a few places in the area. Artesian flowing wells in sandstone at Menomonie in the Red Cedar River valley, at Durand and Meridean in the Chippewa River valley, and in valley fill along Arkansaw Creek were reported by Weidman and Schultz (1915). Several flowing

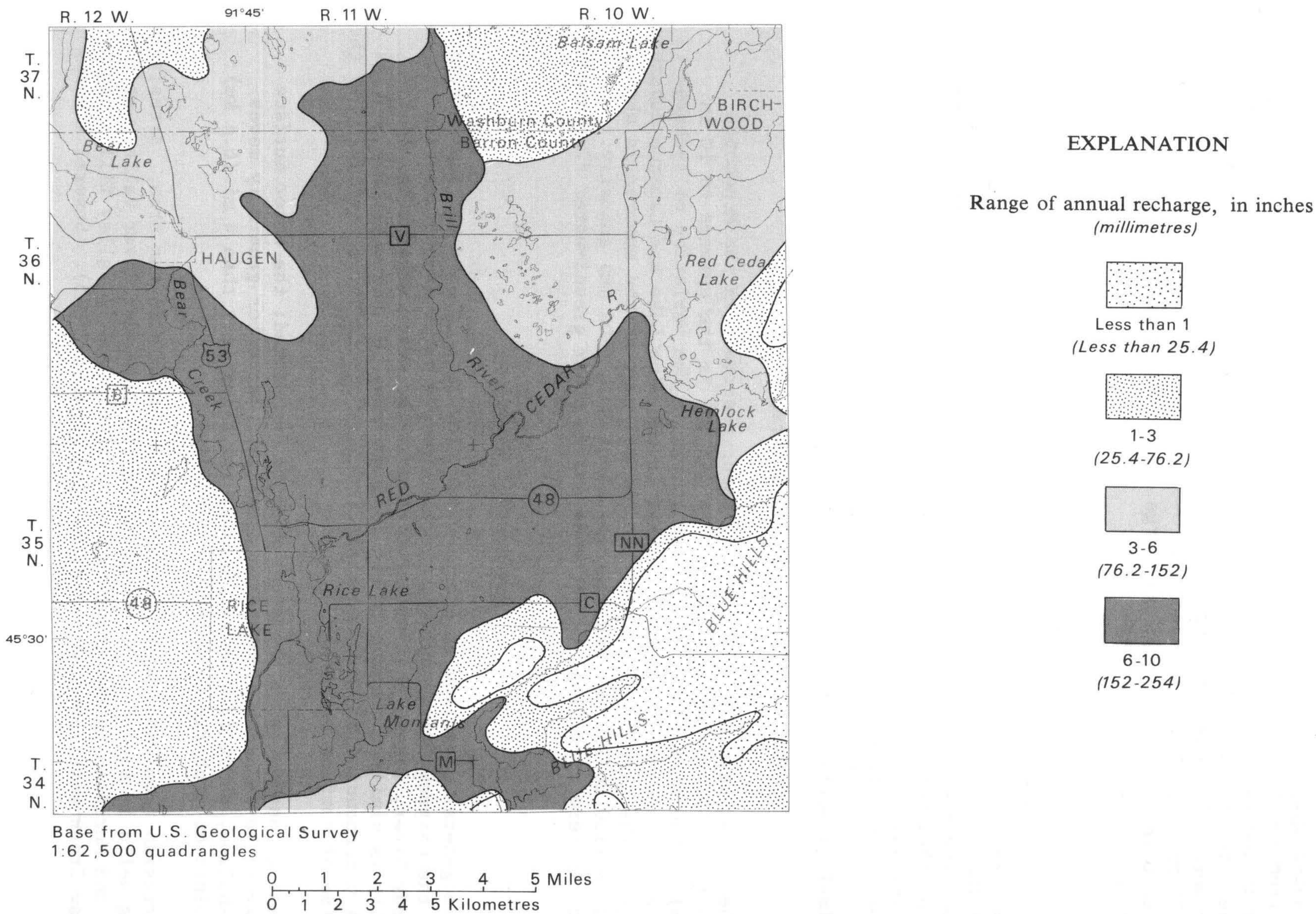
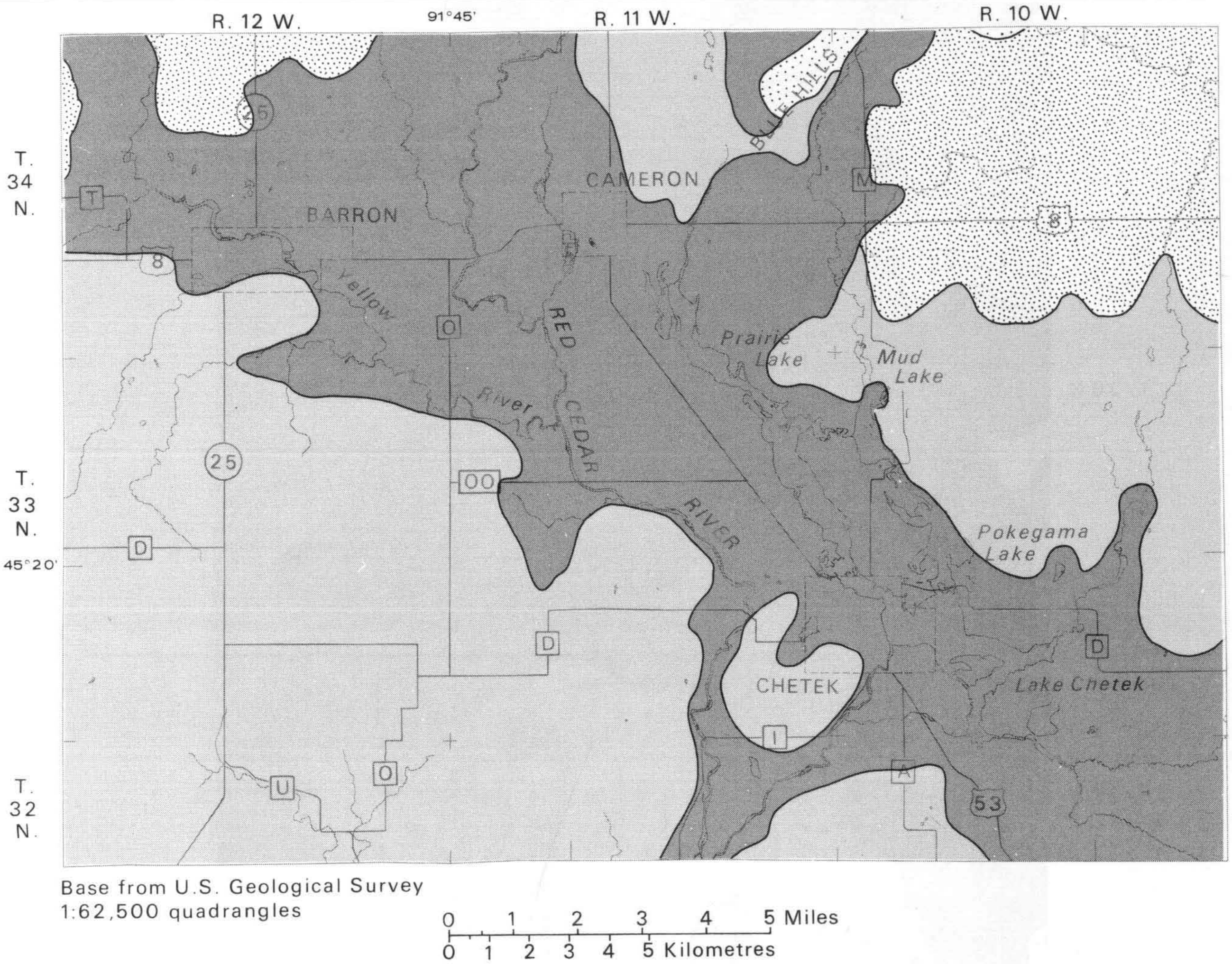


Figure 11. Estimated ground-water recharge in the Rice Lake subarea.



EXPLANATION

Range of annual recharge, in inches
(millimetres)

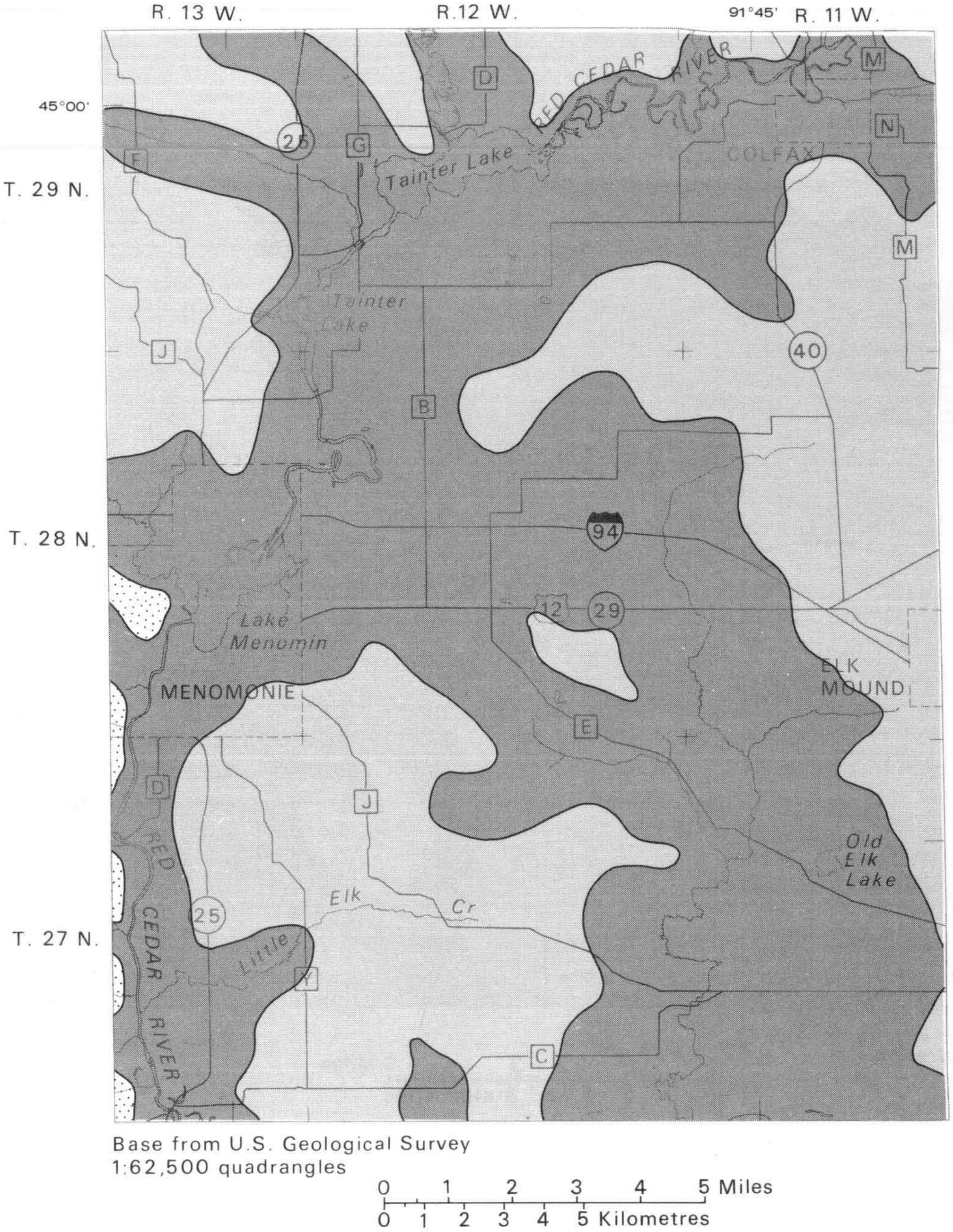
Less than 1
(Less than 25.4)

1-3
(25.4-76.2)

3-6
(76.2-152)

6-10
(152-254)

Figure 12. Estimated ground-water recharge in the Cameron subarea.



EXPLANATION

Range of annual recharge, in inches
(millimetres)

1-3
(25.4-76.2)

6-10
(152-254)

3-6
(76.2-152)

Figure 13. Estimated ground-water recharge in the Menomonie subarea.

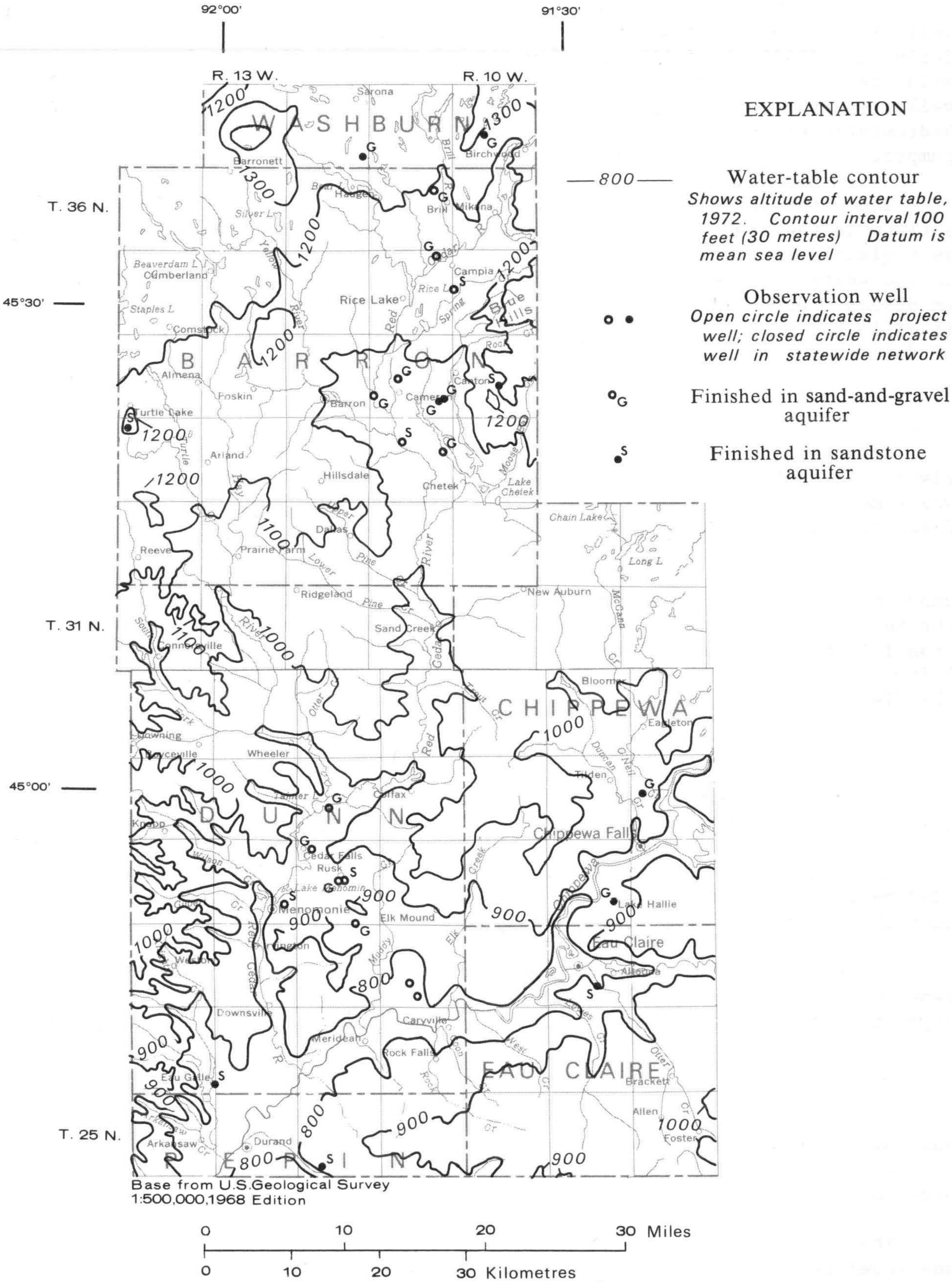


Figure 14. Water table of the Rice Lake-Eau Claire area.

wells in the Red Cedar River valley south of Lake Menomin were reported during the 1940's by drillers. However, no artesian flow was known to exist in 1972. Since the time of drilling, unrestricted flow from artesian wells, together with pumping of other wells in the area, has decreased the hydrostatic pressure in the aquifer, and wells that once flowed now are pumped.

The water table generally is within a few tens of feet of the land surface in the study area. It is shallow near surface-water bodies and emerges as a visible surface in marsh areas. It is deepest below hills, especially in the western part of the area, where depth to water exceeds 200 ft (60 m) in places. Depth to water in the outwash plains ranges from about 3 ft (1 m) in the Cameron subarea to about 95 ft (29 m) in the southeastern part of the Menomonie subarea.

Rice Lake Subarea

Ground water generally moves (fig. 15) toward the Brill and Red Cedar Rivers and southwestward toward Rice Lake and Red Cedar River. Locally the water moves short distances from areas of recharge to points or areas of discharge along lakes and streams.

The altitude of the water table ranges from higher than 1,340 ft (408 m) above mean sea level in the Blue Hills to less than 1,100 ft (335 m) along the Red Cedar River south of Rice Lake. Depth to water in wells ranges from 197 ft (60 m) below land surface beneath hills west of Rice Lake to 5 ft (1.5 m) in the flatlands around Rice Lake. Median depth to water in the flatlands is 25 ft (7.6 m).

Cameron Subarea

Ground water moves generally southward through the Cameron subarea (fig. 16) and conforms to the trend of flow in the Red Cedar River.

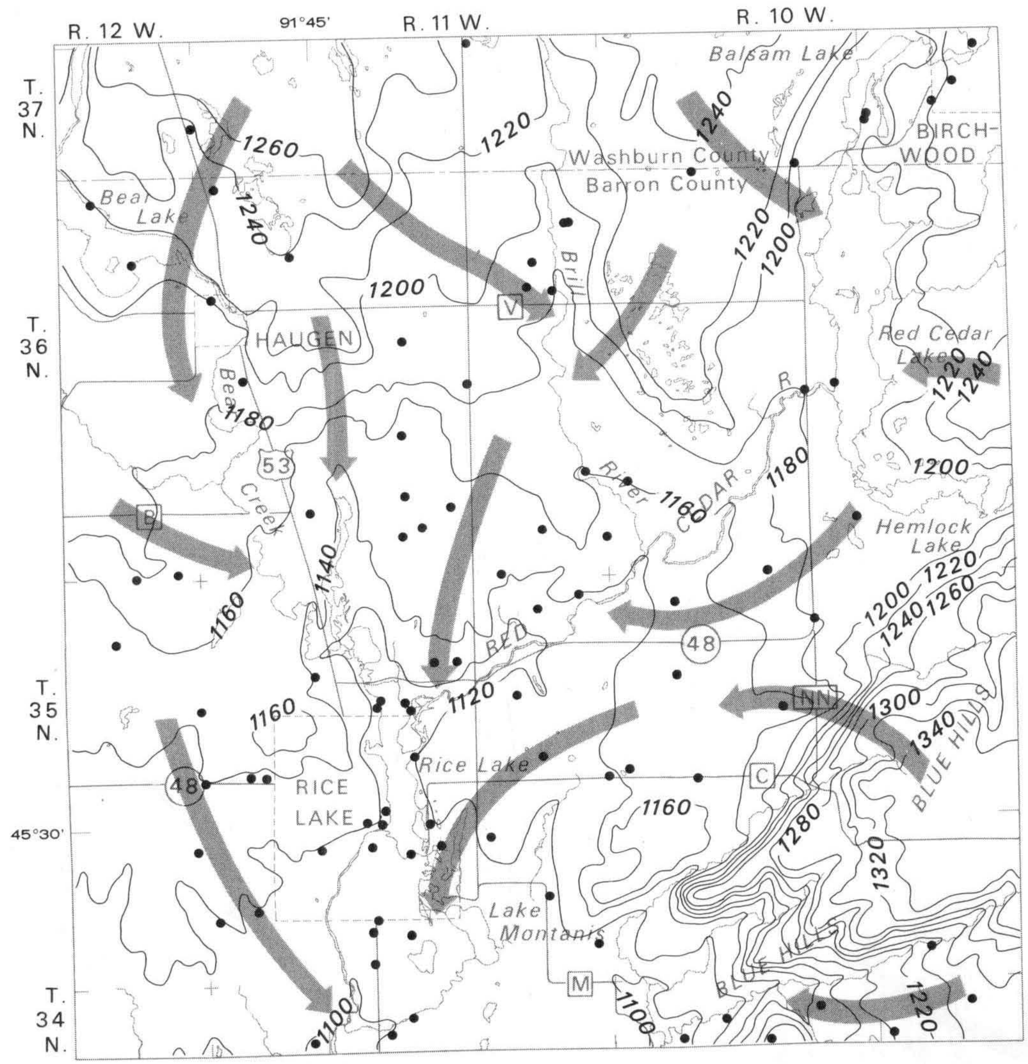
The altitude of the water table ranges from higher than 1,220 ft (372 m) above mean sea level east of Cameron to lower than 1,020 ft (310 m) near the junction of the Chetek and Red Cedar Rivers.

Depth to water in wells ranges from 160 ft (49 m) below land surface beneath hills to 3 ft (1 m) in the outwash plains of the subarea. Median depth to water in the outwash plains is 23 ft (7.0 m).

Menomonie Subarea

Most of the ground water in the Menomonie subarea (fig. 17) moves toward and down the Red Cedar River valley. The ground water in most of the southern half of the subarea, however, moves southeastward down the preglacial valley beneath Iron and Muddy Creeks.

The altitude of the water table ranges from 1,035 ft (315 m) above mean sea level beneath hills in the northeastern part to 715 ft (218 m) in the outwash plains in the southeastern part of the subarea.



Base from U.S. Geological Survey
1:62,500 quadrangles

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

Figure 15. Water table of the Rice Lake subarea.

EXPLANATION

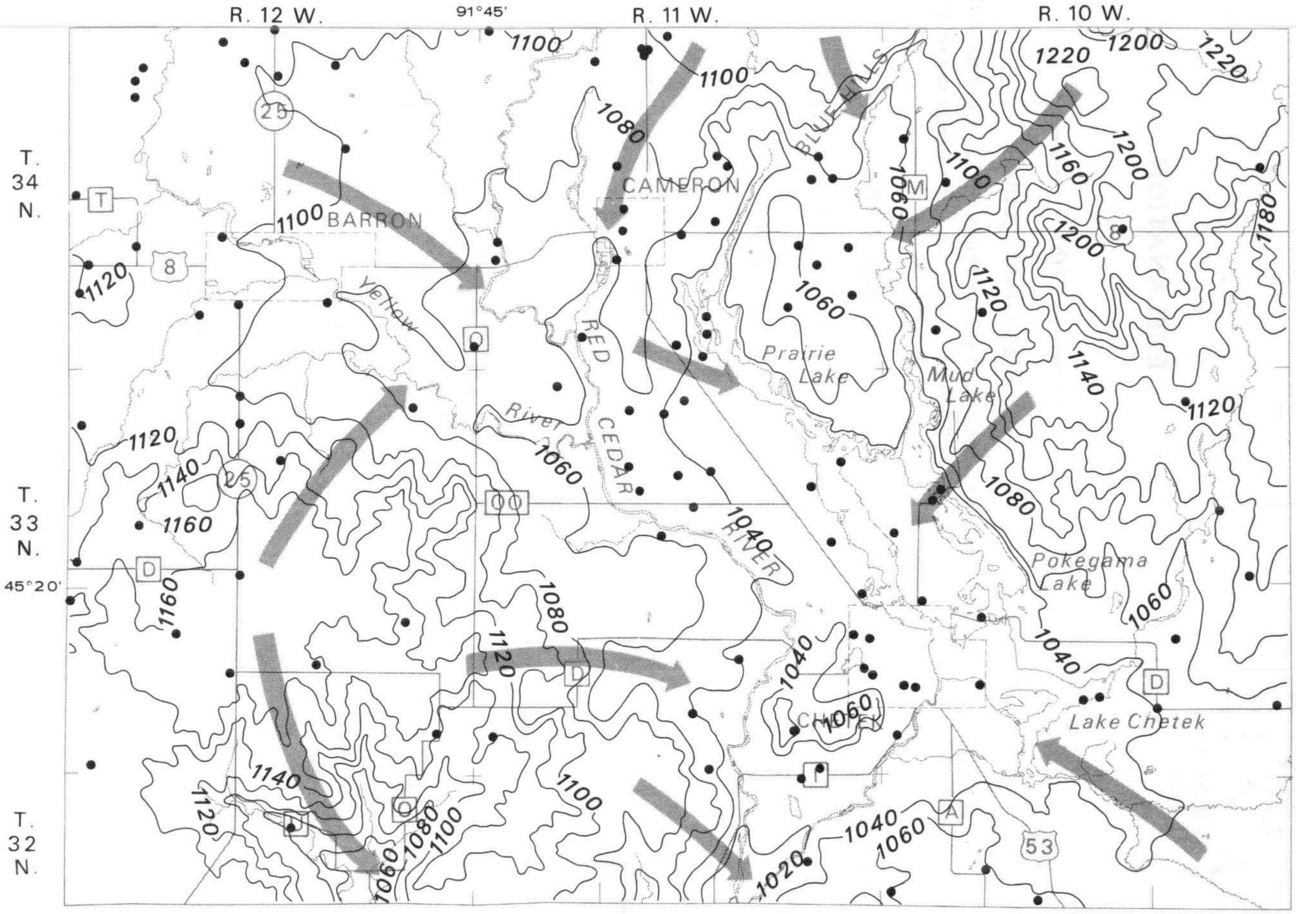
——— 1200 ———

Water-table contour

Shows altitude of water table, 1972. Contour interval 20 feet (6 metres) Datum is mean sea level

Direction of ground-water flow

Well for which water level was obtained



Base from U.S. Geological Survey
1:62,500 quadrangles

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

——— 1040 ———

Water-table contour

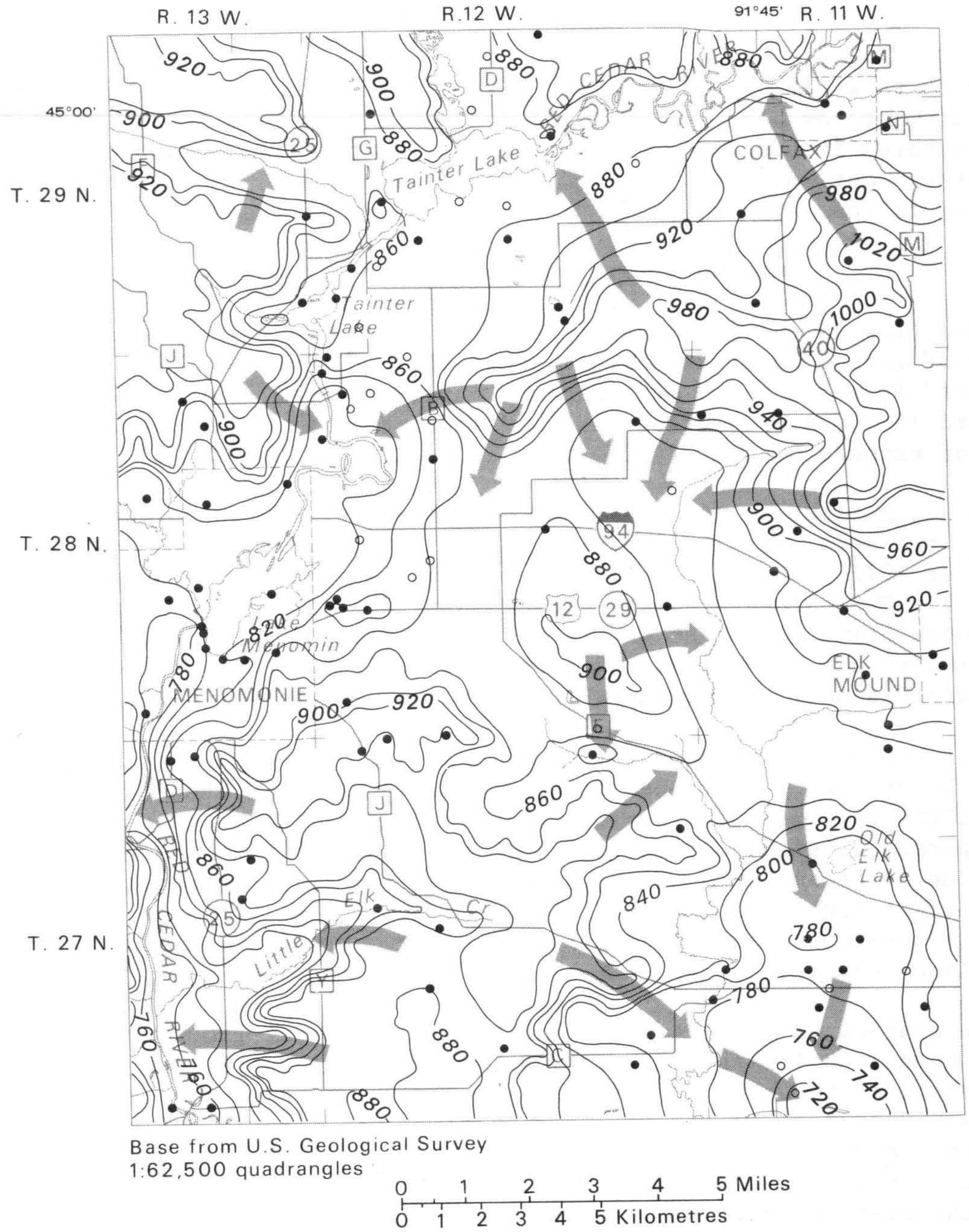
Shows altitude of water table, 1972. Contour interval 20 feet (6 metres) Datum is mean sea level

Direction of ground-water flow

•

Well for which water level was obtained

Figure 16. Water table of the Cameron subarea.



EXPLANATION

———— 860 ————

Water-table contour

Shows altitude of water table, 1972.
Contour interval 20 feet (6 metres)
Datum is mean sea level

Direction of ground-water flow

o •

Well for which water level was obtained

Open circle is well finished in glacial drift ;
closed circle is well finished in sandstone

Figure 17. Water table of the Menomonie subarea.

Depth to water in wells in the outwash plains ranges from 40 to 70 ft (12 to 21 m) below land surface, although in the extreme southeastern part of the subarea it ranges from 60 to 95 ft (18 to 29 m). Depth to water adjacent to most surface-water bodies such as streams, lakes, or wetlands generally is less than 20 ft (6 m) and in places is less than 10 ft (3 m).

Ground-Water Contribution to Streamflow

Base flow is the sustained or fair-weather runoff, and is composed largely of ground-water discharge. Base flow in streams in the study area, determined from discharge measurements during October 24-26, 1972, is shown in figure 18. (Flow-duration analysis indicates streamflow in the area equals or exceeds October 24-26 flows 17 percent of the time.)

As a quantitative measure of actual stream discharge during base-flow periods, two sets of values were determined by correlation of low-flow data of October 1972 with data from the report by Gebert (1971) and are shown in figure 18. The values of 7-day Q_2 and 7-day Q_{10}, the lowest mean discharge for 7 consecutive days that occurs on the average of once in 2 and 10 years, respectively, are shown. Negative numbers indicate losing stream reaches where water is moving from the stream into the ground-water system.

Differences in ground-water runoff rates in the subbasins (fig. 18) are due largely to differences in the volume of ground-water storage and permeability of the aquifers. Ground-water runoff is greatest in areas of thick, permeable glacial deposits, such as outwash plains and end moraines, and in the irrigable land of the study area. In those areas recharge is high, surface runoff is low, and ground-water storage is large. Ground-water runoff is less in areas of thin glacial drift overlying sedimentary or crystalline bedrock.

The reaches of streams receiving highest rates of ground-water discharge greater than 1.50 $(ft^3/s)/mi^2$ or 16.4 $(l/s)/km^2$ are in the east-central and northern parts where stratified sand and gravel predominate (fig. 6). The outwash sand and gravel is the most permeable material of the area. It stores and releases the largest amounts of sustained discharge to streams. The smaller discharges less than 0.8 $(ft^3/s)/mi^2$ or 8.8 $(l/s)/km^2$ generally are in the western half of the area where till or ground moraine predominate. Till of low permeability transmits small amounts of water and correspondingly low amounts of discharge to streams.

AQUIFER CHARACTERISTICS

Availability of ground water depends on the hydrologic characteristics of the aquifers. Transmissivity, which varies with the thickness of saturation and hydraulic conductivity, largely controls the water-yielding capabilities of the aquifers. This section describes the hydrologic or water-bearing characteristics of the sandstone and drift in the study area.

Thickness of Saturated Sandstone

The thickness of saturated sandstone in the Rice Lake-Eau Claire area depends on the total thickness of the rock and on the altitude of the water

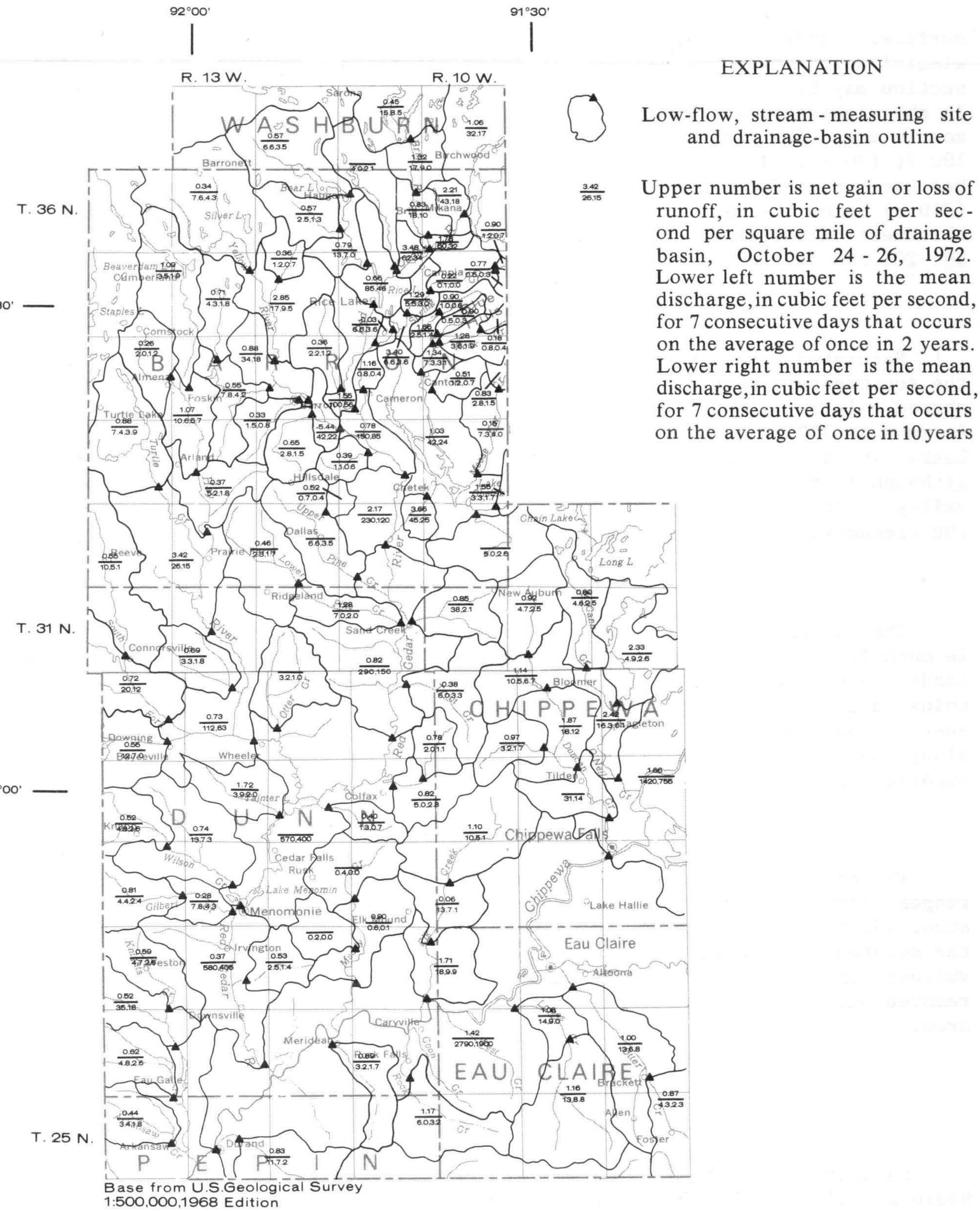


Figure 18. Base flow of streams in the Rice Lake-Eau Claire area during October 24-26, 1972.

surface. Sandstone underlying the valleys, where the water level is in the glacial drift above the bedrock, is fully saturated. However, the saturated section may be thin because part of the sandstone has been removed by erosion. In the highlands, where sandstone is near or at land surface, water levels mostly are a few tens of feet below land surface, but in places are more than 100 ft (30 m). The saturated section of sandstone, however, may be thick because the sandstone is thick. The total thickness is as much as 800 ft (240 m) below the bluffs in the southwestern part of the study area. The thickness of saturated sandstone in the three subareas is shown by figures 19, 20, and 21.

Rice Lake Subarea

Saturated sandstone in the Rice Lake subarea (fig. 19) is thickest in the southwestern part and thins toward the east. The sandstone is a wedge-shaped unit lying on the Precambrian surface that dips west and southwest. As much as 700 ft (210 m) of sandstone is saturated at a site west of Rice Lake. The sandstone beneath the Red Cedar River valley is fully saturated, although it thins to less than 100 ft (30 m) in the northern part of the valley. The sandstone is absent in the Blue Hills east of Rice Lake where the Precambrian surface is exposed.

Cameron Subarea

The thickness of saturated sandstone in the Cameron subarea (fig. 20) is much like that in the Rice Lake subarea. A wedge-shaped block of saturated sandstone more than 700 ft (210 m) thick in the western part of the subarea thins in a northeasterly direction to zero thickness in the Blue Hills northeast of Cameron. It is less than 100 ft (30 m) thick in the bedrock valley along the Chetek chain of lakes (fig. 4) in the southeastern part of the subarea.

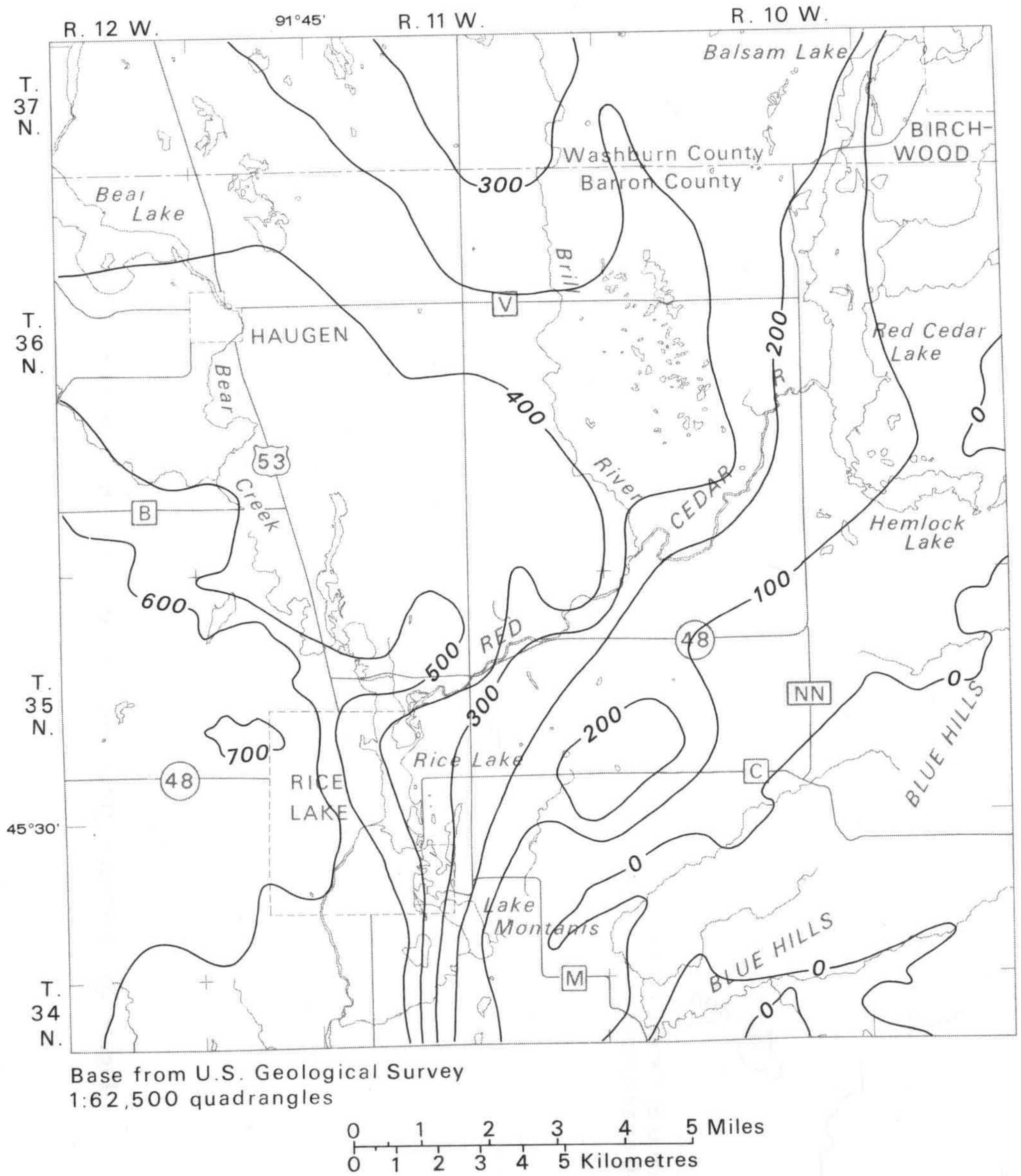
Menomonie Subarea

The thickness of saturated sandstone in the Menomonie subarea (fig. 21) ranges from about 600 ft (180 m) under the hills west of Tainter Lake to about 100 ft (30 m) beneath the outwash plains in the southeastern part of the subarea. The thickest section is under the hills flanking the stream valleys; the thickness decreases toward the valleys, where erosion has removed much of the sandstone. Saturated sandstone underlies the entire area.

Thickness of Saturated Drift

Rice Lake and Cameron Subareas

Saturated outwash sand and gravel (figs. 22 and 23) in the deepest bedrock valleys in the Rice Lake and Cameron subareas exceeds 250 ft (75 m) in thickness; it may be as thick as 300 ft (90 m) in the Rice Lake subarea. These thick, saturated deposits extend southwestward along the Red Cedar River from near Red Cedar Lake to Rice Lake and then southward through Lake Montanis (fig. 22); they continue through the Cameron subarea (fig. 23) southeastward along Prairie Lake-Lake Chetek and extend southeastward out



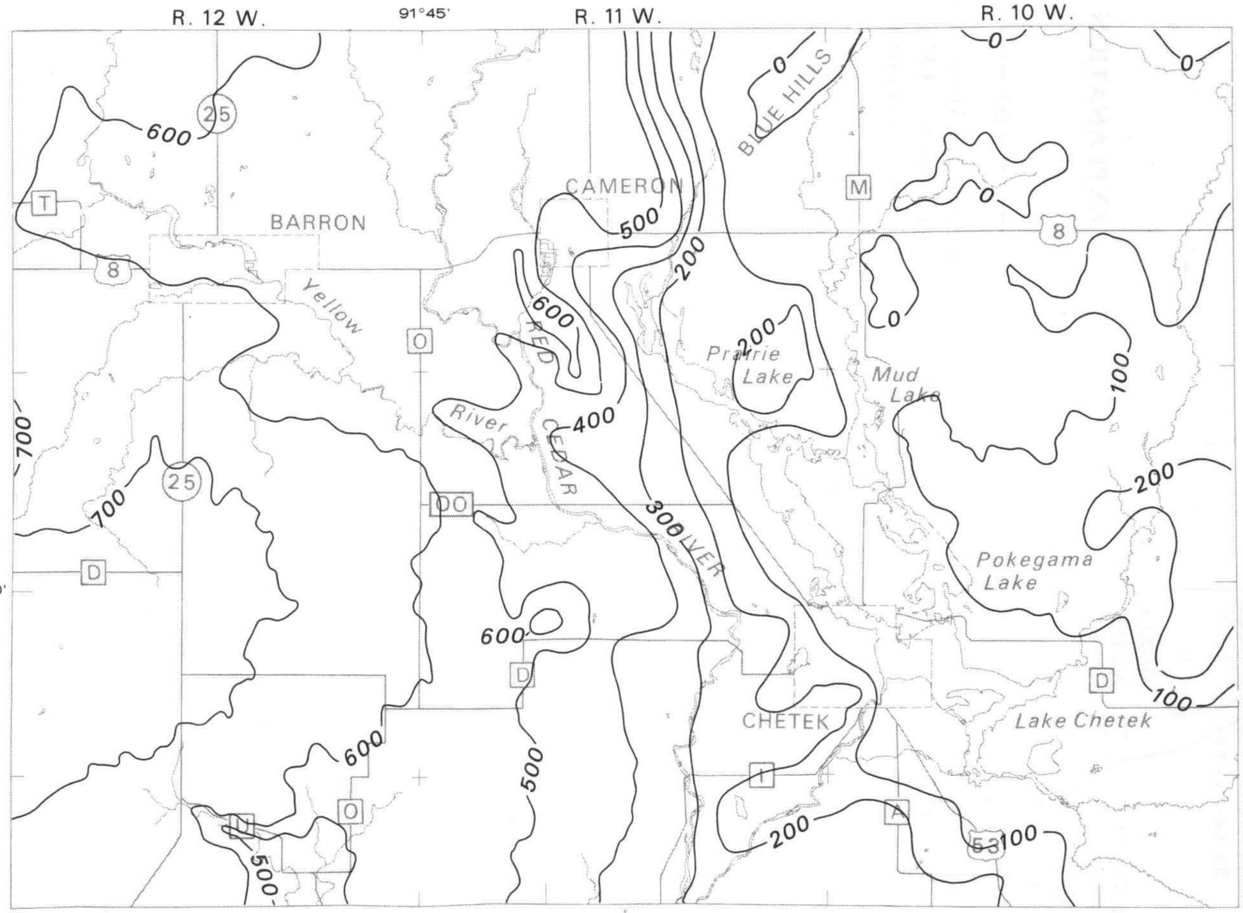
EXPLANATION

——— 600 ———

Line of equal thickness of saturated sandstone, 1972

Interval 100 feet (30 metres)

Figure 19. Saturated thickness of sandstone in the Rice Lake subarea.



Base from U.S. Geological Survey
1:62,500 quadrangles

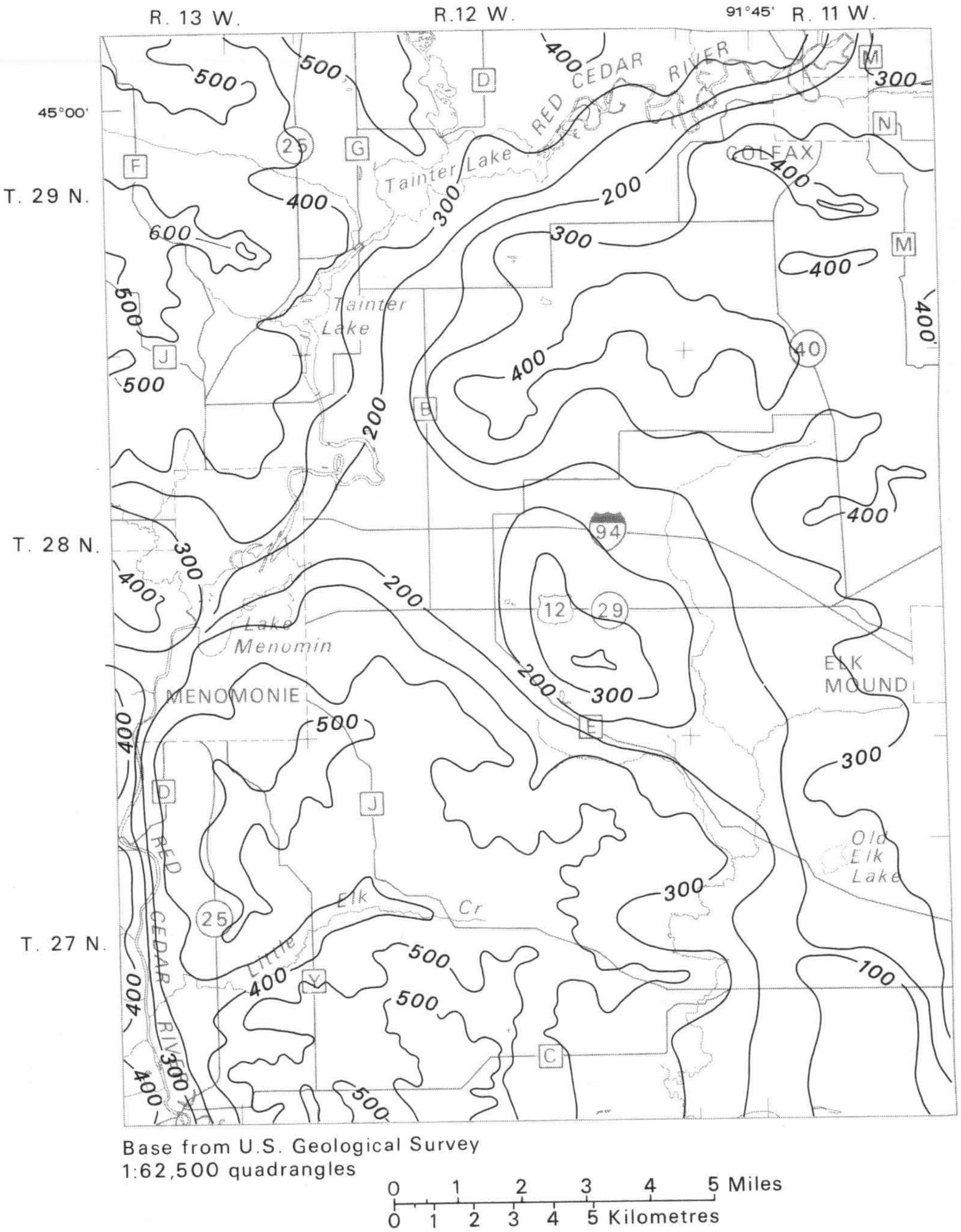
0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

—— *200* ——

Line of equal thickness of saturated sandstone, 1972
Interval 100 feet (30 metres)

Figure 20. Saturated thickness of sandstone in the Cameron subarea.



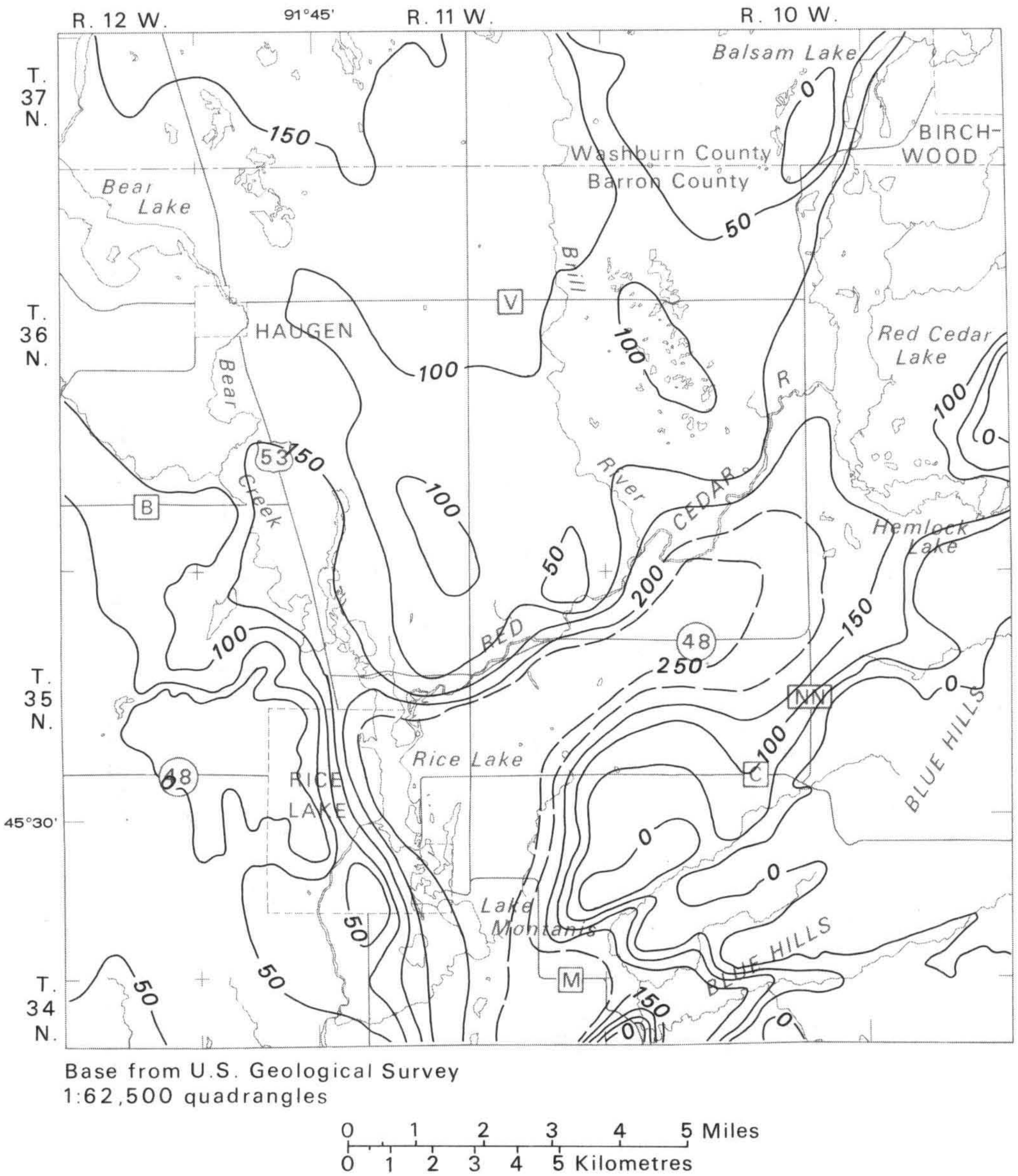
EXPLANATION

——— *300* ———

Line of equal thickness of saturated sandstone, 1972

Interval 100 feet (30 metres)

Figure 21. Saturated thickness of sandstone in the Menomonie subarea.



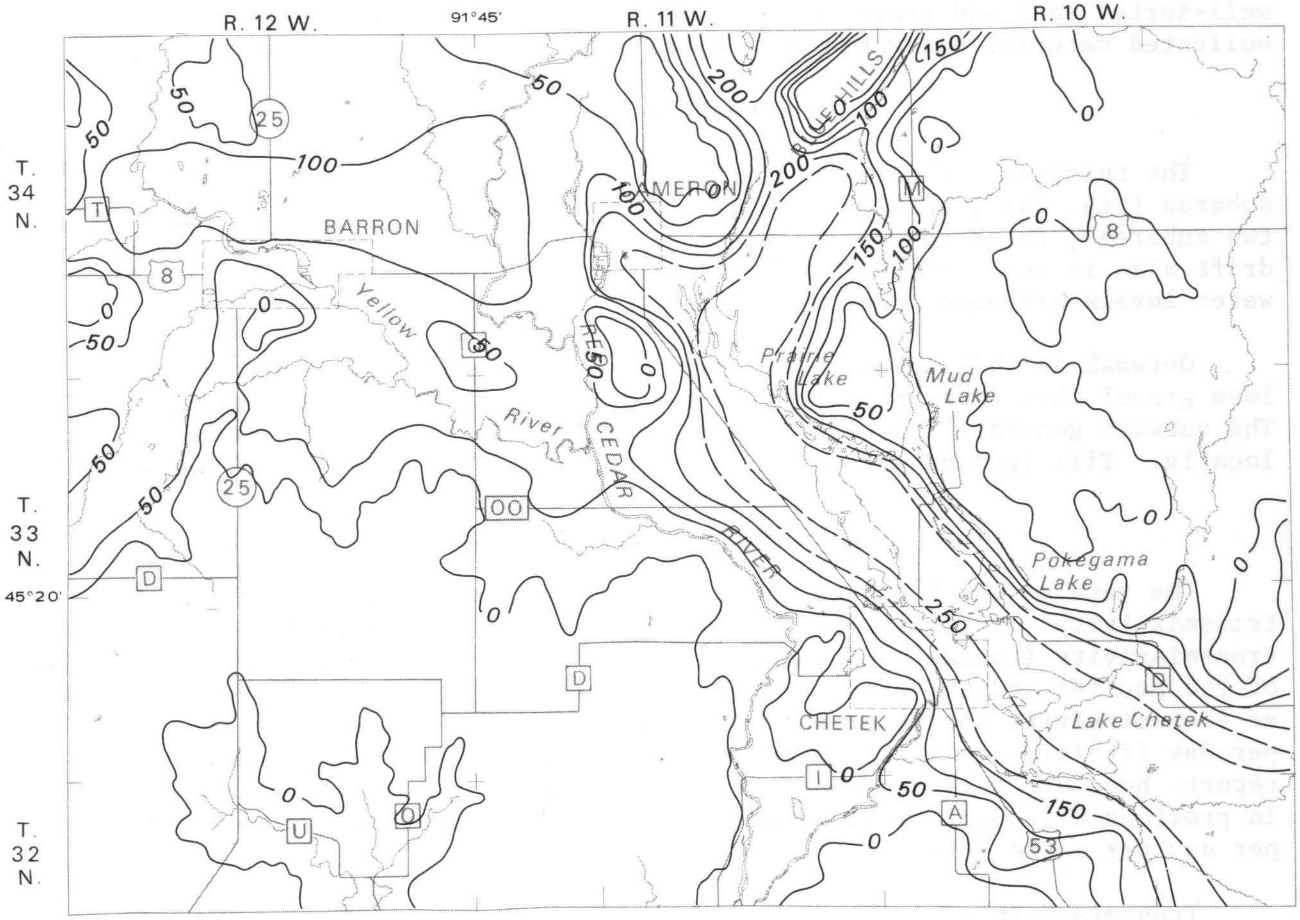
EXPLANATION

——————— *150* ———————

Line of equal thickness of saturated glacial drift, 1972

Dashed where approximately located. Interval 50 feet (15 metres)

Figure 22. Saturated thickness of glacial drift in the Rice Lake subarea.



Base from U.S. Geological Survey
1:62,500 quadrangles

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

——————— 200 — — — —

Line of equal thickness of saturated glacial drift, 1972

Dashed where approximately located. Interval 50 feet (15 metres)

Figure 23. Saturated thickness of glacial drift in the Cameron subarea.

of the southeast corner of the subarea. The saturated section of drift thins to zero in hills flanking the bedrock valleys, where the water level is in bedrock below the unconsolidated deposits.

Glacial deposits within bedrock valleys are mostly clean, stratified, well-sorted sand and gravel ranging from fine sand to large pebbles. Unconsolidated material elsewhere in the two subareas is mainly till.

Menomonie Subarea

The thickness of saturated drift in bedrock valleys in the Menomonie subarea (fig. 24) generally is less than 200 ft (60 m) and, as in the other two subareas, thins to zero in hills on either side of the valleys. The drift also is unsaturated in several small areas within the valleys where water levels are below bedrock surface.

Outwash in this subarea generally is a finer sand with substantially less gravel than that in valleys in the Rice Lake and Cameron subareas. The outwash generally is clean sand, although large lenses of clay occur locally. Till (ground moraine) covers the slopes and hilltops of the subarea.

Transmissivity of Aquifers

The rate at which ground water can be withdrawn depends largely on the transmissivity[1] of the aquifer. Though spoken of as a property of the aquifer, transmissivity (Lohman and others, 1972) embodies also the saturated thickness of the aquifer and the properties of the contained liquid. The standard unit of transmissivity for reports of the U.S. Geological Survey is feet squared per day (ft^2/d), or in metric units, metres squared per day (m^2/d). In this report, however, T is expressed as gallons per day per foot {(gal/d)/ft}, as in previous U.S. Geological Survey reports. The metric equivalent is litres per day per metre {(l/d)/m}.

Transmissivities in the irrigable land of the Rice Lake and Cameron subareas commonly exceed 200,000 (gal/d)/ft {2,480,000 (l/d)/m}. In part of the irrigable land, especially where the thickness of saturated sand and gravel is great, transmissivities exceed 500,000 (gal/d)/ft {6,200,000 (l/d)/m}, and in places may be nearly 1,000,000 (gal/d)/ft {12,400,000 (l/d)/m}.

Transmissivities of sand and gravel in the outwash plains of the Menomonie subarea are substantially lower than in the Barron County subareas because the glacial outwash generally is less permeable and the thickness of saturated d aquifer is less. In the outwash plains of the Menomonie subarea, transmissivity is mostly less than 150,000 (gal/d)/ft {1,860,000 (l/d)/m}, but locally is as high as 170,000 (gal/d)/ft {2,110,000 (l/d)/m}.

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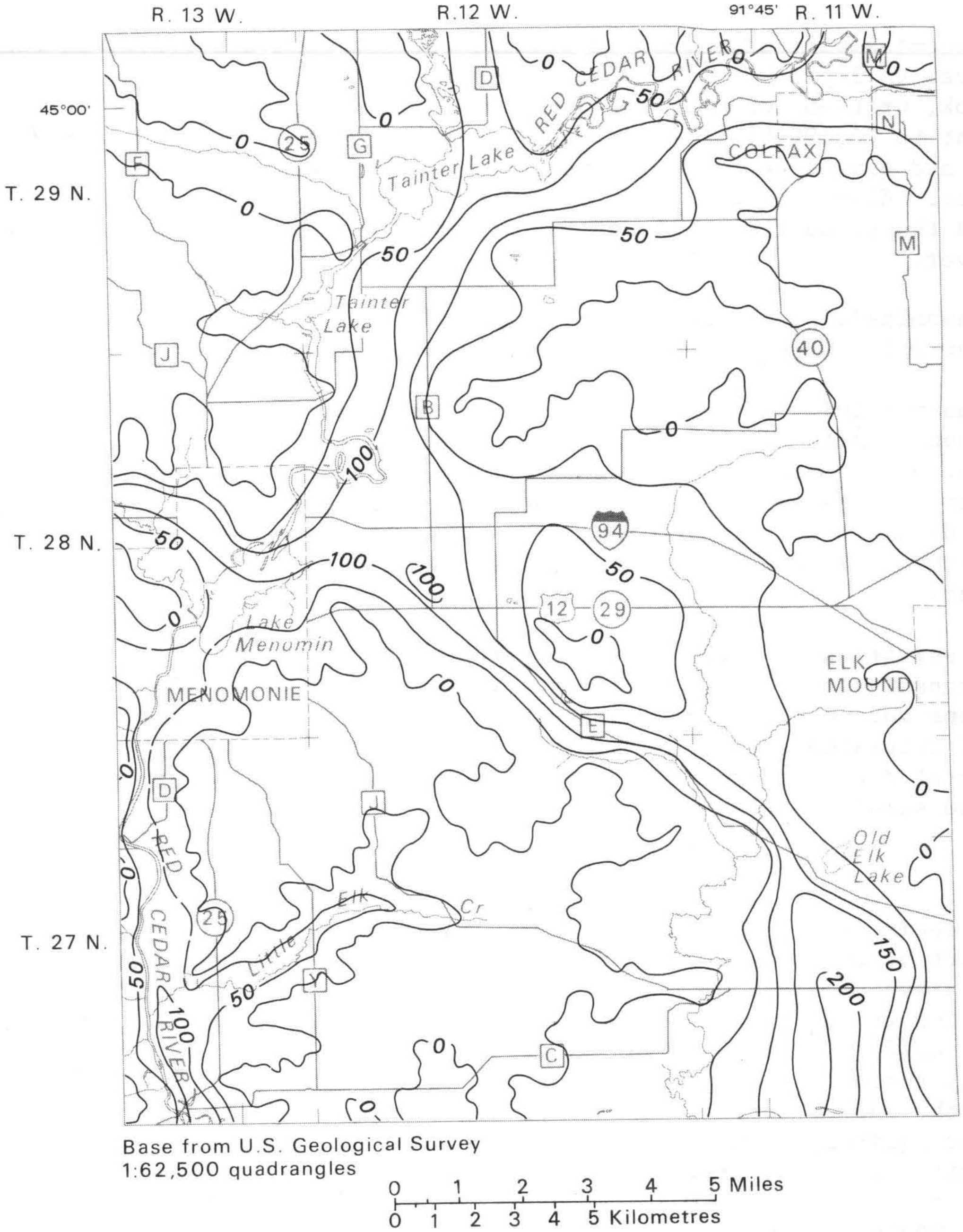
[1]Transmissivity is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths (Lohman and others, 1972).



EXPLANATION

———— *100* ———

Line of equal thickness of saturated glacial drift, 1972

Dashed where approximately located.
Interval 50 feet (15 metres)

Figure 24. Saturated thickness of glacial drift in the Menomonie subarea.

The transmissivity of saturated glacial outwash sand and gravel in the Chippewa River valley at Eau Claire is reported to be 2,000,000 (gal/d)ft (E. A. Hickok, written commun., 1967). Transmissivity of 2,000,000 (gal/d)/ft is equivalent to 24,800,000 (l/d)/m. This high transmissivity is limited to the sand and gravel deposits in the narrow valley of the Chippewa River at Eau Claire. Also, the direction of ground-water flow from the Chippewa River toward the production wells at Eau Claire indicates induced recharge from the river.

The transmissivity of the thin till covering the upper slopes and tops of hills generally is zero because the deposits are generally unsaturated.

The transmissivity of sandstone generally is less than that of glacial sand and gravel. Although the saturated thickness is greater, the hydraulic conductivity, or permeability, of sandstone is much less than that of glacial sand and gravel. Transmissivities of sandstone are less than 50,000 (gal/d)/ft {620,000 (l/d)/m} in most of the area. However, one test resulted in a transmissivity of 170,000 (gal/d)/ft {2,110,000 (l/d)/m} near Lake Menomin in Dunn County.

Transmissivities of aquifers in the study area were determined by several methods. Transmissivities were estimated from analyses of aquifer-test data; approximations were obtained as a product of hydraulic conductivity times thickness of saturated aquifer. The hydraulic conductivities were estimated from a study of specific-capacity data and soil and rock descriptions in drillers' and sample logs of many wells.

Ground-Water Availability

The potential yield from the glacial outwash sand and gravel in the irrigable part of the two Barron County subareas is very large. For example, assume that a hypothetical well with a diameter of 48 in (1,220 mm) fully penetrating 200 ft (60 m) of saturated aquifer having a transmissivity of 500,000 (gal/d)/ft {6,200,000 (l/d)/m} is pumped continuously for 30 days. Theoretically the well would yield about 37,000 gal/min (2,320 l/s) if the drawdown at the end of 30 days was 133 ft (40 m) (equal to two-thirds of the saturated aquifer). This potential yield is about five times the average use of the city of Eau Claire. Under the assumed conditions, the drawdown would be about 1 ft (0.3 m) at a distance of 1.5 mi (2.4 km) from the pumping well, and it would be negligible at a distance of 2.5 mi (4.0 km). The example deals with an ideal aquifer and a totally efficient well. It neglects possible changes in the relation between recharge and discharge of the aquifer during pumping. Because such a well is not practicable, multiple wells of lesser diameter would be used to attain the potential yield.

Actual yields from wells in glacial outwash and sandstone substantiate that abundant ground water is available in the Rice Lake-Eau Claire area. Many wells in glacial outwash along the Chippewa River at Eau Claire and Chippewa Falls produce more than 1,000 gal/min (63 l/s). Nine wells have capacities exceeding 1,900 gal/min (120 l/s); two of these were tested at 2,400 gal/min (152 l/s). Many wells in the outwash plains and Red Cedar River valley in Barron and Dunn Counties also produce more than 1,000 gal/min

(63 l/s). A well tapping glacial sand in Barron County yields 1,350 gal/min (85 l/s), and a well tapping sandstone in Dunn County yields 1,400 gal/min (88 l/s). A well tapping glacial sand in Pepin County was tested at 850 gal/min (54 l/s).

The largest supplies of ground water for irrigation in the Rice Lake-Eau Claire area are available from the glacial outwash sand and gravel in the Rice Lake and Cameron subareas and in the Chippewa River valley near Chippewa Falls and Eau Claire. Yields exceeding 2,000 gal/min (126 l/s) from the sand and gravel in much of those areas could be sustained for many years and would be more than adequate for any irrigation in the foreseeable future. Additional supplies adequate for irrigation are available from the sandstone.

In general, much water for irrigation is available from the glacial drift filling the bedrock valleys and from the underlying sandstone in most of the Rice Lake-Eau Claire area (fig. 25). Yields of 500 gal/min (31.5 l/s) or more are common in nearly all the valley. Yields exceeding 1,000 gal/min (63 l/s) are available in parts of the valley, especially near Rice Lake and Cameron where the thickness of highly permeable glacial drift is more than 250 ft (76 m) in places.

Yields of 500 gal/min (31.5 l/s) generally are available from the sandstone in the western part of the project area (fig. 25). Moderate transmissivities of the sandstone aquifer relate to thick sections, as much as 700 ft (211 m), of saturated aquifer. Yields from the sandstone in the eastern part of the area are less than 500 gal/min (31.5 l/s). In places, particularly in the Blue Hills of Barron County and near Chippewa Falls and Eau Claire, sandstone has been removed by erosion.

Water-Yielding Capabilities of Aquifers

The water-yielding capability of an aquifer is its capacity for being used or developed. Water-yielding capabilities of each aquifer in the three subareas (figs. 26-29) are shown by the theoretical drawdowns in the aquifers caused by pumping at a constant rate continuously for 30 days. Drawdowns at the end of 10 days would be less than at the end of 30 days. Small drawdowns caused by high rates of withdrawals reflect high transmissivity and indicate much available water. Large drawdowns resulting from low rates of withdrawals reflect low transmissivity and indicate small amounts of available water.

The maps (figs. 26-29) show the theoretical drawdowns that would result in the aquifer at the outer edge of the pumped well and at 0.25 mi (0.4 km) from the well. The drawdowns were computed, assuming no recharge and as if a single well in the center of a quarter-section was pumped with no other pumping in adjacent quarter-sections. If the well is at the center of a quarter-section, the drawdown 0.25 mi (0.4 km) from the well denotes well interference at the boundary of the quarter-section. If, however, a well in each of two adjacent quarter-sections was pumped simultaneously at the same rate, the drawdown at the common boundary of the two quarter-sections would be additive, or the sum of the drawdowns effected by each well. Thus, the drawdown would reflect mutual well interference and would be double that shown in the figures.

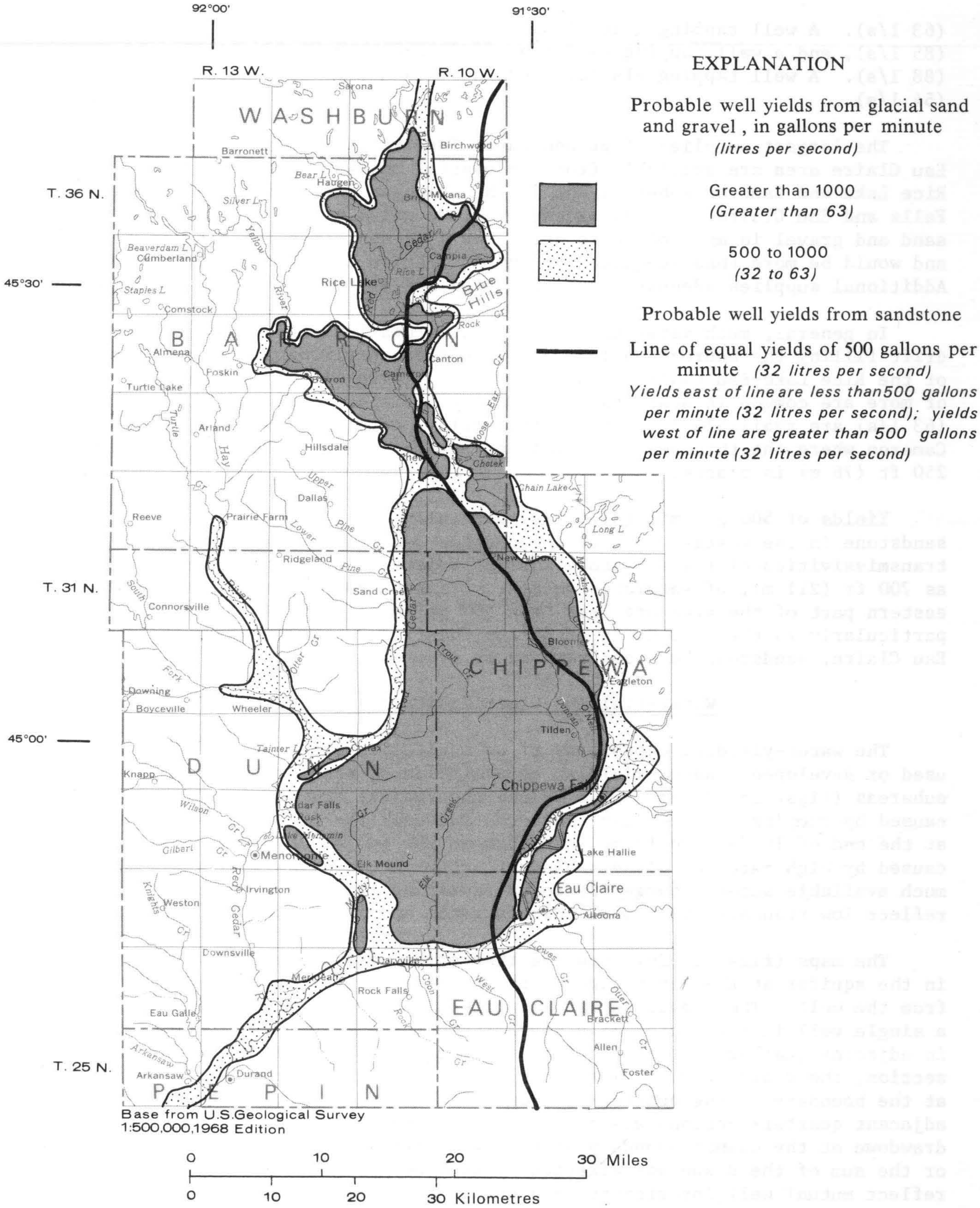


Figure 25. General availability of ground water for irrigation in the Rice Lake-Eau Claire area.

Rice Lake and Cameron Subareas

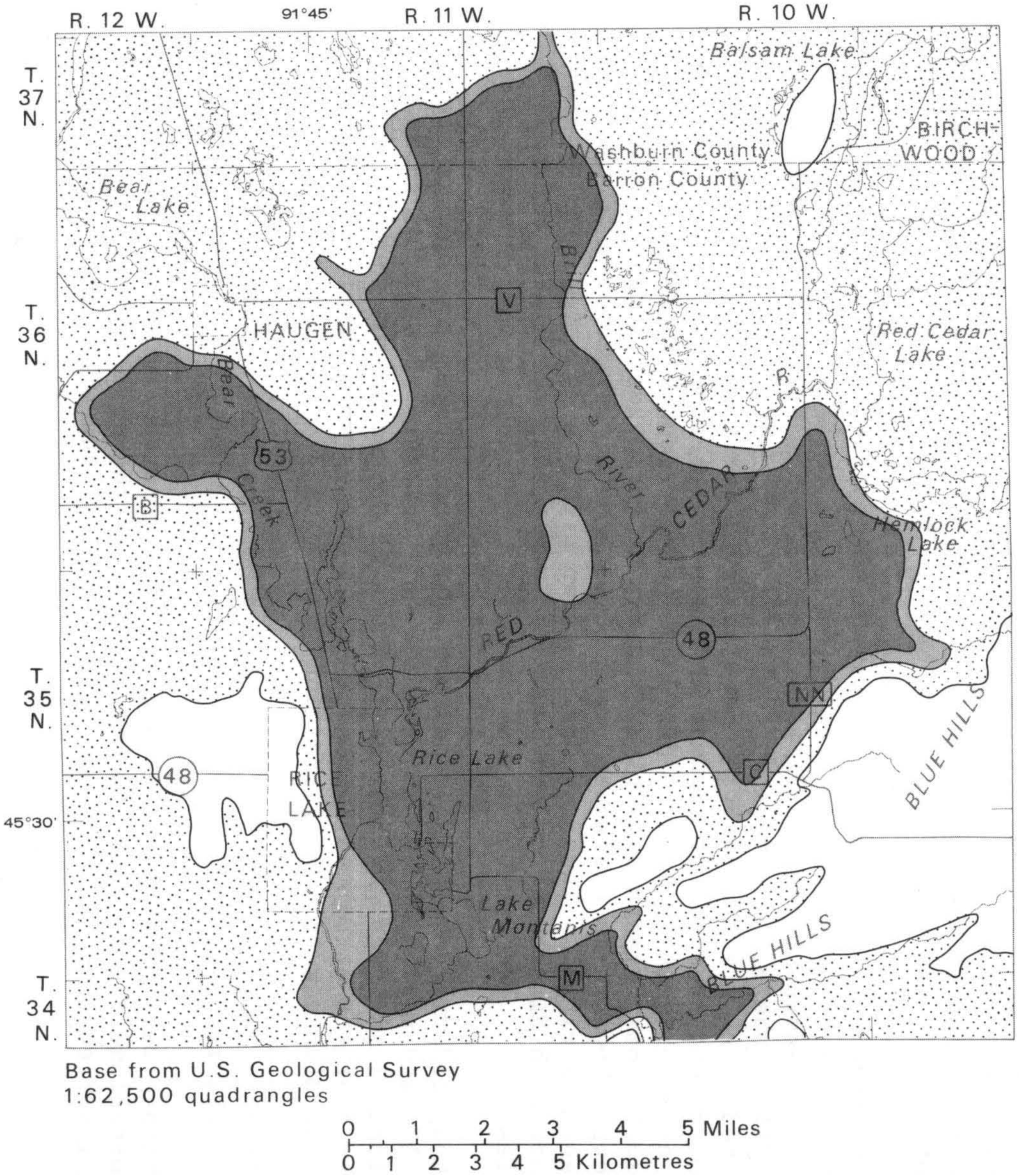
Glacial Drift Aquifer.--Large yields to wells with a resulting small drawdown characterize the glacial drift aquifer in most of the bedrock valley (figs. 3 and 4) within the Rice Lake and Cameron subareas (figs. 26 and 27). The zones of drawdown shown in figures 26 through 31 show the effects of pumping a single well at the specified rate. Continuous withdrawal of water at a rate of 2,000 gal/min (126 l/s) from a single well would cause less than 20 ft (6 m) of drawdown (zone 1) in the aquifer outside the casing of the pumped well and less than 2 ft (0.6 m) of drawdown 0.25 mi (0.4 km) from the pumped well in much of the valley. The 20-ft (6-m) drawdown (zone 1) represents a small part of the thickness of saturated aquifer and indicates that a great amount of water is available from the drift within the valley. Near the outer parts of the rock valley, and in a small tract northeast of Rice Lake, withdrawals of 2,000 gal/min (126 l/s) would result in drawdowns of 20 to 30 ft (6 to 9 m) (zone 2) near the pumped well. Withdrawals of 1,000 gal/min (63 l/s) would result in half the drawdown or 10 to 15 ft (3 to 4.5 m) near the pumped well. In accordance with the conditions stated later in this section, a saturated section at least 60 ft (18 m) thick would be necessary to yield 2,000 gal/min (126 l/s) to a well in which drawdown is 30 ft (9 m). Because the saturated section (figs. 22 and 23) is less than 50 ft (15 m) thick in places near the outer parts of the valley, withdrawals are designated primarily as 1,000 gal/min (63 l/s) for that part of the valley. The thickness of saturated aquifer and, hence, transmissivity decreases sharply toward the edges of the rock valley. Yields, which vary with transmissivity, are very small near the walls of the bedrock valley.

The drawdown is dependent largely on transmissivity and is limited by the thickness of saturated aquifer. (See figs. 19-21 and 22-24.) Areas or zones of drawdowns (figs. 26-31), delineated on the basis of transmissivity, are modified where the saturated thickness is not adequate to support the indicated rate of withdrawal. Zones labeled 1 are areas of least drawdown and correspond to areas of highest transmissivity; zones 2, 3, 4, and 5 are areas of progressively greater drawdowns and correspond to areas of progressively lower transmissivities. In any selected zone, the range of drawdowns shown for a designated rate of withdrawal corresponds to the range of transmissivities. Thus, drawdowns shown within a selected zone generally increase with distance from the boundary, reflecting the higher transmissivities.

Computed drawdowns do not include frictional losses for water entering the wells and moving upward through the well screens. Because of those frictional losses and physical limitations of depleting the aquifer, it is assumed that the saturated thickness at the pumped well should be at least twice the drawdown to support the indicated yield.

Storage coefficients for drift and sandstone were estimated to be 0.2 and 0.0001, respectively.

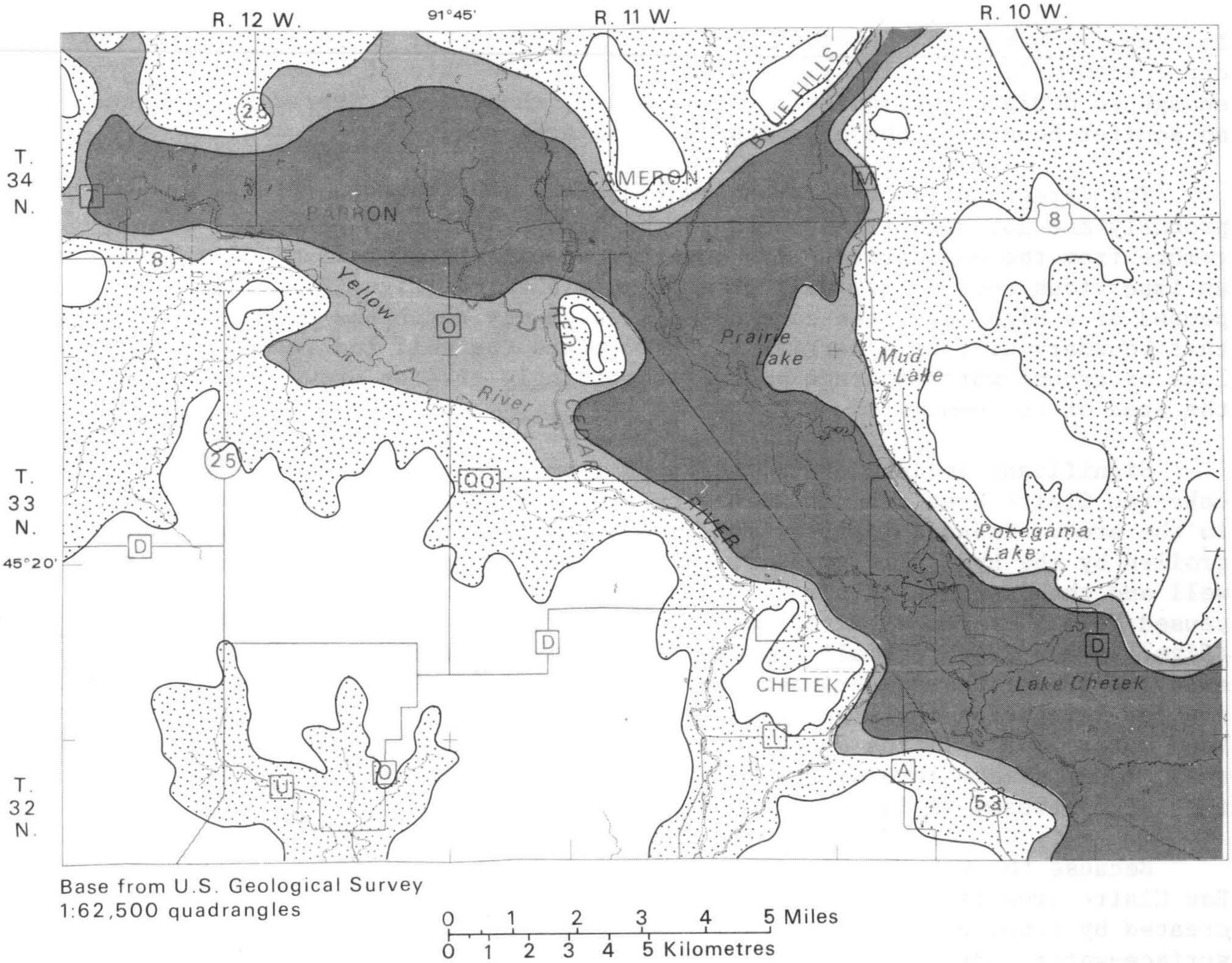
When a well is pumped continuously at a constant rate, the water table (or potentiometric surface) in the vicinity of the well assumes the shape of an inverted cone whose volume increases at a gradually diminishing rate.



EXPLANATION

	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown: 1320 feet *(402 metres)* from well
Zone 1	2000 *(126)*	Less than 20 *(Less than 6)*	Less than 2 *(Less than 0.6)*
Zone 2	1000 *(63)*	10 - 15 *(3-4.6)*	1 - 2 *(0.3-0.6)*
	2000 *(126)*	20 - 30 *(6-9.1)*	2 - 4 *(0.6-1.2)*
Zone 3	Less than 1000 *(Less than 63)*	Variable	Variable
Zone 4	No yield; drift unsaturated or absent		

Figure 26. Water-yielding capabilities of glacial drift in the Rice Lake subarea.



EXPLANATION

	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: 1320 feet *(402 metres)* from well
Zone 1	2000 *(126)*	Less than 20 *(Less than 6)*	Less than 2 *(Less than 0.6)*
Zone 2	1000 *(63)*	10 - 15 *(3-4.6)*	1 - 2 *(0.3-0.6)*
	2000 *(126)*	20 - 30 *(6-9.1)*	2 - 4 *(0.6-1.2)*
Zone 3	Less than 1000 *(Less than 63)*	Variable	Variable
Zone 4	No yield; drift unsaturated or absent		

Figure 27. Water-yielding capabilities of glacial drift in the Cameron subarea.

In time, recharge to the aquifer will equal withdrawal and the cone of depression will essentially stabilize, unless the rate of withdrawal is great enough to deplete the aquifer. If, however, the cone of depression reaches an aquifer boundary, the expansion will be arrested.

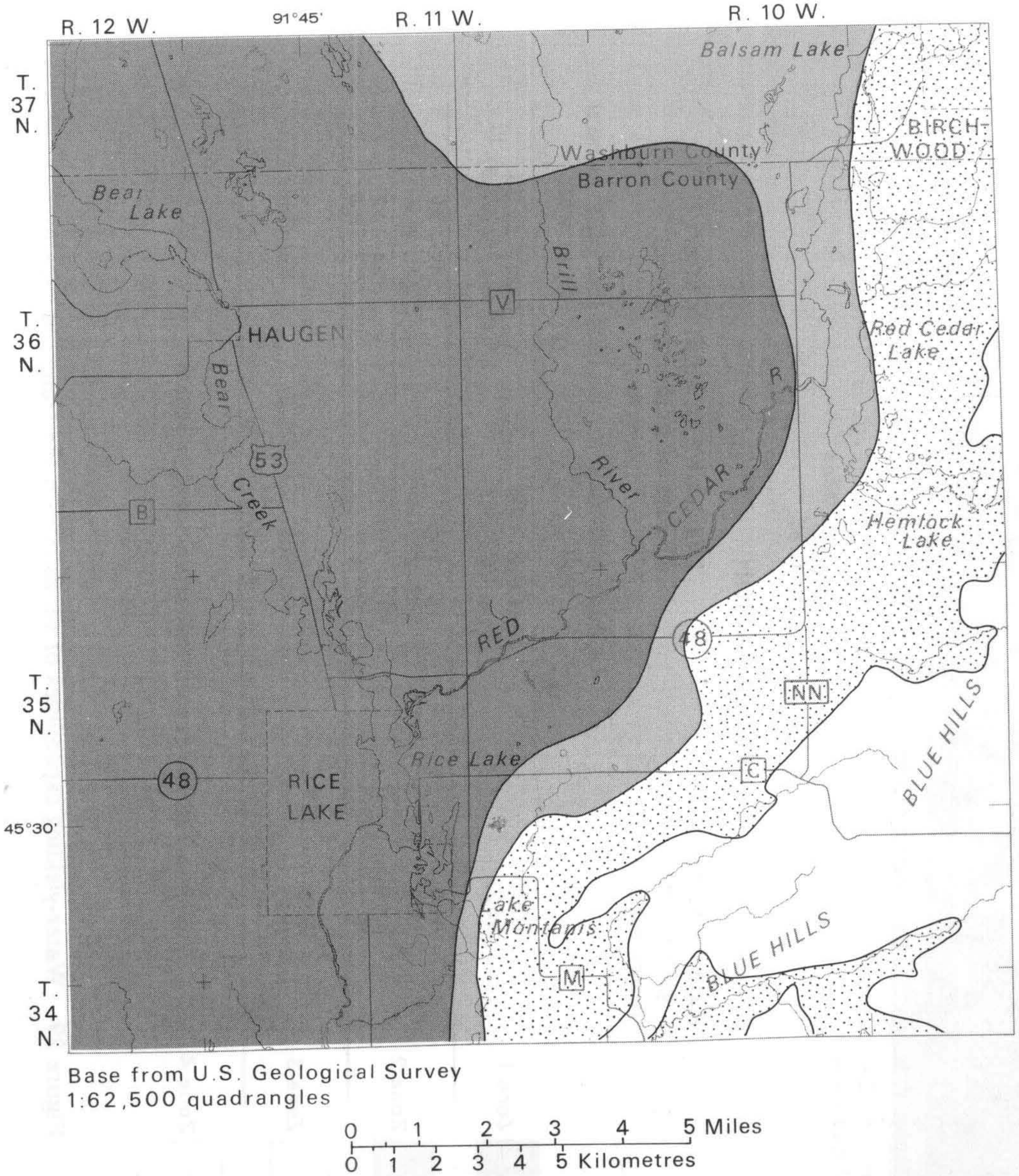
The effects of an aquifer boundary in the Rice Lake-Eau Claire area probably are not significant because the irrigation wells generally are remote from the boundaries. If, however, a well within 0.25 mi (0.4 km) of an impervious rock valley wall or a "no-yield" area (figs. 26-31) were pumped at a high rate, the cone of depression may reach the boundary. If so, that boundary will be a barrier to flow toward the well and result in increased loss of ground-water storage and correspondingly greater drawdown within the area of influence.

Significant amounts of infiltration from streams or lakes in the Rice Lake-Eau Claire area are not likely to result from pumping irrigation wells in the area. Induced infiltration from streams (or lakes) is largely controlled by the hydraulic gradient which depends on the drawdown in the pumping well and the distance of the well from the surface-water body. Drawdowns caused by high rates of withdrawal in the Rice Lake and Cameron subareas (figs. 26 and 27) are small because of the high transmissivities of the glacial sand and gravel that underlies most of the area of soils suitable for irrigation, and the irrigation wells generally are remote from the streams and lakes. Many water levels in the southeastern part of the Menomonie subarea are below small local stream levels, and irrigation wells generally are too remote from the large streams to induce infiltration.

Because the water table in most of the glacial outwash in the Rice Lake-Eau Claire area is above the local stream levels, the cone of depression created by pumping a well near a stream, lake, or wetland may intersect the surface-water body. If so, the hydraulic gradient toward the well may induce infiltration to recharge the aquifer and result in decreased loss of ground-water storage and correspondingly smaller drawdown. Areas of outwash bordering Rice Lake, Lake Chetek, parts of Tainter Lake, and sandy reaches of the Chippewa and Red Cedar Rivers are principal areas where high-capacity wells within 0.25 mi (0.4 km) of the surface-water body may induce recharge. Lake bottoms and streambeds composed of fine-grained sediments (silt and clay) would impede potential infiltration.

Not all the water that is pumped for irrigation is consumed by plants or evaporated. Some of the water, especially if an excess is applied, seeps downward to recharge the ground-water body. Thus, the effective withdrawal of ground water from storage is reduced and drawdowns are correspondingly reduced. An estimated 10 to 20 percent of water pumped for irrigation returns to the ground-water reservoir.

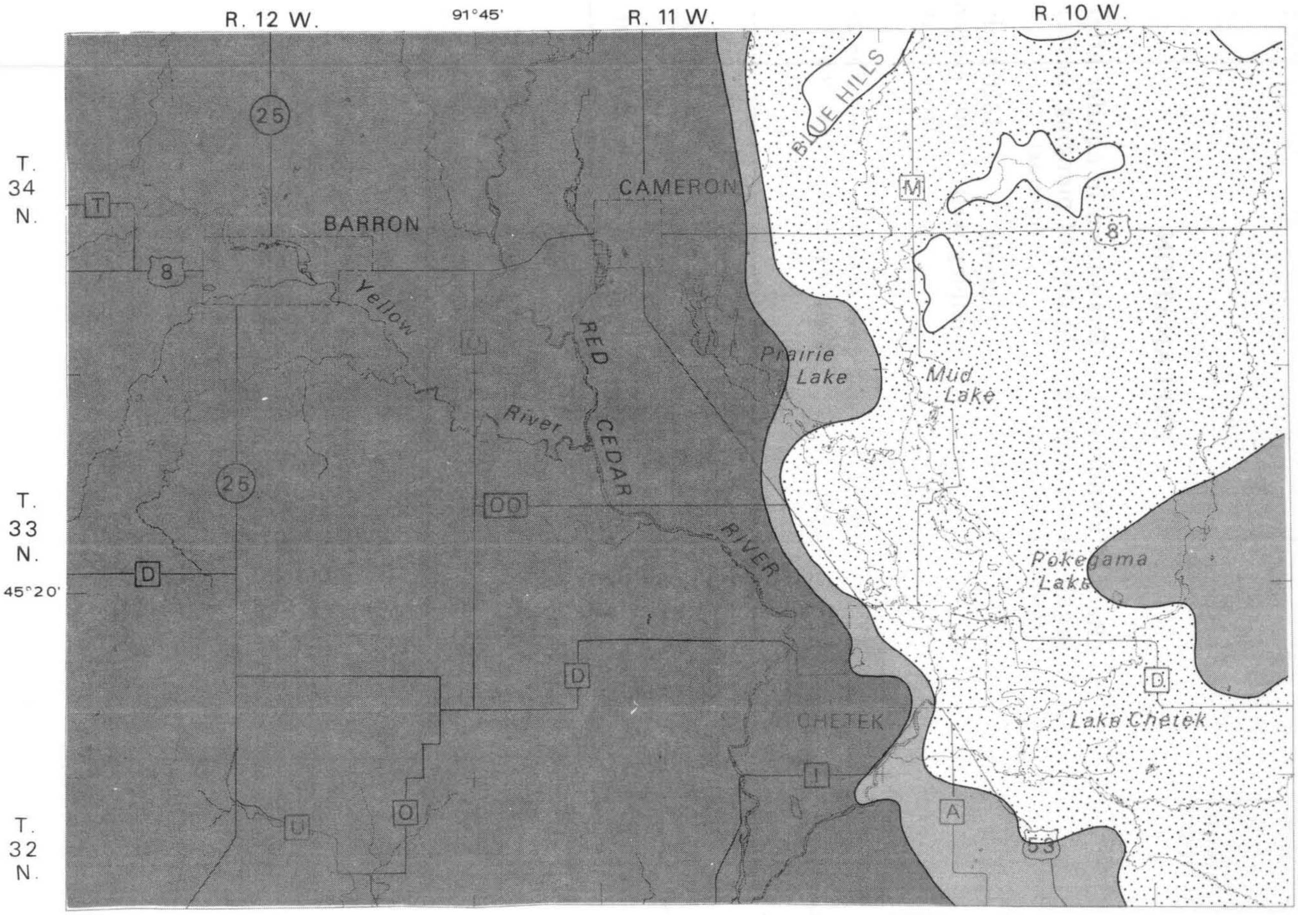
Sandstone Aquifer.--Withdrawals of 1,000 gal/min (63 l/s) from a single well tapping the full thickness of the sandstone aquifer in most of the western half of the Rice Lake and Cameron subareas (zone 1) would cause a drawdown of less than 100 ft (30 m) in the aquifer adjacent to the pumped well (figs. 28 and 29) and less than 24 ft (7.5 m) 0.25 mi (0.4 km) from the pumped well. Where withdrawals of 1,000 gal/min (63 l/s) are possible in



EXPLANATION

	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: 1320 feet *(402 metres)* from well
Zone 1	1000 *(63)*	Less than 100 *(Less than 30)*	Less than 24 *(Less than 7.3)*
Zone 2	500 *(32)*	50 - 100 *(15-30)*	12 - 21 *(3.7-6.4)*
	1000 *(63)*	100 - 200 *(30-61)*	24 - 42 *(7.3-12.8)*
Zone 3	Less than 500 *(Less than 32)*	Variable	Variable
Zone 4	No yield; sandstone unsaturated or absent		

Figure 28. Water-yielding capabilities of sandstone in the Rice Lake subarea.



Base from U.S. Geological Survey
1:62,500 quadrangles

0 1 2 3 4 5 Miles
0 1 2 3 4 5 Kilometres

EXPLANATION

	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: 1320 feet *(402 metres)* from well
Zone 1	1000 *(63)*	Less than 100 *(Less than 30)*	Less than 24 *(Less than 7.3)*
Zone 2	500 *(32)*	50 - 100 *(15-30)*	12 - 21 *(3.7-6.4)*
	1000 *(63)*	100 - 200 *(30-61)*	24 - 42 *(7.3-12.8)*
Zone 3	500 *(32)*	Variable	Variable
Zone 4	No yield; sandstone unsaturated or absent		

Figure 29. Water-yielding capabilities of sandstone in the Cameron subarea.

the small tract (zone 2) in the eastern part of the Cameron subarea and in the central and eastern parts of both subareas (zone 2), drawdowns near the pumped wells would range from 100 to 200 ft (30 to 60 m). Corresponding drawdowns 0.25 mi (0.4 km) from the pumped well would range from 24 to 42 ft (7.5 to 13 m) and would represent significant well interference. Withdrawals of 500 gal/min (31.5 l/s) would result in half the drawdowns caused by withdrawals of 1,000 gal/min (63 l/s). Withdrawals in zone 2 in the central and eastern parts of the subarea are designated primarily as 500 gal/min (31.5 l/s) because withdrawal of 1,000 gal/min (63 l/s) is possible in part of the zone only. Yields from sandstone in zone 3 of the two subareas are small because the thickness of saturated sandstone (figs. 19 and 20) generally is small. The sandstone is missing entirely in the Blue Hills area (zone 4).

Menomonie Subarea

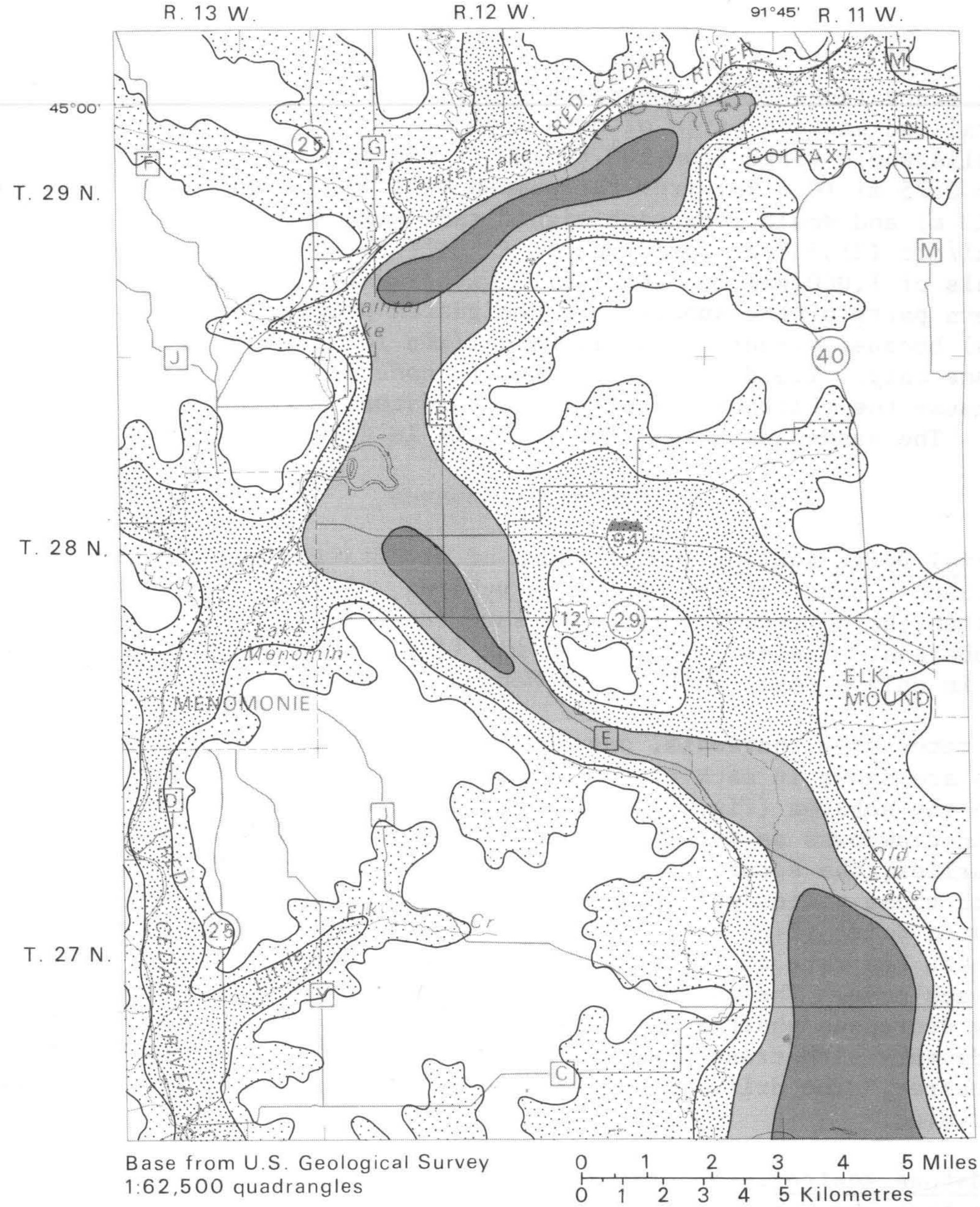
Glacial Drift Aquifer.--High rates of withdrawal from the glacial drift are possible in parts of the Menomonie subarea, although drawdowns would be greater than those resulting from the same rate of withdrawal in the Barron County subareas. Yields of 2,000 gal/min (126 l/s) from a single well are possible in only a small part of the Menomonie subarea (zone 1, fig. 30).

Two rates of withdrawals, one double the other, and their resulting drawdowns are shown in each of three zones (1, 2, and 3) within the bedrock valley in the subarea (fig. 30). The higher rate of withdrawal in each zone results in drawdowns as much as 40 ft (12 m). In accordance with the conditions stated earlier, the saturated aquifer should be at least 80 ft (24 m) thick to sustain those yields where drawdown is 40 ft (12 m). Because the thickness of saturated drift (fig. 24) is less than 50 ft (15 m) in parts of each of those zones, the rate of withdrawal is designated primarily as the lower rate in each zone. The thickness of saturated aquifer and, hence, the transmissivity decreases sharply with distance up the slopes of the uplands. The yields vary with transmissivity and are very small in those parts (zone 4) of the subarea. The drift in the highlands (zone 5) of the Menomonie subarea is unsaturated.

Sandstone Aquifer.--Moderately large yields are available from the sandstone throughout the Menomonie subarea. The theoretical drawdowns caused by withdrawals of 500 gal/min (31.5 l/s) are shown in figure 31. The drawdowns in the aquifer near the pumped well would range from less than 40 ft (12 m) where transmissivity is highest to more than 60 ft (18 m) where transmissivity is lowest. Well interference at a distance 0.25 mi (0.4 km) from the pumped well would range from less than 11 ft (3.5 m) to more than 14 ft (4 m).

Yields of 1,000 gal/min (63 l/s) from the sandstone, not shown in figure 31, are available in the highlands where the saturated section is thick. The drawdown caused by withdrawals of 1,000 gal/min (63 l/s) would be double that resulting from the withdrawal of 500 gal/min (31.5 l/s) (fig. 31).

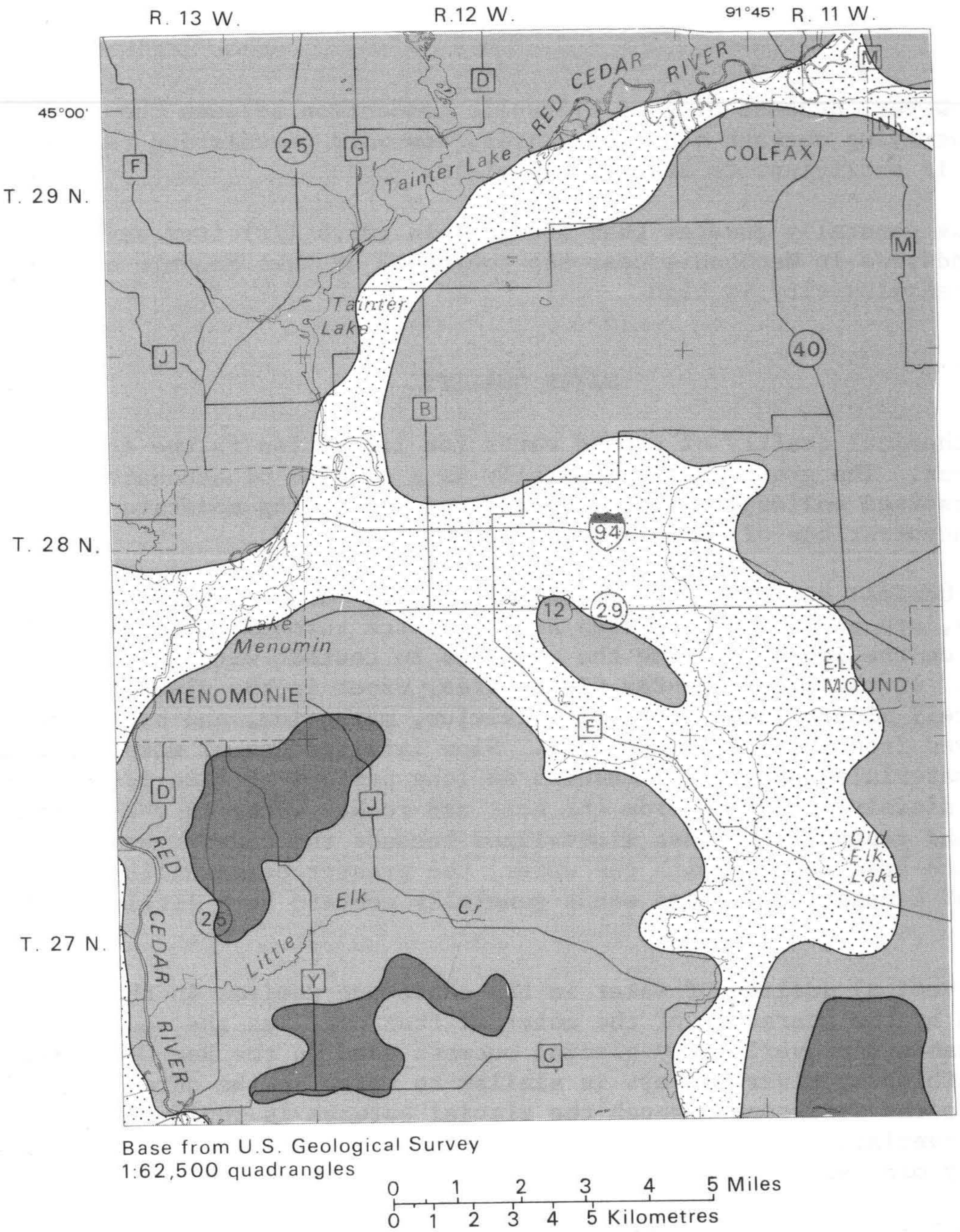
Several wells penetrating the sandstone aquifer underlying glacial deposits in the rock valleys, especially in the southeastern part of the subarea, yield in excess of 1,000 gal/min (63 l/s), although the thickness of saturated sandstone (fig. 21) appears to be too small to support that



EXPLANATION

Zone	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: 1320 feet *(402 metres)* from well
Zone 1	1000 *(63)*	Less than 20 *(6)*	Less than 2 *(0.6)*
	2000 *(126)*	Less than 40 *(12)*	Less than 4 *(1.2)*
Zone 2	500 *(32)*	10 - 20 *(3-6)*	Less than 1 *(0.3)*
	1000 *(63)*	20 - 40 *(6-12)*	1 - 2 *(0.3-0.6)*
Zone 3	250 *(16)*	10 - 20 *(3-6)*	Less than 1 *(0.3)*
	500 *(32)*	20 - 40 *(6-12)*	Less than 1 *(0.3)*
Zone 4	Less than 250 *(16)*	Variable	Variable
Zone 5	No yield; drift unsaturated or absent		

Figure 30. Water-yielding capabilities of glacial drift in the Menomonie subarea.



EXPLANATION

	Rate of withdrawal, in gallons per minute *(litres per second)*	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: Outside pumping well	Drawdown in aquifer after 30 days of pumping, in feet *(metres)*: 1320 feet *(402 metres)* from well
Zone 1	500 *(32)*	Less than 40 *(Less than 12)*	Less than 11 *(Less than 3.4)*
Zone 2	500 *(32)*	40 - 60 *(12-18)*	11 - 14 *(3.4-4.3)*
Zone 3	500 *(32)*	Greater than 60 *(Greater than 18)*	Greater than 14 *(Greater than 4.3)*

Figure 31. Water-yielding capabilities of sandstone in the Menomonie subarea.

yield. However, because of good hydraulic connection between the sandstone and the overlying outwash sand and gravel, downward percolation to the sandstone is sufficient to sustain the yield.

Yields generally greater than 500 gal/min (31.5 l/s) from several wells in the sandstone in Menomonie near the south end of Lake Menomin are sustained because transmissivity is high.

WATER QUALITY

The chemical quality of ground water for irrigation in the study area is excellent. The ground water generally is a calcium bicarbonate water, low in dissolved solids, moderately hard, and containing moderate amounts of iron. Concentrations of boron and sodium are very low.

The chemical quality of ground water depends on the composition, solubility, and surface area of the soil and rock through which the water moves and on the length of time the water is in contact with the rock materials. In the Rice Lake-Eau Claire area, water in the glacial moraines is moderately mineralized, containing calcium, magnesium, and bicarbonate ions derived from the calcareous till. Slow infiltration of water through the fine materials in the till results in long periods of time in which the water can dissolve minerals from the soil and rock. Water in the glacial outwash sand generally is less mineralized because the coarser sands have less surface-area contact with the water, the greater permeability shortens the time of contact, and clean sands generally contain very little soluble material.

The chemical quality of water in the sandstone aquifer in the area is influenced by the character of the material that overlies the sandstone. Water in sandstone overlain by glacial outwash sand in the Red Cedar River and lower Chippewa River valleys is similar to water in the outwash sand; recharge to the sandstone through the glacial outwash is rapid. Water in sandstone overlain by thick drift (till) with only small amounts of sand is more highly mineralized than in sandstone overlain by glacial outwash.

Mineralization of ground water is generally least in the eastern part of the area and increases westward. Concentrations of dissolved solids in the ground water (fig. 32) indicate the areal distribution of mineralization. The concentration of dissolved solids in 79 sampled wells ranged from 35 to 330 mg/l (milligrams per litre). The least (35 mg/l) was in a well tapping sandstone near New Auburn in the northwestern part of Chippewa County; the greatest (330 mg/l) was in a well tapping glacial drift west of Menomonie in Dunn County. However, throughout the area the concentration of dissolved solids did not differ significantly between the two aquifers.

Dissolved-solids concentration greater than 750 mg/l in the soil is a salinity hazard (U.S. Salinity Laboratory staff, 1954). None of the water tested had as much as half this concentration.

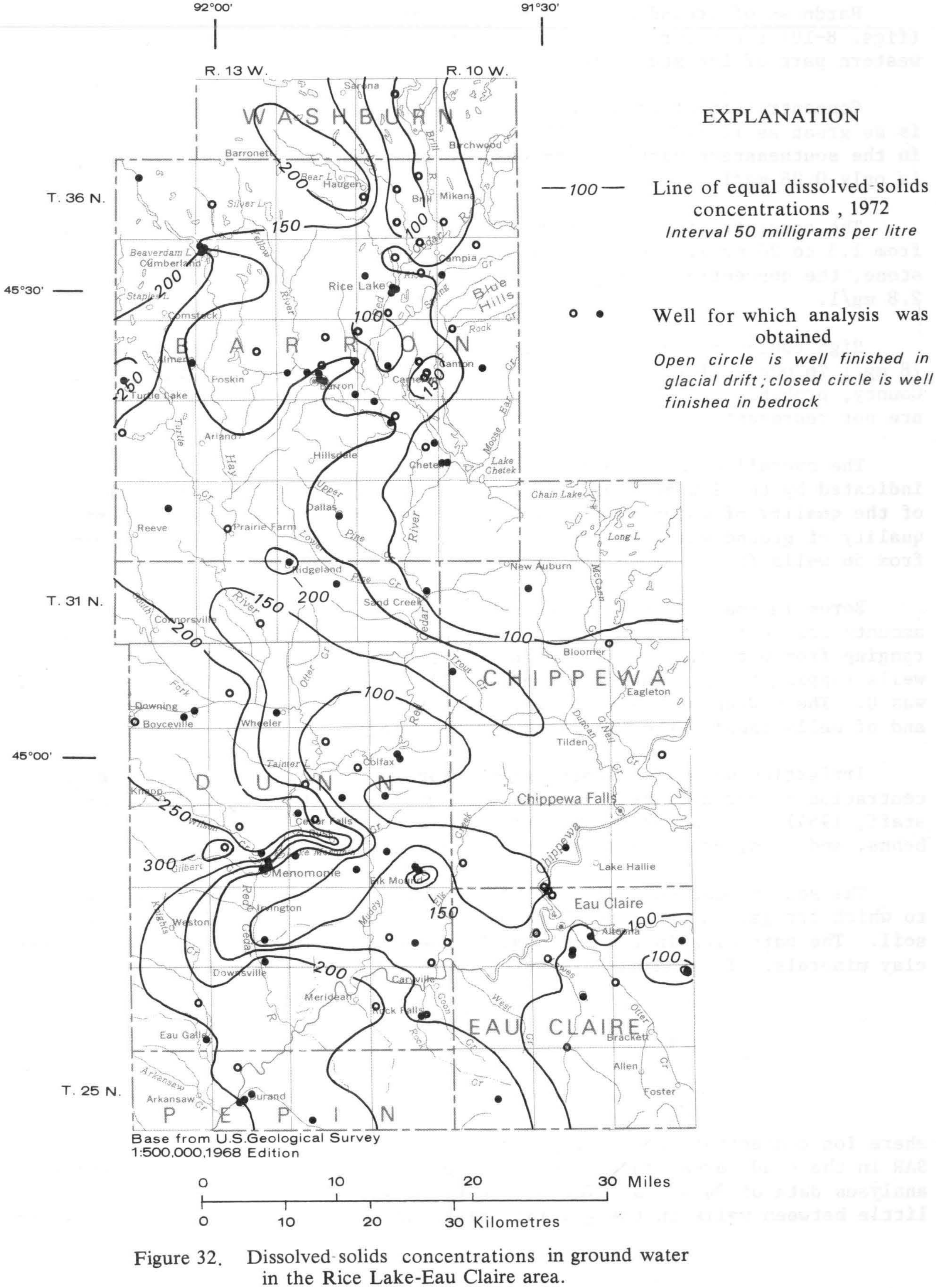


Figure 32. Dissolved-solids concentrations in ground water in the Rice Lake-Eau Claire area.

Hardness of ground water is not a problem. In the irrigable area (figs. 8-10) the water generally is soft to moderately hard. Water in the western part of the study area is hard to very hard.

Concentration of iron, which differs erratically throughout the area, is as great as 12 mg/l in a well tapping the glacial drift near Rock Falls in the southeastern part of Dunn County, although the median in that aquifer is only 0.06 mg/l.

The concentration of sodium in wells tapping the glacial drift ranges from 1.3 to 20 mg/l, with a median of 3.4 mg/l; in wells tapping the sandstone, the concentration ranges from 0.9 to 8.3 mg/l, with a median of 2.8 mg/l.

High concentrations of nitrate in well water (fig. 33), as much as 78 mg/l in one well tapping glacial drift in the southeastern part of Dunn County, probably reflect very local contamination from organic wastes and are not representative of the aquifer water.

The overall excellence of the chemical quality of water in the area is indicated by the low medians of concentrations (fig. 33) and the similarity of the quality of water in the two aquifers. Small variations of chemical quality of ground water in the area are indicated by the analyses of water from 56 wells (table 3) in the area.

Boron in small amounts is essential to plant nutrition, but excessive amounts are toxic to some plants. The concentration of boron is very low, ranging from 0 to 0.54 mg/l. The concentration in samples from 14 of 32 wells tapping the glacial drift and from 11 of 21 wells tapping the sandstone was 0. The median of the other wells tapping the glacial drift was 0.06 mg/l and of wells tapping the sandstone was 0.14 mg/l.

Irrigation water for semitolerant crops is rated excellent if the concentration of boron content is less than 0.67 mg/l (U.S. Salinity Laboratory staff, 1954). The major crops irrigated in the study area, potatoes, peas, beans, and corn, are classified as semitolerant to boron.

The sodium-adsorption-ratio (SAR) predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil. The particles in the soil having the highest exchange capacity are the clay minerals. The sodium-adsorption-ratio of a water is defined as:

$$SAR = \frac{(Na^{+})}{\sqrt{\frac{(Ca^{+2}) + (Mg^{+2})}{2}}}$$

where ion concentrations are expressed in milliequivalents per litre. The SAR in the study area ranged from 0.03 to 0.83, as determined from chemical analyses data of 84 wells. The median value was 0.18. The SAR differed little between wells in the glacial drift and those in sandstone. The median

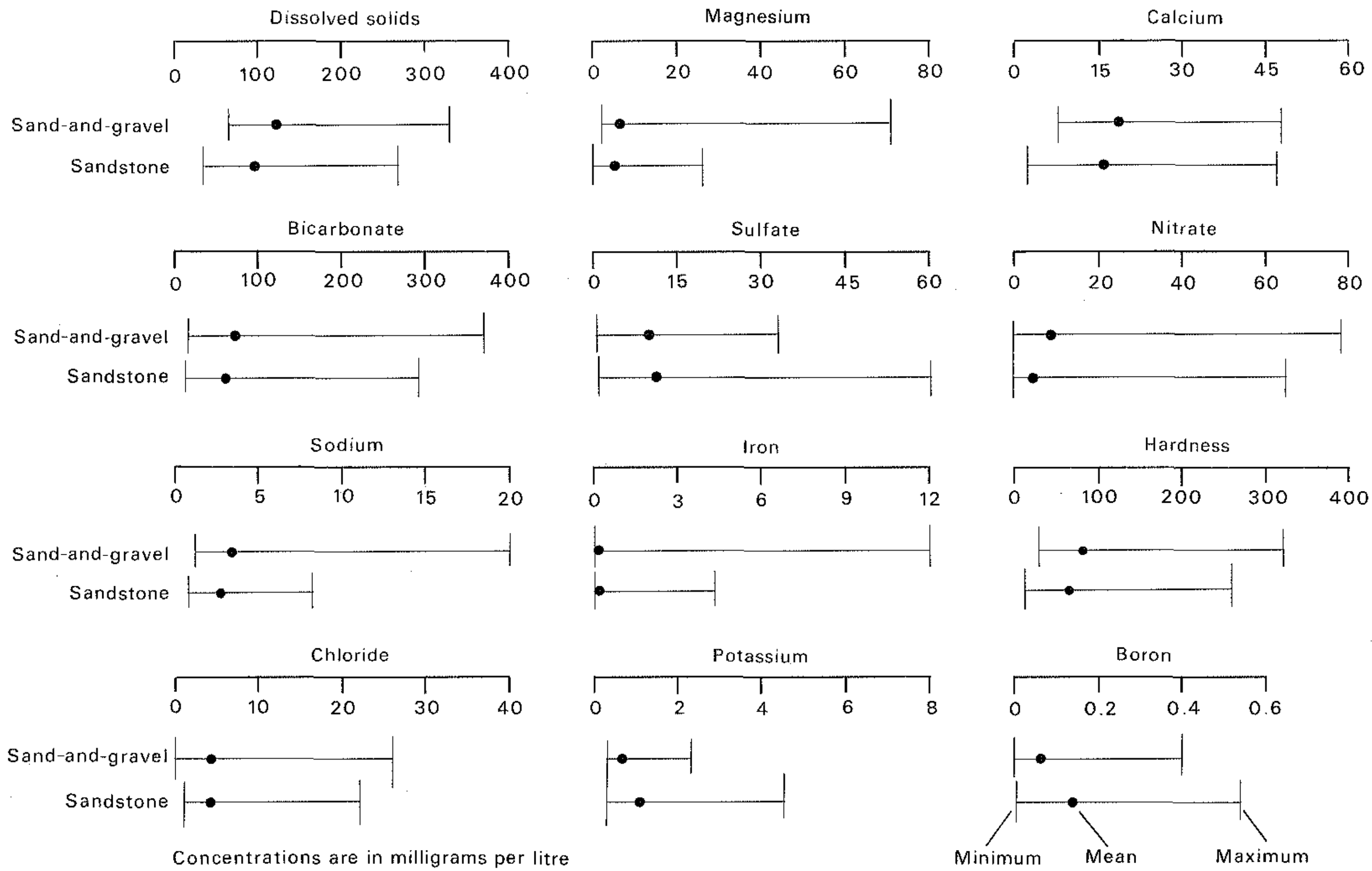


Figure 33. Quality of water by aquifer.

Table 3.--Representative chemical analyses of ground water in 1972--Continued

(Analyses in milligrams per litre except as noted)

Well location[1/]	Well depth (ft)	Aquifer	Date of collection	Iron (Fe) and Manganese (Mn) (µg/l)	Boron (B) (µg/l)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (N)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	pH (s.u.)
Barron County																			
33/11/ 5-132	80	Sandstone	4- 6-72	50	0	20	2.9	3.5	1.1	41	0	6.4	5.0	0.1	6.3	118	62	28	6.6
33/11/ 9- 34	33	Sandstone	5-31-72	40	130	26	7.9	3.1	.5	23	0	7.4	20	.1	15	182	98	78	6.6
33/11/ 9-156	76	Drift	5-31-72	20	0	15	4.8	2.8	.7	36	0	7.8	6.0	.1	5.4	113	57	28	7.0
33/11/24-201	48	Sandstone	5-31-72	60	0	8.2	2.3	3.0	1.1	16	0	8.6	3.5	.2	3.2	67	30	17	6.2
33/11/24-202	59	Drift	5-31-72	20	40	9.3	3.6	2.6	.6	30	0	8.4	.0	.1	3.2	69	38	14	7.0
34/10/22-153	132	Sandstone	5-18-72	350	540	3.1	1.6	2.7	1.7	12	0	3.4	6.0	.0	1.5	50	14	4	6.4
34/11/ 7-210	62	Drift	6- 1-72	60	0	7.7	2.9	3.7	.6	30	0	1.8	4.0	.1	1.6	79	31	6	7.0
34/11/23-211	63	Drift	6- 1-72	0	0	24	7.0	5.0	.4	78	0	11	11	.1	3.6	146	89	25	6.9
34/11/25- 62	80	Drift	6- 1-72	0	110	24	9.0	11	.6	40	0	33	14	.1	8.6	195	97	64	6.6
34/11/25-144	90	Drift	6- 9-72	910	120	24	7.0	4.3	.6	53	0	5.8	16	.0	7.2	164	89	46	6.7
34/12/10-219	84	Drift	6- 1-72	20	0	19	9.4	4.3	.3	104	0	3.2	4.0	.1	1.6	130	86	1	7.4
34/12/22-131	55	Drift	4- 6-72	100	50	14	6.6	4.0	.5	60	0	5.0	5.0	.1	2.7	106	62	13	6.8
34/12/24-113	73	Drift	6- 9-72	30	400	24	7.0	3.9	.7	54	0	15	12	.0	5.2	152	89	45	7.4
34/12/30-222	115	Sandstone	6- 1-72	3,790	110	7.5	3.8	2.8	.4	47	0	.6	4.0	.2	.00	58	34	0	6.5
34/12/36-224	40	Sandstone	5-31-72	260	260	10	3.2	3.5	3.5	39	0	11	6.8	.0	1.7	83	38	6	6.0
35/10/ 3-197	40	Drift	4- 5-72	30	0	12	3.5	3.4	.7	50	0	4.6	2.0	.1	1.0	79	44	4	6.9
35/10/18-151	136	Sandstone	4- 5-72	10	0	16	3.2	3.3	.8	53	0	1.8	4.5	.1	1.9	95	53	10	6.7
35/11/ 2-129	90	Drift	6- 9-72	0	180	24	5.2	4.5	.7	73	0	6.2	10	.0	3.4	136	82	22	7.0
35/11/ 9-231	57	Drift	6-13-72	370	280	19	5.2	3.0	.5	77	0	4.6	6.5	.0	.04	88	69	6	7.4
35/11/14-199	86	Drift	4- 5-72	40	20	15	6.2	3.6	.9	72	0	3.8	2.0	.1	.84	99	63	4	6.8
35/11/18-232	245	Sandstone	6- 1-72	20	0	18	7.7	3.9	.3	99	0	2.6	3.9	.1	.38	116	76	0	7.0
35/11/33-236	96	Drift	6- 1-72	160	70	19	7.7	4.5	.4	67	0	6.4	17	.1	3.2	131	79	24	6.6
36/10/30-194	38	Drift	4- 5-72	370	70	20	6.6	3.6	.9	84	0	5.4	4.5	.1	1.9	116	77	8	6.9
36/11/11-196	43	Drift	4- 5-72	50	40	20	5.4	3.6	1.3	76	0	6.2	4.0	.1	2.2	116	72	10	6.9
36/11/15-195	50	Drift	4- 5-72	60	60	16	2.3	3.6	1.1	48	0	6.4	4.0	.0	2.7	91	50	10	6.5
36/11/19-193	76	Drift	4- 5-72	60	60	44	11	4.2	1.1	164	0	10	8.0	.1	2.1	210	160	20	7.3
36/11/27-198	57	Drift	4- 5-72	30	0	17	3.9	3.4	1.1	55	0	8.0	3.5	.1	1.8	93	58	14	6.9
Chippewa County																			
28/ 9/21-167	93	Sandstone	6-10-72	20	---	18	6.9	3.8	1.1	42	0	18	8.9	.1	5.4	124	74	39	6.7
28/10/29-166	53	Drift	6-10-72	110	---	11	3.4	3.2	.5	41	0	13	1.0	.2	1.1	80	42	8	7.2
29/ 8/15-165	120	Drift	6- 9-72	0	0	20	8.4	4.5	1.6	99	0	6.6	4.0	.2	1.1	115	84	4	7.8
30/ 8/ 6-162	98	Drift	6- 9-72	50	0	16	7.3	3.2	.3	83	0	1.6	5.5	.2	1.5	106	70	2	7.3
30/10/18-163	87	Sandstone	6- 9-72	40	0	26	8.6	4.7	1.4	43	0	19	20	.3	9.5	189	100	66	6.3
31/ 9/18-164	100	Sandstone	6- 9-72	10	0	2.2	1.6	1.6	.8	15	0	.6	5.0	.2	.50	35	12	0	6.1
Dunn County																			
26/11/18-160	39	Drift	5-23-72	90	0	28	8.2	6.1	2.1	38	0	14	7.0	.2	18	216	100	72	6.7
27/11/20-127	89	Drift	5-25-72	30	0	17	5.8	2.5	1.2	27	0	11	10	.1	7.4	141	66	44	6.7
27/11/27-155	326	Sandstone	8-21-72	-----	---	13	4.5	2.7	.5	45	0	10	4.0	.1	1.8	96	51	14	7.4
27/13/23-161	124	Sandstone	5-24-72	130	0	14	4.3	2.0	.7	44	0	16	2.0	.2	1.0	88	52	16	6.6
27/13/35- 90	340	Sandstone	4- 6-72	2,890	0	47	18	8.3	1.6	216	0	17	12	.3	.00	220	190	14	7.5
28/11/20-114	250	Sandstone	5-26-72	280	0	15	5.2	1.3	1.0	59	0	13	1.0	.6	.00	83	59	10	6.8
28/12/ 6-165	105	Sandstone	6- 1-72	1,040	70	44	15	4.1	1.4	150	0	41	10	.0	.27	212	170	48	7.1
28/12/ 9-164	102	Drift	6- 1-72	310	0	45	14	2.6	.9	174	0	21	6.0	.0	.04	183	170	27	7.7
28/12/15-118	42	Drift	5-26-72	810	0	29	9.5	20	2.3	42	0	19	26	.1	17	272	110	77	7.2
28/12/25-163	100	Sandstone	5-25-72	50	0	13	.0	2.7	1.4	17	0	16	4.0	.4	.88	65	32	18	6.4
28/13/20-162	91	Drift	5-24-72	710	0	13	71	2.6	1.4	370	0	24	4.5	.2	.00	330	320	22	7.7
29/11/32- 43	86	Sandstone	6-10-72	40	40	19	2.3	2.8	4.5	19	0	17	10	.0	7.0	110	57	42	7.0
29/12/ 9-126	87	Drift	6- 8-72	30	260	15	3.8	1.6	1.0	46	0	8.6	3.0	.0	1.7	68	53	16	6.8
29/12/24-166	167	Drift	6- 2-72	4,580	30	20	5.5	2.5	.3	86	0	.4	2.0	.0	.92	97	72	2	6.6
29/12/29-121	145	Drift	8- 7-72	490	30	27	11	2.4	1.5	114	0	7.4	9.0	.1	2.9	130	110	19	7.6
29/12/35- 41	91	---------	6- 1-72	50	40	20	8.1	1.3	.6	71	0	8.2	4.0	.0	2.9	92	84	26	6.9
30/13/20-128	93	Drift	6- 8-72	500	10	48	26	1.8	.4	256	0	10	5.0	.2	1.2	233	230	17	7.9
31/12/11-168	106	Sandstone	6- 8-72	0	150	40	21	.9	.6	200	0	18	4.2	.2	.52	187	190	22	7.5
31/13/26-167	54	Drift	6- 8-72	80	90	18	9.7	1.3	.6	61	0	21	9.0	.1	2.1	121	85	35	7.0
Eau Claire County																			
26/ 8/ 7-146	89	Drift	6-10-72	20	---	13	5.6	1.8	.7	68	0	4.2	.0	.3	.41	78	56	0	7.1
26/ 9/15-143	143	Sandstone	5-25-72	1,980	0	16	5.6	2.0	1.4	75	0	6.4	1.5	.5	.07	83	63	2	6.8
26/ 9/33- 90	46	Drift	6- 2-72	7,130	0	8.3	3.2	2.5	.5	18	0	19	3.0	.0	.04	58	34	18	6.8
27/ 8/25-144	50	Sandstone	5-31-72	1,530	150	8.5	3.8	2.1	1.5	14	0	17	8.2	.0	.54	57	36	25	5.8
Pepin County																			
25/12/32- 40	160	Sandstone	5-23-72	480	200	44	26	1.1	1.1	242	0	17	2.0	.2	.07	217	220	18	7.9

[1/] Wells in this report are designated according to a two-part identification number. The first part is their location by township, range, and section, respectively. The second part is the well's serial number within the county.

SAR for sand and gravel wells was 0.19; for sandstone wells, 0.17. According to a diagram used for evaluating irrigation water, published by the U.S. Salinity Laboratory in 1954, none of the irrigation water in the study area is likely to cause salinity problems.

Analyses of several water samples from the glacial drift aquifer in Barron and Dunn Counties indicated no pesticides.

WATER USE

Most water used in the area is ground water except for hydroelectric-power generation. All municipal supplies are ground water. The cities of Eau Claire and Chippewa Falls withdraw water from glacial outwash; all other municipalities in the area withdraw water from sandstone. Nearly all industry in the area is supplied by municipalities. The greatest withdrawals of ground water are in the population centers of Eau Claire, Chippewa Falls, Menomonie, and Rice Lake. Small withdrawals for domestic and rural supplies, mainly from wells in glacial drift, are distributed throughout the area. A summary of water use in the area during 1972 is shown in table 4.

Water used for irrigation during 1972 totaled 149 million gallons (560 million litres) and was less than 1½ percent of the total withdrawal of ground water. Irrigation water is pumped chiefly in the glacial outwash plains of the valleys of Red Cedar River and several of its tributaries in the three subareas. Most water for irrigation near Rice Lake and Cameron is withdrawn from outwash sand and gravel. Near Menomonie and in the southeastern part of Dunn County water is withdrawn from both of the major aquifers.

The withdrawal of 149 million gallons (560 million litres) of water for irrigation during 1972 is equivalent to 450 acre-ft (555,000 m^3). Because precipitation during the 1972 growing season was more than average, less water for irrigation was pumped than in most other years.

A A high-capacity well (yield of 100,000 gal/d {378,500 l/d} or more) requires a permit from the Wisconsin Department of Natural Resources. The permit may be denied if the withdrawal of water would adversely affect the source of a public water supply. Present (1975) withdrawals for irrigation do not affect public supplies.

Yields from one or both aquifers are adequate for irrigation throughout the land where soils are suitable for irrigation in the Menomonie subarea. Water for irrigation is available in large supply from glacial outwash deposits in the Menomonie subarea, although less than in the two Barron County subareas. Water supplies from the glacial outwash in much of the central part of the bedrock valley in the subarea will remain adequate for irrigation under present conditions for many years. In the Red Cedar River valley south of Menomonie and along the bedrock valley walls, the glacial outwash yields moderate supplies but will not sustain large withdrawals for long periods. Adequate yields, however, are available from the underlying sandstone. Most wells open to the sandstone draw water indirectly from the overlying glacial outwash, which is hydraulically connected with the sandstone.

Table 4.--Use of water in 1972[1]

(Million gallons)

Use	Source and type of supply				Total
	Ground water		Surface water		
	Public	Private	Public	Private	
Withdrawal					
Irrigation	Negligible	146	0	3	149
Municipal	7,871	0	0	0	7,871
Domestic	0	1,102	0	0	1,102
Industrial	0	1,268	0	0	1,268
Livestock	0	620	0	2,410	3,030
Subtotal	7,871	3,136	0	2,413	13,420

[1]Excludes hydroelectric-power generation.

Several logs of wells in the valley extending from Cameron to Chippewa Falls indicate that the hydrogeology is similar to that near Cameron and Chippewa Falls. Large amounts of water probably are available for irrigation from the glacial drift in that valley.

SUMMARY

An abundance of ground water of excellent chemical quality is available for irrigation in the Rice Lake-Eau Claire area.

Yields in excess of 1,000 gal/min (63 l/s) are available from glacial sand and gravel in outwash plains in the Red Cedar River valley. This includes (1) most of the land suitable for irrigation in Barron County, and (2) parts of the land suitable for irrigation north of Menomonie and in the southwestern part of Dunn County. Similar yields also are available in much of the Chippewa River valley near the cities of Chippewa Falls and Eau Claire.

Yields sufficient for irrigation, some in excess of 1,000 gal/min (63 l/s), are available also from sandstone underlying glacial deposits in the rock valleys. Because the two aquifers generally are connected hydraulically, wells penetrating the sandstone also withdraw water indirectly from the glacial drift as recharge.

Ground water in the area is a calcium bicarbonate water, generally low in dissolved solids, and is of excellent chemical quality for irrigating crops. The concentration of boron in the water is less than the rated tolerance for most sensitive crops.

Ground-water levels during the wet year of 1972 were higher than average, and no significant lowering of the water table caused by pumping for irrigation was noticeable. High transmissivities, especially in the glacial sands filling the rock valleys of Barron County, indicate that pumping for irrigation can be increased greatly and have no widespread effect on the water table.

Because the water quality does not limit irrigation and ground-water quantities are available nearly everywhere, the principal limiting factor to irrigation is adequate acreage of suitable soils. Economic factors are not considered in this report.

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