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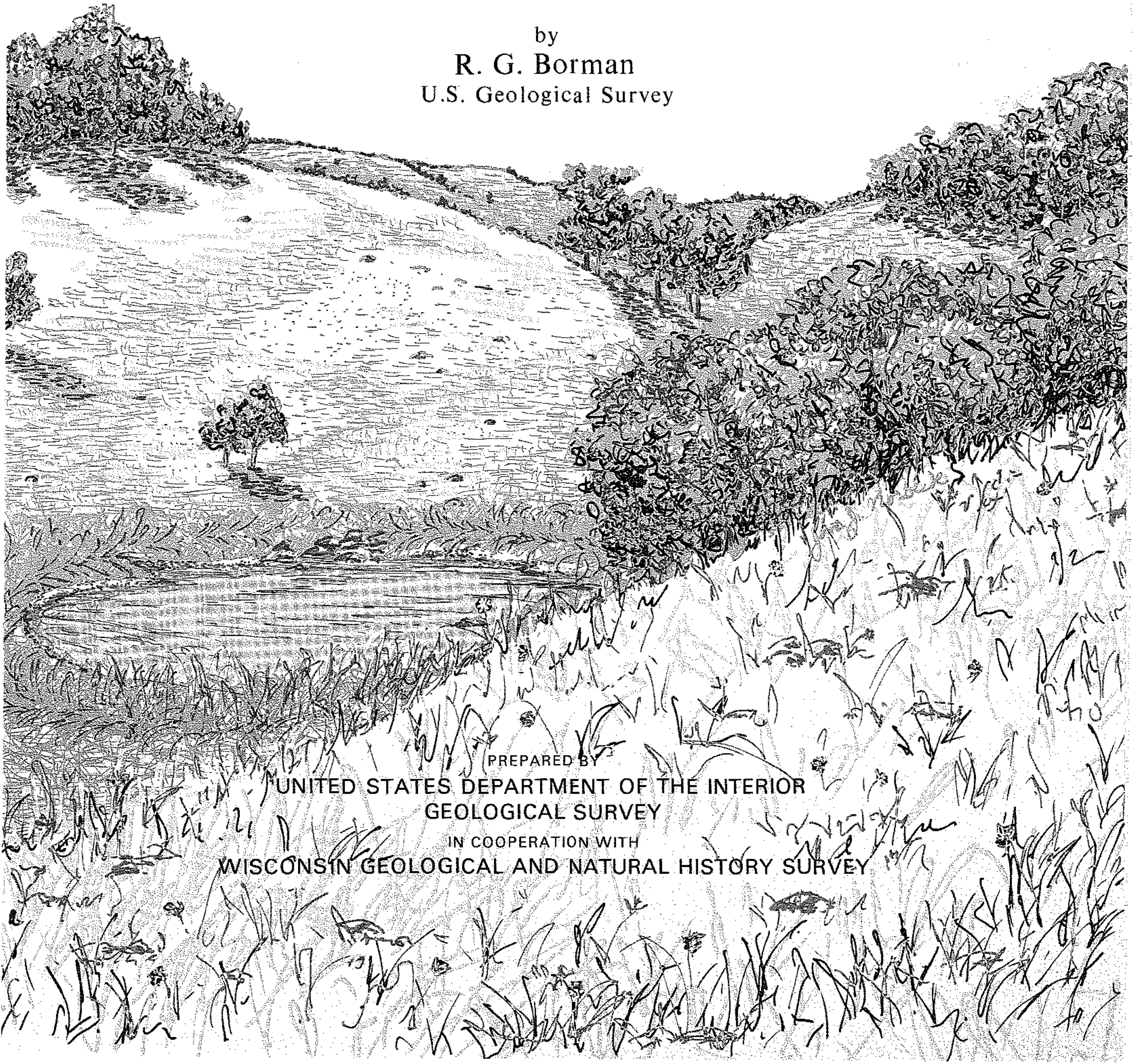
Ground-Water Resources and Geology of Walworth County, Wisconsin

by
R. G. Borman
U.S. Geological Survey



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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
November 1976

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CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

Multiply English units	By	To obtain SI units
acres	0.004047	square kilometers (km^2)
inches (in)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square miles (mi^2)	2.590	square kilometers (km^2)
gallons per minute (gal/min)	.06309	liters per second (l/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
feet per day (ft/d)	.3048	meters per day (m/d)
cubic feet per second per square mile {(ft^3/s)/mi^2}	.01093	cubic meters per second per square kilometer {(m^3/s)/km^2}
cubic feet per second (ft^3/s)	28.32	liters per second (l/s)

Ground-Water Resources and Geology of Walworth County, Wisconsin

R. G. Borman

ABSTRACT

Population growth in Walworth County, Wisconsin, requires an increasing amount of ground water. Good quality water is available from the sand-and-gravel, Niagara, Galena-Platteville, and sandstone aquifers in the county. As much as 15 gallons per minute (0.95 liters per second) can be obtained from individual wells almost everywhere in the county. Well yields of 1,000 gallons per minute (63 liters per second) are available from glacial drift where it contains sufficient thickness of saturated sand and gravel. The sand-and-gravel aquifer is an important source of municipal water. Estimated well yields from most of the Niagara aquifer, a Silurian age dolomite as thick as 125 feet (38.1 meters), exceed 100 gallons per minute (6.3 liters per second). The Niagara aquifer occurs in the eastern third of the county. The Galena-Platteville aquifer, chiefly dolomite, is present in the western half of the county where it is as thick as 325 feet (99.1 meters). Estimated yields from this aquifer exceed 500 gallons per minute (32 liters per second). The sandstone aquifer underlies the entire county and ranges from less than 800 feet (240 meters) thick in the northwest corner to more than 2,200 feet (670 meters) in the east. This aquifer is capable of yielding 1,000 gallons per minute (63 liters per second) to individual wells and is a principal source of municipal water.

The chemical quality of water from the four aquifers is similar, and is all hard, having a median hardness between 300 and 350 milligrams per liter. Median values for dissolved solids range between 300 and 350 milligrams per liter. Iron and manganese commonly are present in bothersome amounts (combined total exceeding 0.3 milligrams per liter).

About 6.6 million gallons per day (0.29 cubic meters per second) of ground water was pumped in the county in 1971, 53 percent from the sand-and-gravel aquifer, 41 percent from the sandstone aquifer, and 6 percent from the Niagara and Galena-Platteville aquifers. About 40 percent of the water pumped was for residential use and about 38 percent was for industrial and commercial purposes.

INTRODUCTION

Walworth County is located in southeastern Wisconsin (fig. 1) adjacent to the Illinois-Wisconsin State line. Elkhorn, the county seat, is approximately in the center of the county and is about 40 mi (64 km) southwest of Milwaukee and 50 mi (80 km) southeast of Madison.

According to the U.S. Bureau of Census, the population of Walworth County in 1970 was 63,444, of which 24,537 lived in urbanized areas (incorporated cities or villages with 2,500 or more inhabitants). The total area of Walworth County is 557 mi^2 (1,440 km^2), of which 20 mi^2 (52 km^2) are lakes. The county has 28 lakes covering 35 acres (0.14 km^2) or more (Wisconsin Department of Natural Resources, no date).

Walworth County is experiencing rapid population growth, amounting to about 21 percent between 1960 and 1970. Increasing population puts greater stress on the water resources.

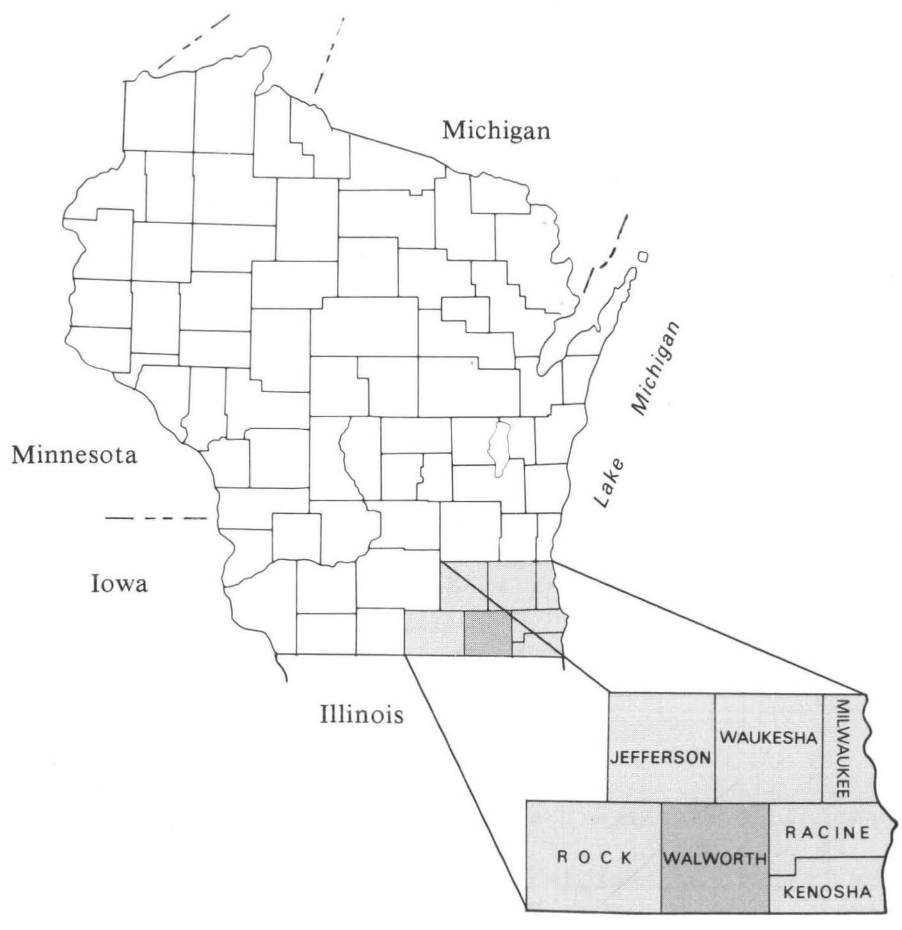


Figure 1. Location of Walworth County in Wisconsin.

The purpose of this report is to discuss the occurrence, movement, quality, and availability of water in the unconsolidated deposits and underlying bedrock and is intended as an information base for water planners and users in the future development of the water resources.

The scope of the project included collection and analyses of ground-water samples and well-log, water-level, water-use, pumpage, aquifer-test, and streamflow data. The geology was studied only in enough detail to determine the ground-water hydrology.

This study was a cooperative project between the U.S. Geological Survey and the University of Wisconsin-Extension, Geological and Natural History Survey. Many municipal and county officials, State agencies, drillers, and individual well owners provided well and water information. Many persons allowed access to their wells for water-level measurements or for collecting water samples for chemical analysis. Special acknowledgment is made to the Wisconsin Department of Natural Resources for supplying well records, to the Wisconsin State Laboratory of Hygiene for chemical analysis of water samples, and to the Wisconsin Public Service Commission for pumpage records.

GEOLOGY

The materials that control the movement and storage of ground water in Walworth County range from the basement rocks of Precambrian age to the unconsolidated glacial deposits, alluvium, and soils of Pleistocene and Holocene ages. Bedrock is overlain by glacial drift throughout the county.

BEDROCK GEOLOGY

The bedrock, from oldest to youngest, includes Precambrian crystalline rocks; Cambrian sandstone; Ordovician dolomite, sandstone, and shale; and Silurian dolomite (table 1). Many of these rocks underlie only parts of the county. All of these rock units dip toward the east.

PRECAMBRIAN ROCKS

Crystalline rocks of Precambrian age underlie the entire county. The Precambrian rock surface slopes to the east throughout the county and ranges from about 900 ft (270 m) below land surface (100 ft or 30 m below sea level) at Whitewater to more than 2,400 ft (730 m) below land surface (1,600 ft or 490 m below sea level) along the east county line. The Precambrian rocks have low permeability and mark the lower limit of ground-water movement.

CAMBRIAN ROCKS

Cambrian sandstone overlies the Precambrian rocks and is present under the entire county. It consists of five units. They are, from bottom to top, the Mount Simon, Eau Claire, Galesville, and Franconia Sandstones, and the Trempealeau Formation. In this report Cambrian sandstone is not differentiated. The sandstone thickens to the east, ranging from about 540 ft (160 m) at Whitewater to about 1,700 ft (520 m) along the eastern county line. The ability of Cambrian sandstone to store and yield water and its great thickness make it an important source of water.

ORDOVICIAN ROCKS

Ordovician sedimentary rocks present in Walworth County include the Prairie du Chien Group (mostly dolomite), St. Peter Sandstone, the Platteville and Decorah Formations and Galena Dolomite, undifferentiated (mostly dolomite and herein called the Galena-Platteville unit), and Maquoketa Shale. The St. Peter Sandstone and the Galena-Platteville unit are present throughout the county, the Prairie du Chien Group is discontinuous. The Maquoketa Shale is present in the eastern half of the county, having been removed by erosion in the western half (fig. 2).

All of these rocks dip eastward. For example, the upper surface of the St. Peter Sandstone dips to the east and ranges in altitude from more than 650 ft (200 m) along the northern one-fourth of the western county line to less than 150 ft (46 m) along the southern one-third of the eastern county line. The base of the Maquoketa Shale also dips to the east and ranges in altitude from about 700 ft (210 m) at its westernmost extent near Elkhorn and Walworth to less than 400 ft (120 m) in the southeast corner of the county.

The Galena-Platteville unit and the St. Peter Sandstone are the most important water-yielding Ordovician rocks. The Prairie du Chien Group yields some water to wells, but is never the primary water-yielding unit tapped by wells. The Maquoketa Shale yields little water and is a barrier to vertical ground-water movement.

SILURIAN ROCKS

Silurian dolomite is the youngest rock unit in Walworth County and is found in the eastern third of the county (fig. 2). This dolomite is an important aquifer for domestic supplies. The base of the Silurian rocks dips to the east and forms an eastward-plunging syncline in the southeastern part of the county.

BEDROCK SURFACE

The bedrock geology map (fig. 2) shows the type of rock that would be exposed if the unconsolidated material above it were stripped away. The uppermost bedrock unit throughout most of the county is dolomite: Silurian dolomite in the east, and Ordovician dolomite in the west. These are separated by the Maquoketa Shale.

Bedrock topography (fig. 3) was shaped by preglacial and glacial erosion of the exposed bedrock. The most striking features are the bedrock valleys in much of the county. These valleys were formed by removal of the easily erodable Maquoketa Shale. (Compare figs. 2 and 3.) The bedrock surface ranges from an altitude of 850 ft (260 m) east of Elkhorn and along the western county line to less than 500 ft (150 m).

QUATERNARY GEOLOGY

The unconsolidated deposits overlying bedrock in Walworth County are largely glacial sediments of Quaternary age, but they also include some surficial marsh deposits and alluvium of Holocene age. The glacial sediments include end moraine, ground moraine, outwash, and lake-basin deposits (fig. 4).

Table 1.--Stratigraphy of Walworth County

System	Rock unit	Lithology
QUATERNARY	Holocene deposits	Unconsolidated clay, silt, sand, gravel, and organic matter.
	Pleistocene deposits	Unconsolidated clay, silt, sand, gravel, cobbles, boulders, and organic matter.
SILURIAN	Undifferentiated dolomite	Dolomite, white to gray. Crevices and solution channels abundant but discontinuous.
ORDOVICIAN	Maquoketa Shale	Shale, dolomitic, blue-gray; contains dolomitic beds as thick 40 feet.
	Galena Dolomite, Decorah Formation, and Platteville Formation, undifferentiated	Dolomite and some slightly shaly dolomite, light-gray to blue-gray.
	St. Peter Sandstone	Sandstone, fine- to medium-grained, white to light-gray; dolomitic in some places, shaly at base in some places.
	Prairie du Chien Group	Dolomite, gray or white; some sandstone and sandy dolomite.

CAMBRIAN	Trempealeau Formation	Sandstone, very fine- to medium-grained; dolomite, light-gray, interbedded with siltstone.
	Franconia Sandstone	Sandstone, very fine- to medium-grained; siltstone or dolomite; sandstone, dolomitic at base, medium- to coarse-grained.
	Galesville Sandstone	Sandstone, fine- to medium-grained, light-gray.
	Eau Claire Sandstone	Sandstone, fine- to medium-grained, light-gray to light-pink, dolomitic; some shale beds.
	Mount Simon Sandstone	Sandstone, white to light-gray; fine- to coarse-grained, mostly medium; some beds dolomitic, some interbedded shale.
PRECAMBRIAN	Precambrian rocks, undifferentiated	Crystalline rocks.

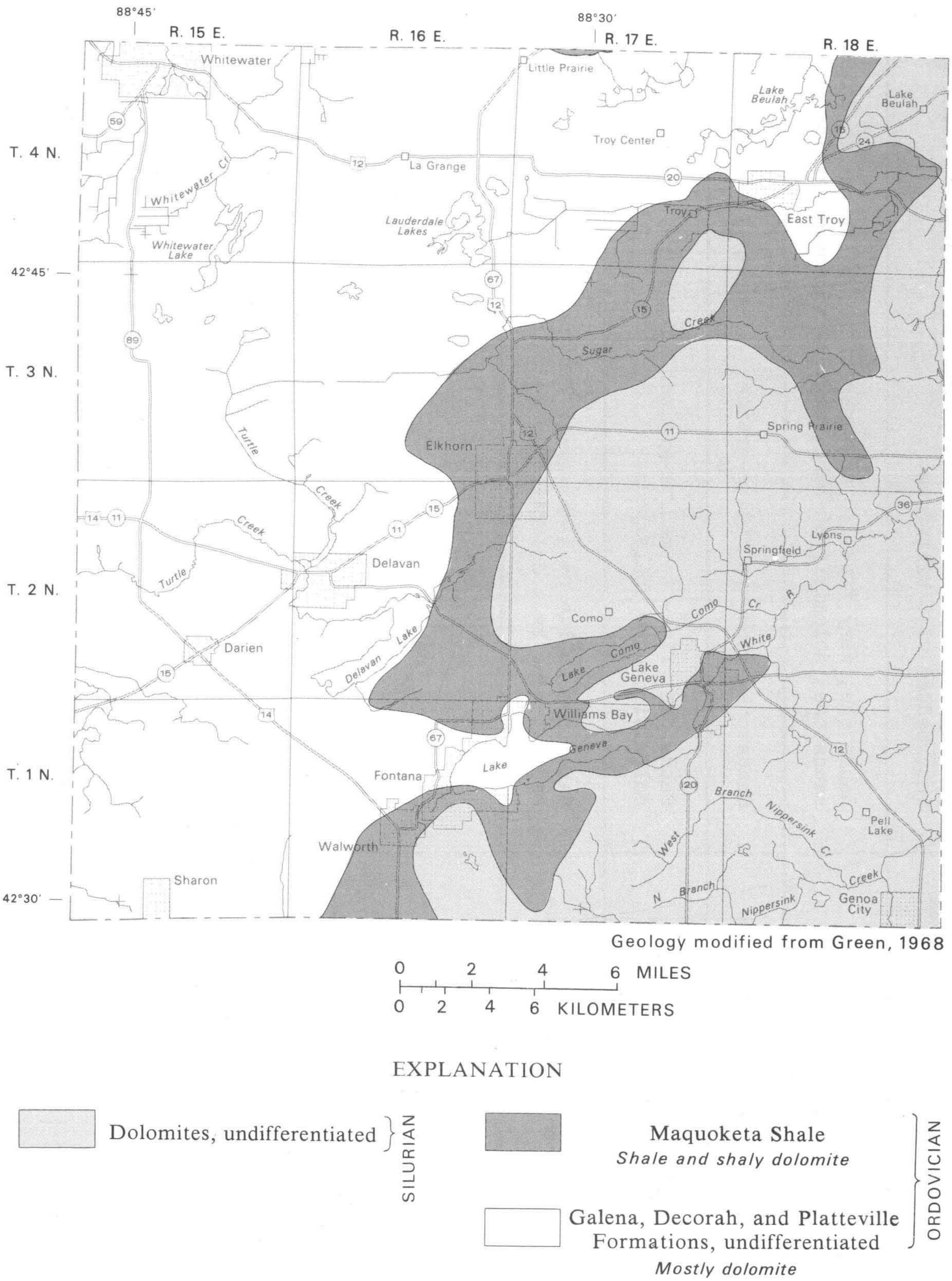
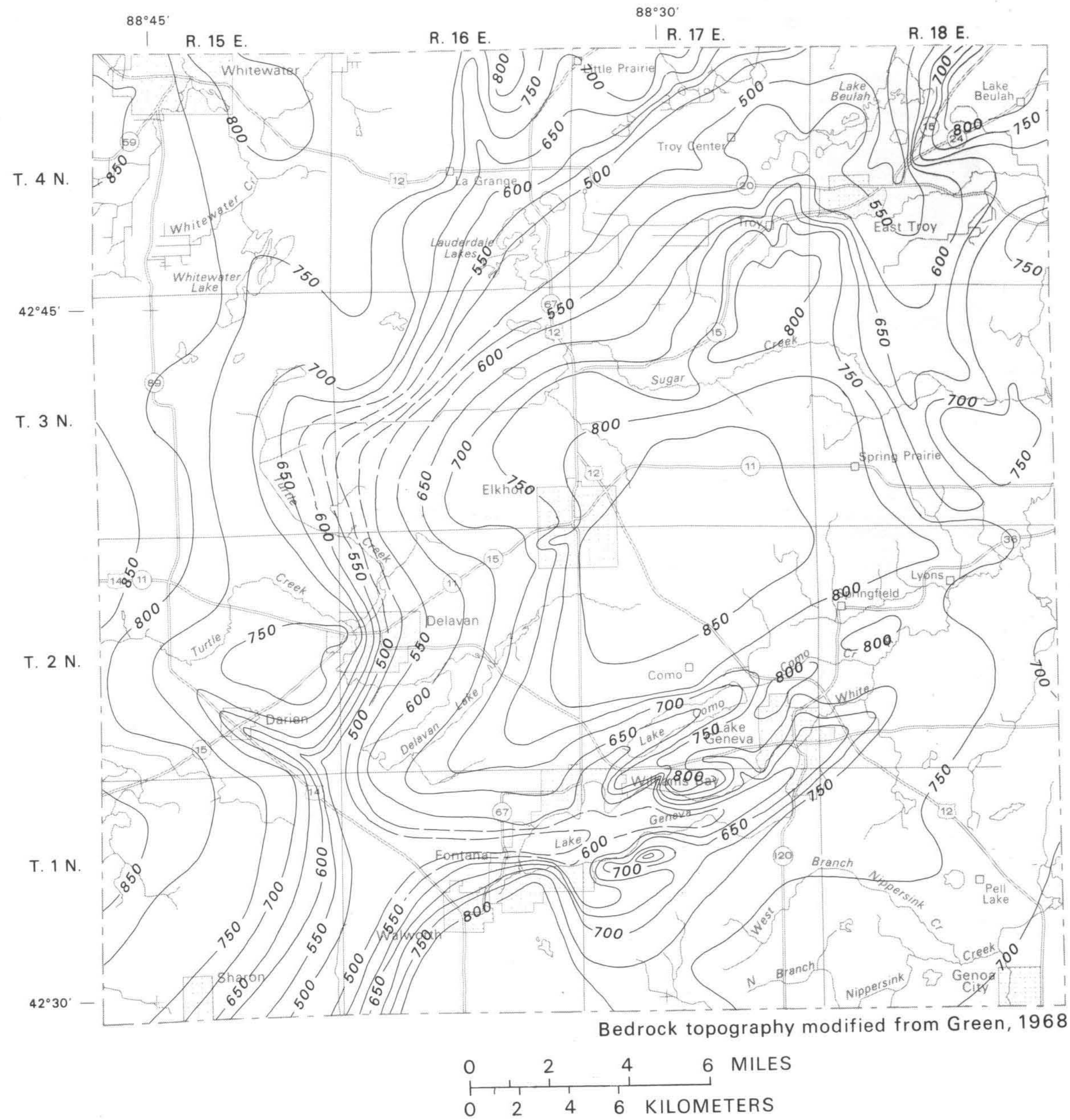


Figure 2. Bedrock geology.



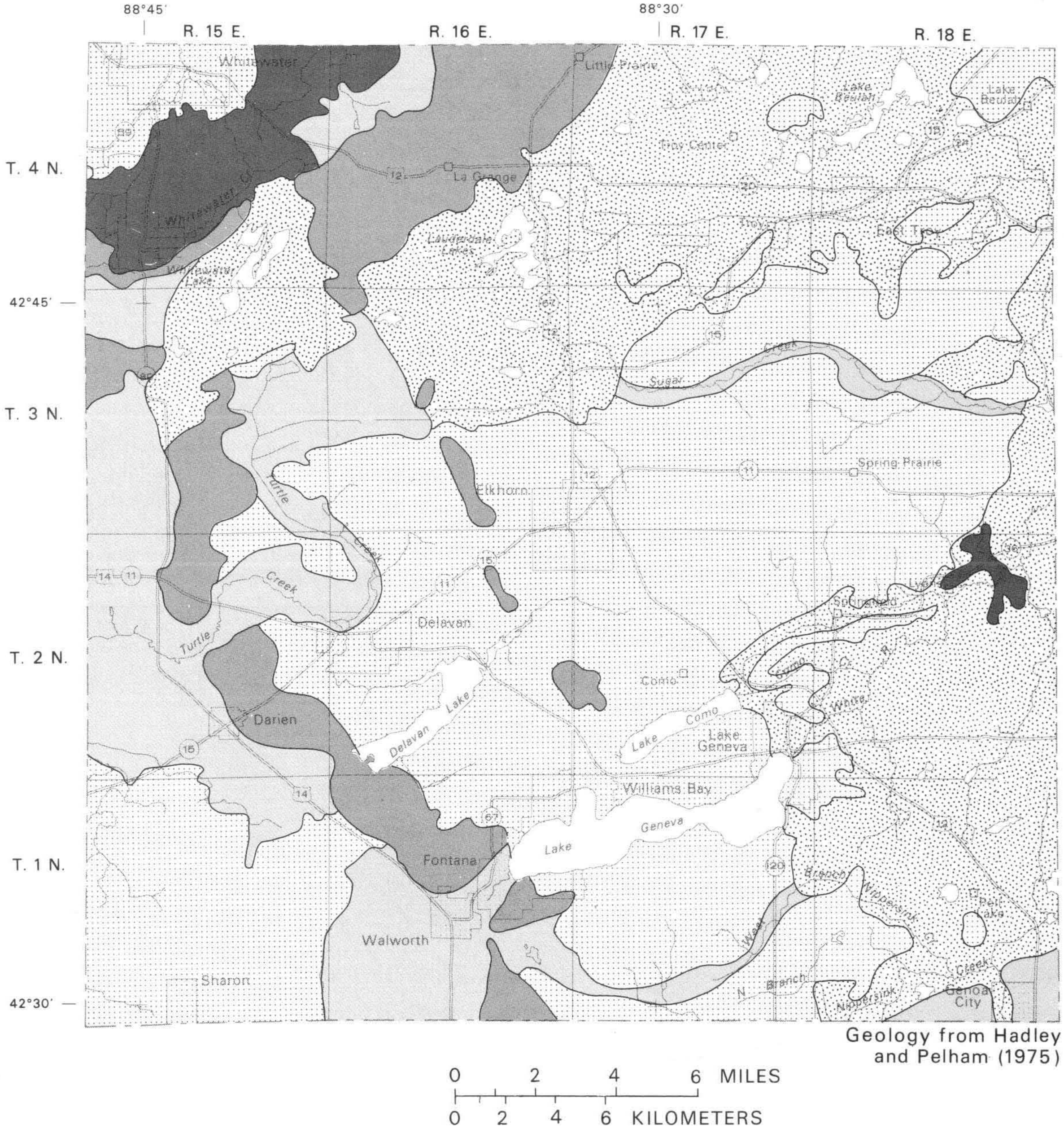
EXPLANATION

——— 750 — — — —

Bedrock contour

Shows altitude of bedrock surface. Dashed where approximately located. Contour interval 50 feet (15 meters) Datum is mean sea level.

Figure 3. Bedrock topography



EXPLANATION

End moraine

Ground moraine

Outwash

Pitted outwash and other ice-contact deposits

Lake-basin deposits

Figure 4. Glacial geology.

End moraines are formed by deposition at the margin of a glacier at a time when melting equals its rate of advance. They consist of unsorted debris ranging in size from clay to boulders. End moraine topograpny typically consists of a ridge with a rolling to hummocky surface, often with internal drainage. In plan view the ridge is typically a gentle arc.

The end moraines in Walworth County were formed mainly by the Green Bay glacier and Delavan lobe of the Lake Michigan glacier during Wisconsin Glaciation. In Walworth County the end moraine from the Green Bay glacier is in the northwest corner of the county, from the vicinity of Whitewater to Little Prairie. End moraines from the Delavan lobe lie in a series of arcs from Little Prairie on the northern county line to Darien and Fontana. The Kettle Moraine is an interlobate moraine formed between the Green Bay glacier and the Delavan lobe and in Walworth County extends from directly south of Whitewater northeast to the Walworth-Jefferson County line. Remnants of an older end moraine are found in south-central Walworth County southeast of the village of Walworth.

Ground moraine is deposited beneath glacial ice during its advance or retreat. It is deposited as a blanket of unsorted rock debris of irregular thickness, ranging in size from clay to boulders, and may be buried by later glacial deposits. In Walworth County ground moraine from the Green Bay glacier is northwest of the Green Bay end moraine, and ground moraine from the Lake Michigan glacier is north and east of the Delavan lobe end moraine. Older ground moraine of the Illinois glaciers is in the southwest corner of the county. Ground moraine usually has moderate relief and forms a gently undulating plain with no definite alinement to the undulation. In some areas, however, elongate hills of ground moraine, called drumlins, are alined along the direction of ice movement.

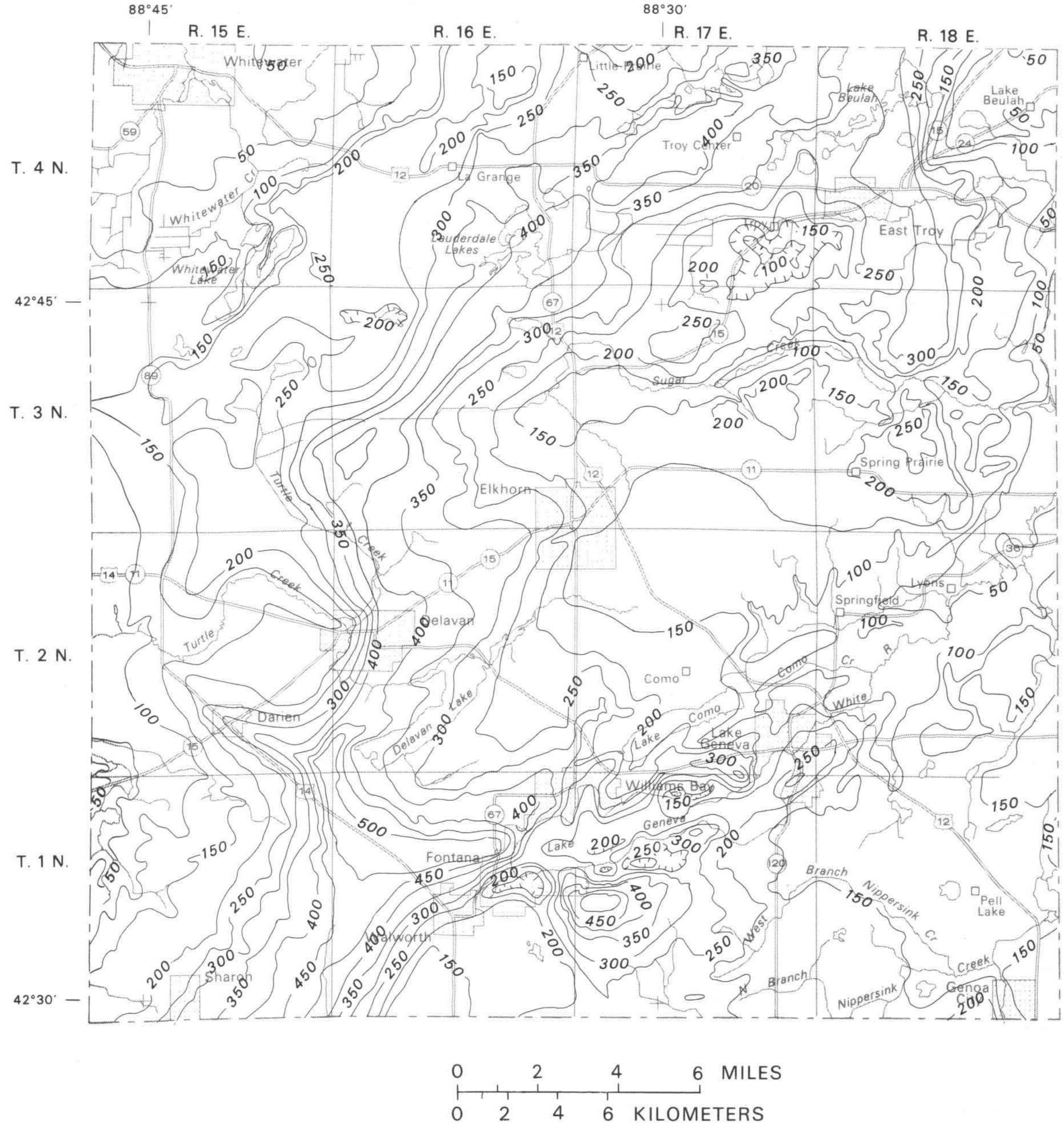
An outwash plain is a stratified deposit, consisting of gravel, sand, silt, and clay, laid down by water from melting ice fronts. In Walworth County outwash plains of sand and gravel, in places covered by a layer of clay, were deposited in front of the Green Bay and Delavan lobe ice fronts. Buried outwash deposits from earlier glaciation are apparent from drill-hole logs, but they cannot be mapped accurately.

Lake-basin deposits are composed of materials derived from glaciers and laid down in fresh-water lakes. In Walworth County, lake-basin deposits are in the northwest near Whitewater and in the east-central part of the county.

Alluvium is a deposit of unconsolidated materials laid down by running water. In Walworth County minor amounts of alluvium ranging in size from clay to gravel are found along streams.

Marsh deposits were formed by decaying vegetation. They are generally thin and are found in low-lying areas of the county.

The combined thickness of unconsolidated glacial deposits, alluvium, and marsh deposits ranges from less than 50 ft (15 m) in places along the west and east borders of the county to more than 500 ft (150 m) north of the village of Walworth and south of Lake Geneva (fig. 5). Thicknesses are greatest where glacial materials fill the bedrock valleys and in areas of topographic highs formed by end moraines.



EXPLANATION

250 — Line of equal thickness of unconsolidated materials
Interval 50 feet (15 meters)

Figure 5. Thickness of unconsolidated materials.

GROUND-WATER HYDROLOGY

PRINCIPAL AQUIFERS

All Walworth County depends on ground water for potable water supplies. The principal sources of these supplies are, in general order of depth below land surface, the sand-and-gravel aquifer, the Niagara aquifer, the Galena-Platteville aquifer, and the sandstone aquifer.

The sand-and-gravel aquifer consists of unconsolidated sand and gravel deposits in glacial drift and alluvium. These deposits occur over much of the county, either at land surface or buried beneath less permeable drift.

The Niagara aquifer in Walworth County consists of dolomite of Silurian age, which overlies the Maquoketa Shale over the eastern third of the county.

The Galena-Platteville aquifer is the Galena-Platteville unit of Ordovician age in the western half of the county, where it is not overlain by Maquoketa Shale. In this area, where the Galena-Platteville unit is the uppermost bedrock, it is fractured and contains solution channels. Because many domestic wells are finished in it, the Galena-Platteville aquifer warrants discussion as a separate aquifer.

The sandstone aquifer includes all sedimentary bedrock below the Maquoketa Shale, where the shale is present, and below the Galena-Platteville unit, where the shale is absent. The bottom of the sandstone aquifer is the surface of the impermeable Precambrian rocks. The aquifer is continuous over the county and includes, in ascending order from oldest to youngest, sandstones of Cambrian age, and the Prairie du Chien Group and St. Peter Sandstone of Ordovician age. The Galena-Platteville unit is included within the sandstone aquifer where the Maquoketa Shale is present. The Galena-Platteville unit contains few fractures or solution channels and yields little water to wells where it is overlain by Maquoketa Shale.

The Maquoketa Shale separates the Niagara and sandstone aquifers in the eastern part of the county. The Maquoketa Shale has been removed by erosion in the western part of the county. Because of its very low permeability, the shale restricts the vertical movement of water and confines water in the sandstone aquifer.

RECHARGE AND MOVEMENT

The source of all ground water in the area is precipitation. Between 1 and 10 in (25.4 to 254 mm) of precipitation per year infiltrates and recharges the ground-water reservoir in Walworth County. The amount that infiltrates depends mainly on the type of rock material at the land surface. Recharge is least in areas covered by fine-grained clayey till, greater in silty-sandy till, and greatest where sand and gravel are at the surface.

Recharge to each aquifer is largely controlled by the permeability of the overlying units. Recharge to the shallowest bedrock aquifer is high where the aquifer is overlain by outwash and end moraine and low where water must pass through clay or silty till.

Most water circulates through the unconsolidated material and shallow bedrock units and then discharges to streams. Ground-water interchange between these shallow units occurs because of head differences between them.

Water seeps downward and recharges the sandstone aquifer because the head is greater in the shallow units. Some recharge is through the Maquoketa Shale in the eastern part of the county, but most is west of the limit of occurrence of the shale. Discharge from the sandstone aquifer in most of Walworth County is through wells, with little or no natural discharge to surface-water bodies. Water in the sandstone aquifer also moves regionally from the county to pumping centers in southeast Wisconsin and northeast Illinois.

LOW-FLOW RUNOFF

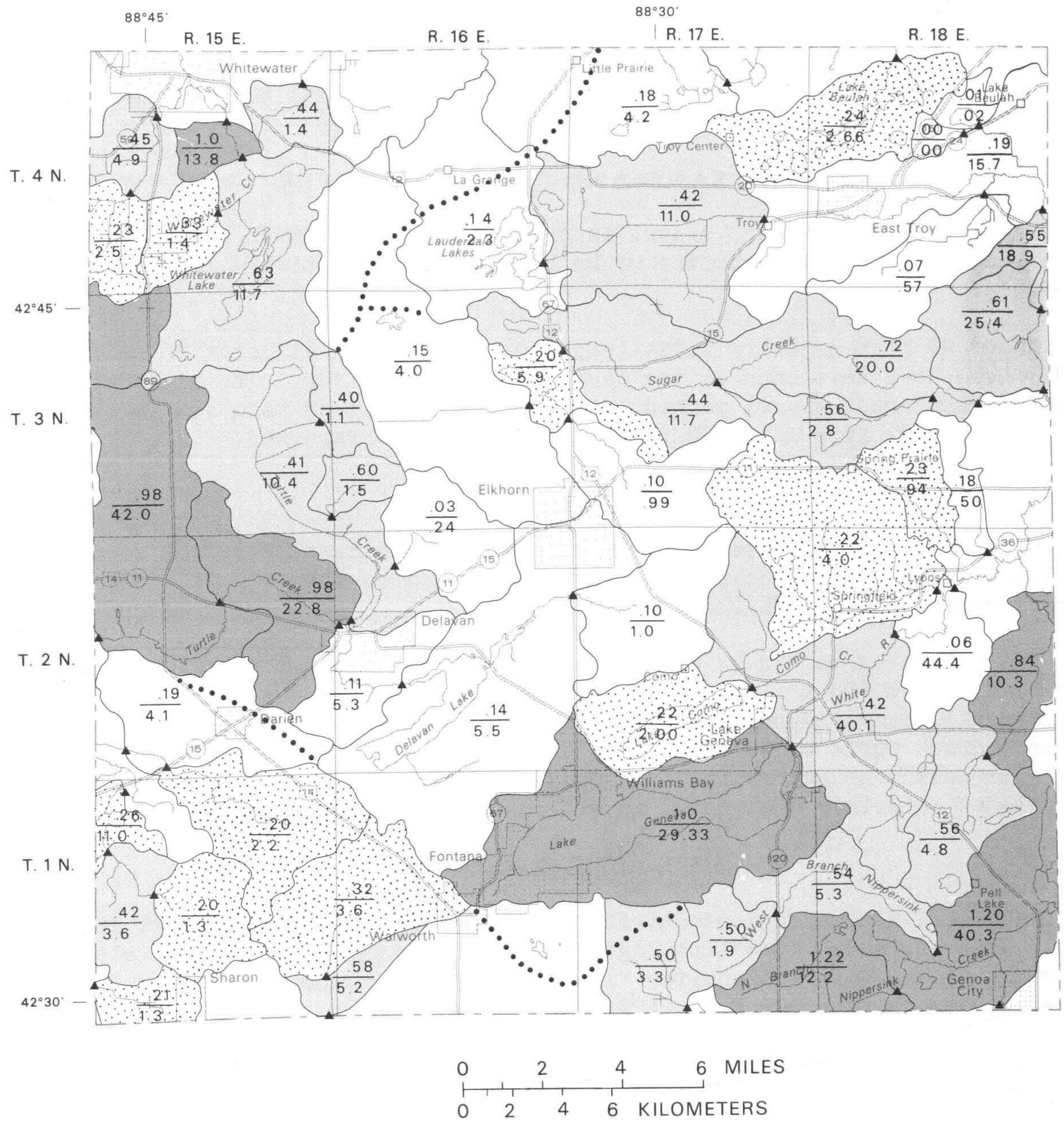
The ability of near-surface deposits to yield water is indicated by streamflow during dry periods when ground water maintains streamflow.

Runoff rates can largely be explained by the type of surficial material drained by the streams. Figure 6 shows runoff in terms of streamflow per unit area of contributing basin. Areas with high runoff rates {0.40 $(ft^3/s)/m^2$ and more or 4.4 x 10^{-3} $(m^3/s)/km^2$ and more} generally drain areas of permeable materials, mostly outwash and end moraine, whereas areas with low runoff rates {0 to 0.39 $(ft^3/s)/m^2$ or 0.00 to 4.3 x 10^{-3} $(m^3/s)/km^2$} generally drain areas of less permeable material, mostly ground moraine. Examples of high runoff areas are several subbasins in the Turtle Creek area in the west-central part of the county and in the southeastern part of the county near Genoa City (fig. 6). The area diagonally through the center of the county, from Sharon to East Troy, is an example of a low runoff-rate area.

Some areas have a runoff rate higher or lower than expected, based on the type of material drained. Two of these areas are in the northwestern part of the county; subbasins near Whitewater Lake have a rate higher than would be expected from ground moraine and lake clay; and the subbasins to the east of Whitewater Lake have a rate lower than would be expected from outwash and terminal moraine. The apparent anomaly is due to a displacement eastward of the ground-water divide with respect to the surface-water divide. The streams to the west are drawing ground water from a larger area than the surface-water subbasin on which the runoff figure is based. Ground water, recharged in the northwest part of the subbasins of the headwaters of Sugar Creek, Honey Creek, and the unnamed creek north of Honey Creek, moves northwest and discharges as springs and seeps in the subbasins near Whitewater.

GROUND-WATER AVAILABILITY

Ground water is available throughout the county, but individual well yields and well depths differ widely. Small yields of ground water, about 15 gal/min (0.95 l/s), are obtained by drillers almost everywhere in the county. Domestic wells are from 50 to 550 ft (15 to 170 m) deep and are completed in the sand-and-gravel aquifer or the shallowest bedrock aquifer. As determined by a representative sample of well-construction reports, about 67 percent of the domestic wells are completed in the sand-and-gravel aquifer, 11 percent in the Niagara aquifer, 22 percent in the Galena-Platteville aquifer, and a few in the sandstone aquifer. Most domestic wells in the county are less than 200 ft (60 m) deep.



EXPLANATION

Runoff, in cubic feet per second per square mile (cubic meters per second per square kilometer) of subbasin

- 0.0-0.19 (0.0-0.0021)
- 0.20-0.39 (0.0022-0.0043)
- 0.40-0.79 (0.0044-0.0086)
- 0.80 (0.0087) and above

Boundary of surface-water subbasin

Ground-water divide
Shown only where significantly displaced from the surface-water divide

Surface-water measuring site

.33 / 1.4 — Values for net gain in runoff for subbasins and discharges at measuring sites
Upper number is net gain in runoff in cubic feet per second per square mile of subbasin. Lower number is discharge in cubic feet per second.

Figure 6. Low-flow runoff, June 26-28, 1972.

Large supplies of ground water for industries and municipalities are more difficult to obtain because wells for these supplies require more complex drilling and construction techniques. The sand-and-gravel and sandstone aquifers are capable of the highest yields.

THE SAND-AND-GRAVEL AQUIFER

Water-bearing sand and gravel is present throughout much of the county. It may extend down from the surface or be buried below relatively impermeable materials.

About 20 high-capacity wells (capable of producing at least 70 gal/min or 4 l/s) have been developed in the sand-and-gravel aquifer. The high-capacity wells are screened, gravel packed, and generally are less than 150 ft (46 m) deep. Yields as high as 2,300 gal/min (140 l/s) are reported.

THICKNESS AND EXTENT

The saturated thickness of unconsolidated deposits ranges from zero in the northwest and northeast corners of the county to more than 450 ft (140 m) in the bedrock valley east of Sharon (fig. 7).

The saturated thickness of the sand-and-gravel aquifer ranges from zero to more than 300 ft (90 m) (fig. 8). This thickness of the sand-and-gravel aquifer includes all saturated permeable unconsolidated material from the land surface to the bedrock surface, whether it is exposed, is overlain by relatively impermeable deposits, or occurs in beds separated by relatively impermeable deposits. It includes materials designated in well records as sand-size or larger.

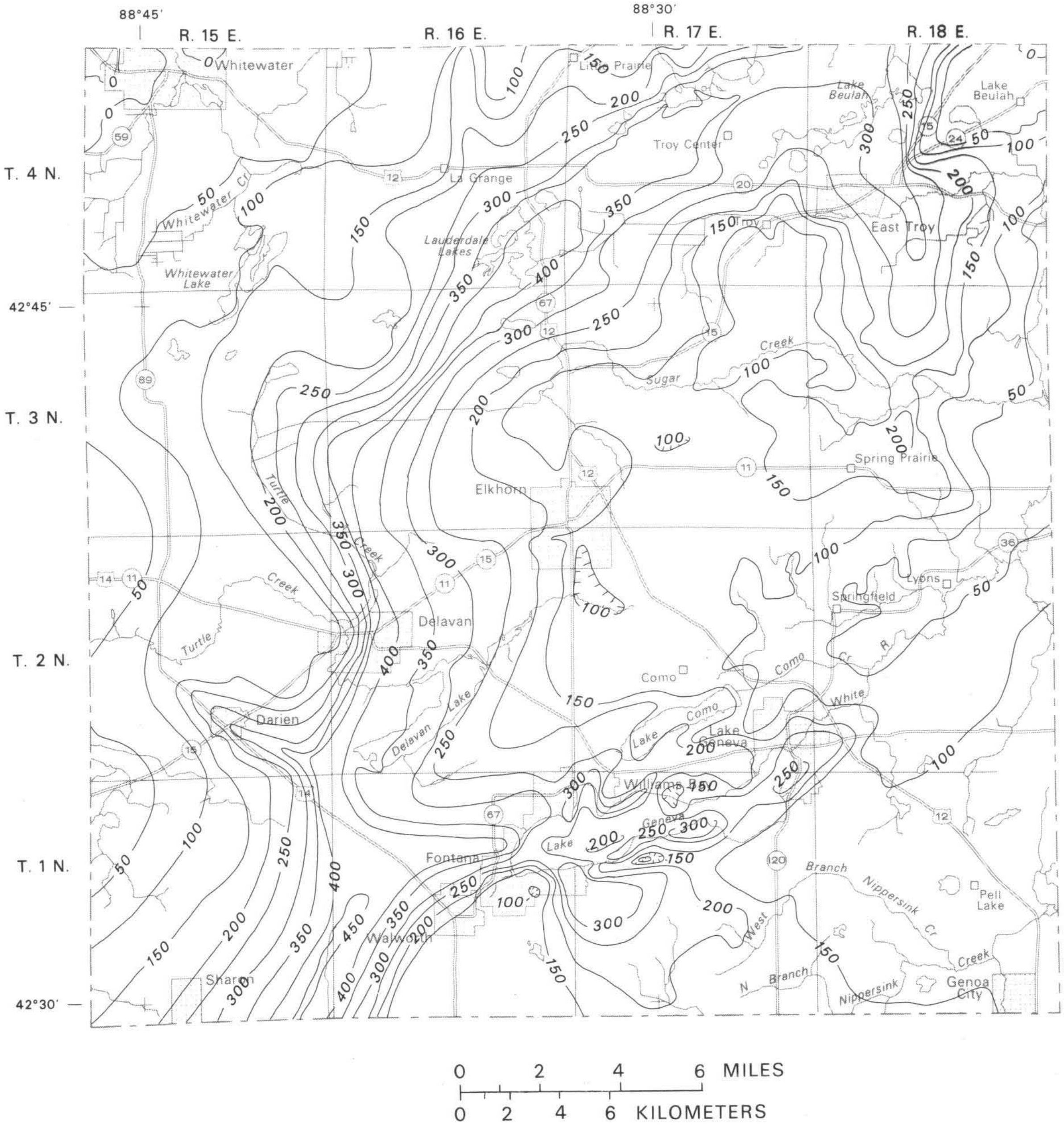
HYDRAULIC CONDUCTIVITY

Values of hydraulic conductivity for the sand-and-gravel aquifer in Walworth County were estimated from lithologic and specific-capacity data for about 100 wells finished in the aquifer. These estimates ranged from about 80 ft/d (24 m/d) to more than 400 ft/d (120 m/d).

The hydraulic conductivity of the sand and gravel is 10 to 50 times greater than most of the consolidated bedrock. Small thicknesses of saturated sand and gravel, therefore, may yield comparatively large quantities of water to properly constructed wells.

WATER TABLE

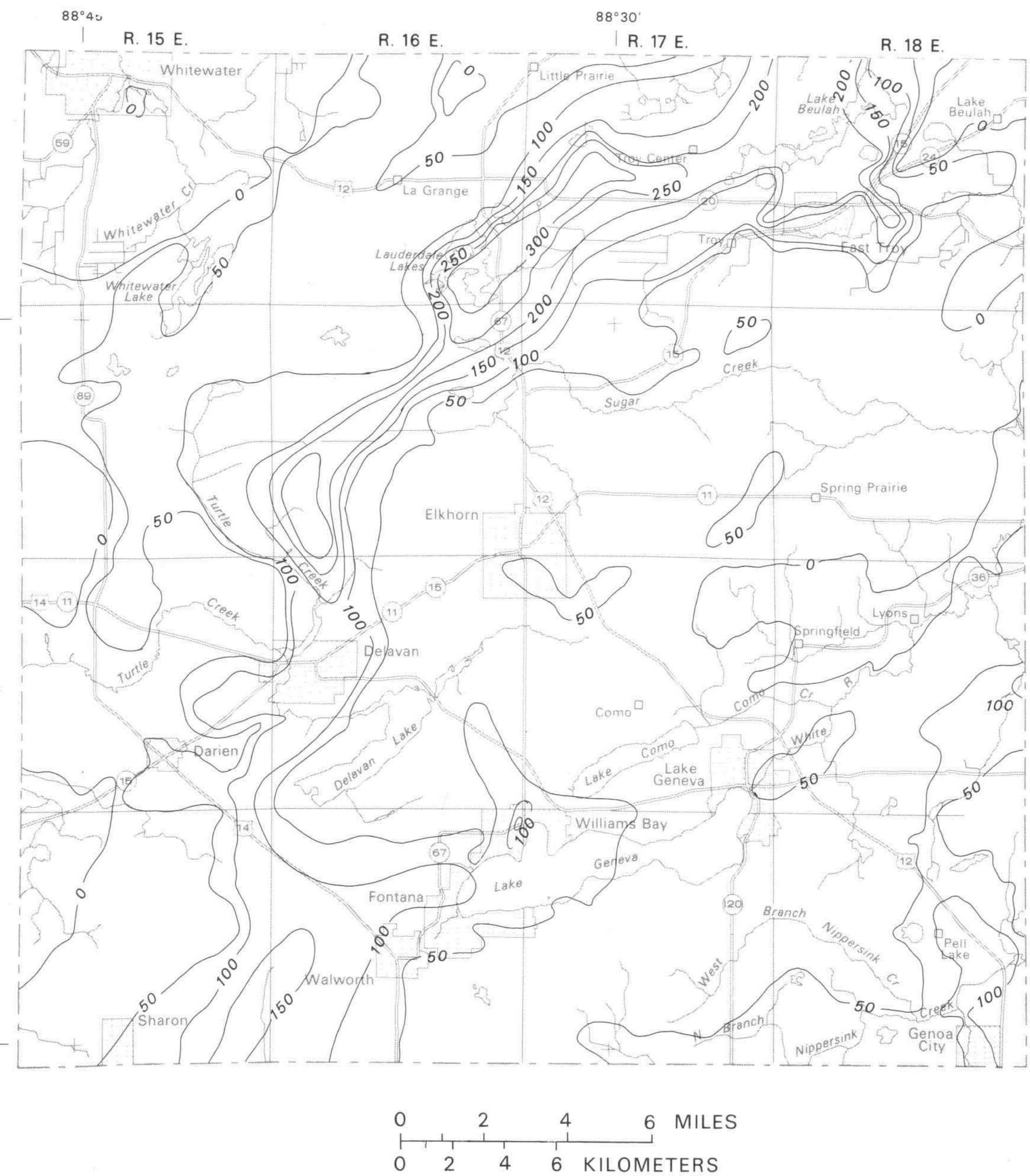
The water-table map (pl. 1) shows the altitude of the top of the zone of saturation in the unconfined aquifer. For the most part, the water table lies within the glacial drift. The altitude ranges from more than 1,000 ft (300 m) east of Elkhorn to less than 775 ft (236 m) along Sugar and Honey Creeks and the White River in the eastern part of the county. The water table generally is a subdued replica of the land surface and is higher under topographic highs, such as those east of Elkhorn and south of Lake Geneva, and lower under topographic lows, such as along Honey Creek and under Lakes Geneva and Como. Areas where the depth to water is less than 10 ft (3 m) for at least part of the year occur in the low-lying parts of the county (fig. 9) along streams, lakes, and wetlands.



EXPLANATION

150 — Line of equal saturated thickness of unconsolidated materials
Interval 50 feet (15 meters)

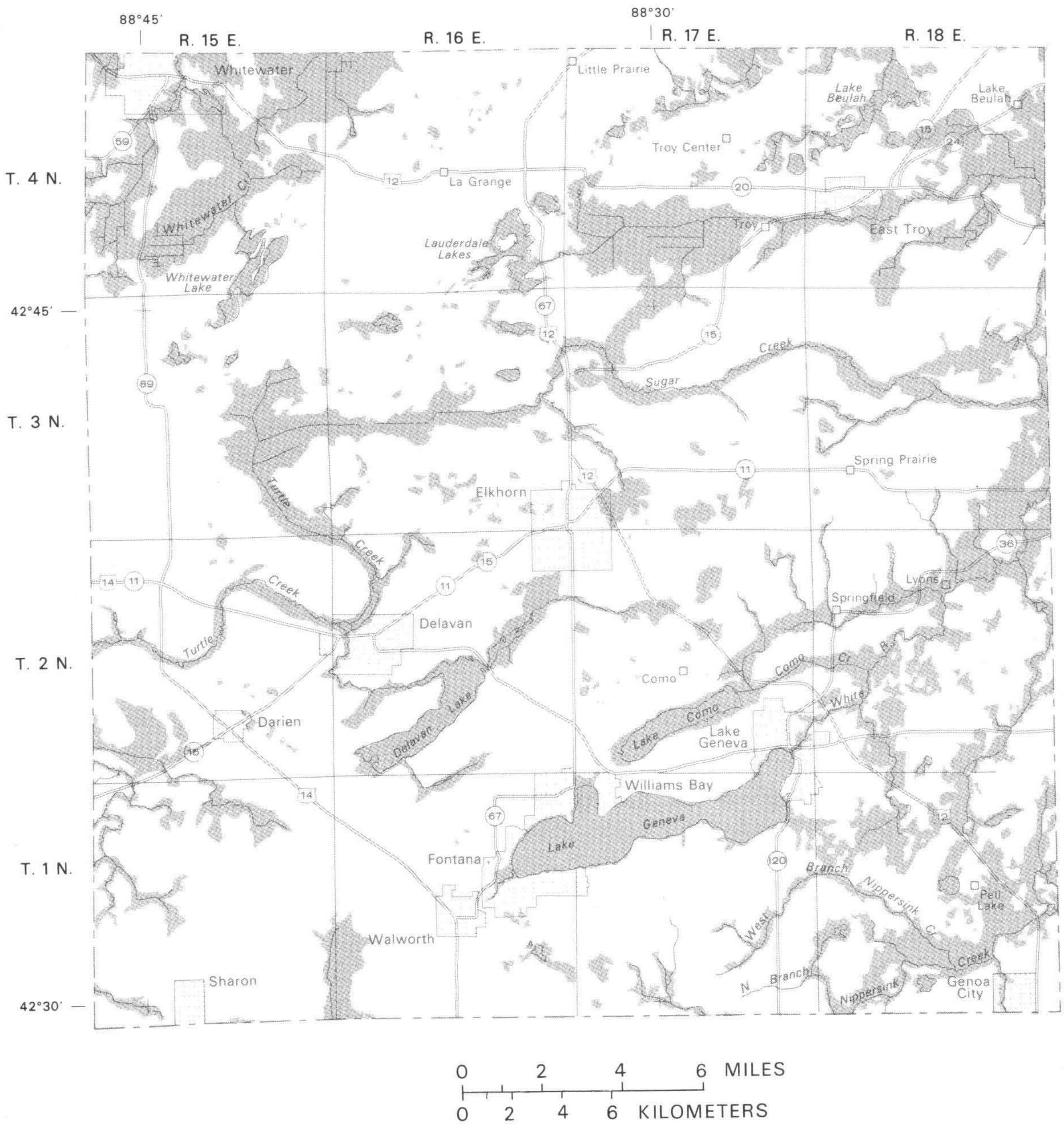
Figure 7. Saturated thickness of unconsolidated materials.



EXPLANATION

——— 150 ——— Line of equal saturated thickness of sand-and-gravel aquifer
Interval 50 feet (15 meters)

Figure 8. Saturated thickness of the sand-and-gravel aquifer.



EXPLANATION

Area where depth to water is less than 10 feet (3.0 meters)

Figure 9. Areas where the depth to water is less than 10 feet.

The map was prepared at a scale of 1:24,000 using topographic and stream data as well as water-level data from wells. The water levels are only from wells finished in sand and gravel, Silurian dolomite, and the Galena-Platteville unit, where not covered by Maquoketa Shale. Some water levels were measured, and others were reported by drillers at the time of completion of the wells. Judgment was used in selecting water levels in areas where closely grouped wells showed a wide range in water-level altitude due to artesian conditions, perched water table, or greatly differing well depths in a recharge or discharge area. An example of artesian water levels exists northwest of the Kettle Moraine, where clay confines ground water moving to the northwest from east of the moraine. Here, wells penetrating strata beneath the clay are flowing. An example of water levels differing with depth occurs in a recharge area near Delavan Lake, where deeper wells (300 ft or 90 m deep) have water levels 40 ft (12 m) lower than shallow wells.

PROBABLE WELL YIELDS

Well yields sufficient for domestic use are possible wherever the sand-and-gravel aquifer is present. Higher yields sufficient for industrial or municipal uses are available in much of the county.

Figure 10 shows the well yields possible from the sand-and-gravel aquifer and is based on the hydraulic conductivity and saturated thickness of the aquifer. The map should be used with caution because wells may have to penetrate and be screened through the entire saturated thickness of sand and gravel (which may not be economically feasible) in order to achieve these yields. Effective well diameters of 2 ft (0.6 m) may be required, especially for yields of more than 500 gal/min (32 l/s). Recharge may limit the ability of a well or well field to provide sustained yields of more than 500 gal/min.

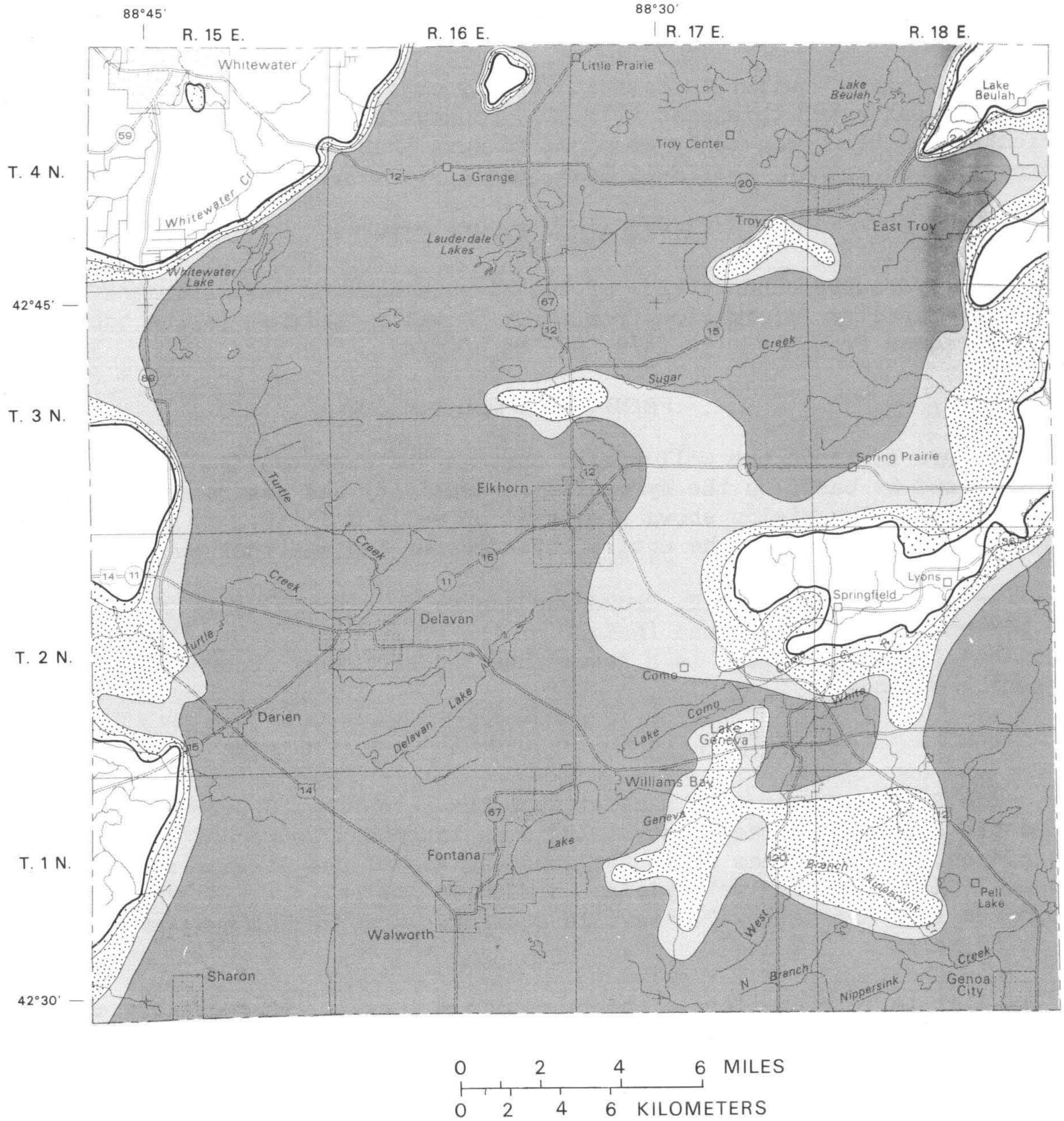
In preparing figure 10, drawdowns caused by pumping wells were limited to two-thirds of the total head (the total head is equal to the saturated thickness of unconsolidated materials, figure 7). This is a reasonable but arbitrary limitation of drawdown useful for planning purposes.

Saturated unconsolidated deposits void of sand and gravel may yield some water, but sustained yields of more than a few gallons per minute are unlikely.

THE NIAGARA AQUIFER

The Niagara aquifer furnishes water for only 11 percent of the private domestic supplies in Walworth County, but it is an important source of water because it occurs in many areas where the sand-and-gravel aquifer is absent. Wells have pumped as much as 400 gal/min (24 l/s) from this aquifer. Most wells, however, pump less than 50 gal/min (3.2 l/s).

Water in this aquifer, although confined locally, is generally under water-table conditions. Water levels of wells in this aquifer are represented by the water-table map (pl. 1). The aquifer is, with few exceptions, completely saturated in Walworth County because the water table is in the overlying glacial drift.



EXPLANATION

Probable well yields

- Chances of more than 100 gallons per minute (6.3 liters per second) are poor.
- Chances of 100 - 500 gallons per minute (6.3-32 liters per second) are good
- Chances of 500-1000 gallons per minute (32-63 liters per second) are good
- Chances of more than 1000 gallons per minute (63 liters per second) are good

——— Boundary of saturated sand-and-gravel aquifer

Figure 10. Probable well yields from the sand-and-gravel aquifer.

THICKNESS AND EXTENT

The Niagara aquifer in Walworth County consists of dolomite of Silurian age. Its saturated thickness (fig. 11) ranges from zero, where the Silurian dolomite has been removed by erosion, to more than 100 ft (30 m) in the northeast corner of the county, near Pell Lake, and north and south of Lake Geneva.

HYDRAULIC CONDUCTIVITY

The hydraulic conductivity of the Niagara aquifer was estimated from specific-capacity information from about 50 wells finished in the aquifer. Values ranged from 1 to 130 ft/d (0.3 to 40 m/d).

PROBABLE WELL YIELDS

Figure 12 shows the well yields that may be expected from the Niagara aquifer and is based on the hydraulic conductivity and saturated thickness of the aquifer. The yields shown are based on wells 1 ft (0.3 m) in diameter, penetrating and open to the entire thickness of the aquifer.

In preparing figure 12, drawdowns caused by pumping wells were limited to 40 percent of the total head (height of the water table above the bottom of the aquifer) (fig. 13). This is a reasonable but arbitrary drawdown useful for planning purposes.

THE GALENA-PLATTEVILLE AQUIFER

The Galena-Platteville aquifer supplies water for 22 percent of the private domestic supplies in the county. It is an important source of supply because it is present in many areas where the sand-and-gravel and Niagara aquifers are absent. High-capacity well yields as much as 300 gal/min (19 l/s) have been reported from the Galena-Platteville aquifer. Most wells, however, pump less than 50 gal/min (3.2 l/s).

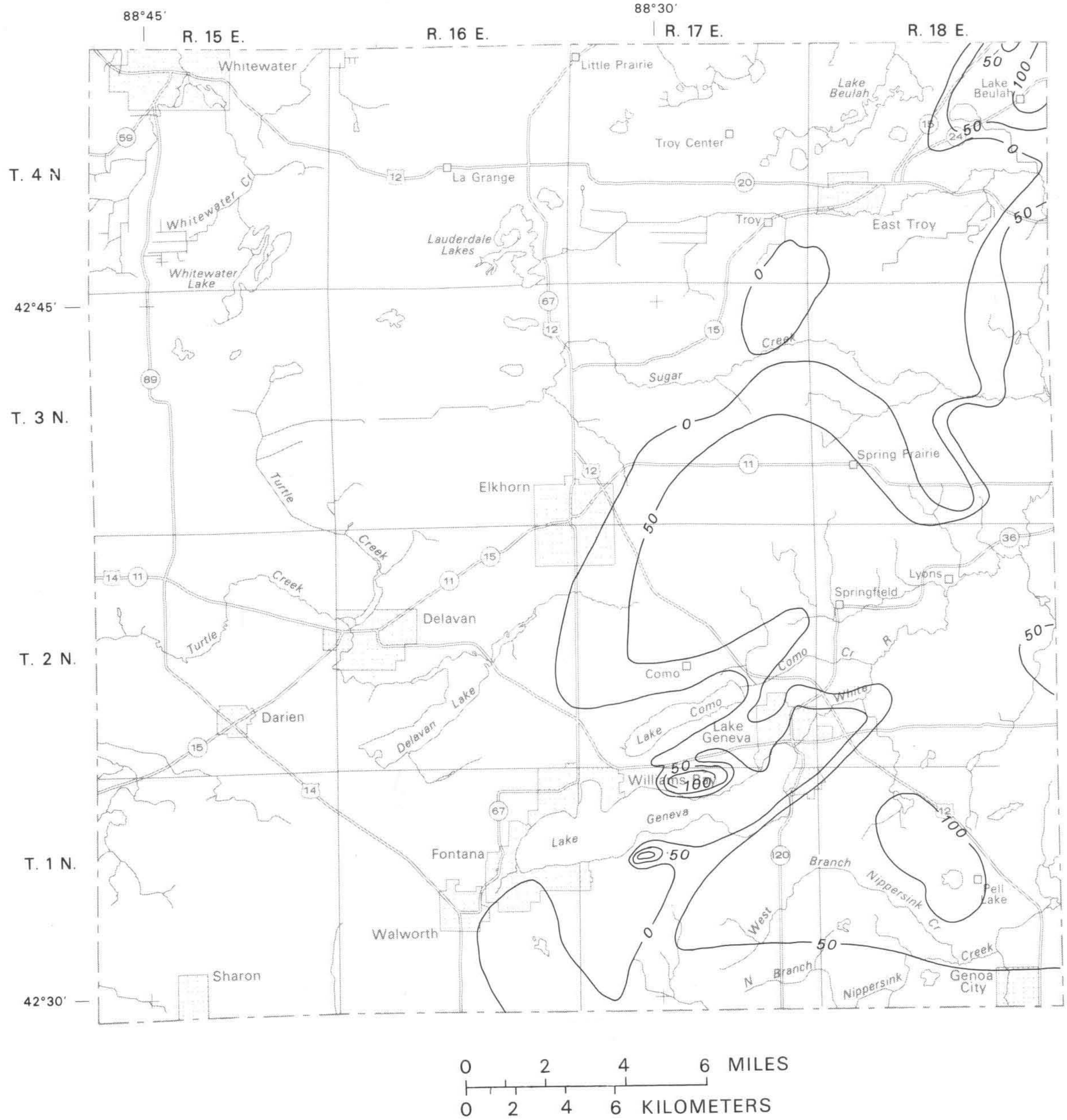
Water in this aquifer, although confined locally, is generally under water-table conditions. Water levels of wells in the aquifer are represented by the water-table map (pl. 1). The aquifer is, except for a small area near Whitewater, completely saturated in Walworth County.

THICKNESS AND EXTENT

The Galena-Platteville aquifer in this report is dolomite of the Galena-Platteville unit, where it is not overlain by Maquoketa Shale. Its saturated thickness ranges from less than 50 ft (15 m) in the bottom of much of the preglacial bedrock valley east of Sharon to more than 300 ft (91 m) along the west limit of the Maquoketa Shale (fig. 14).

HYDRAULIC CONDUCTIVITY

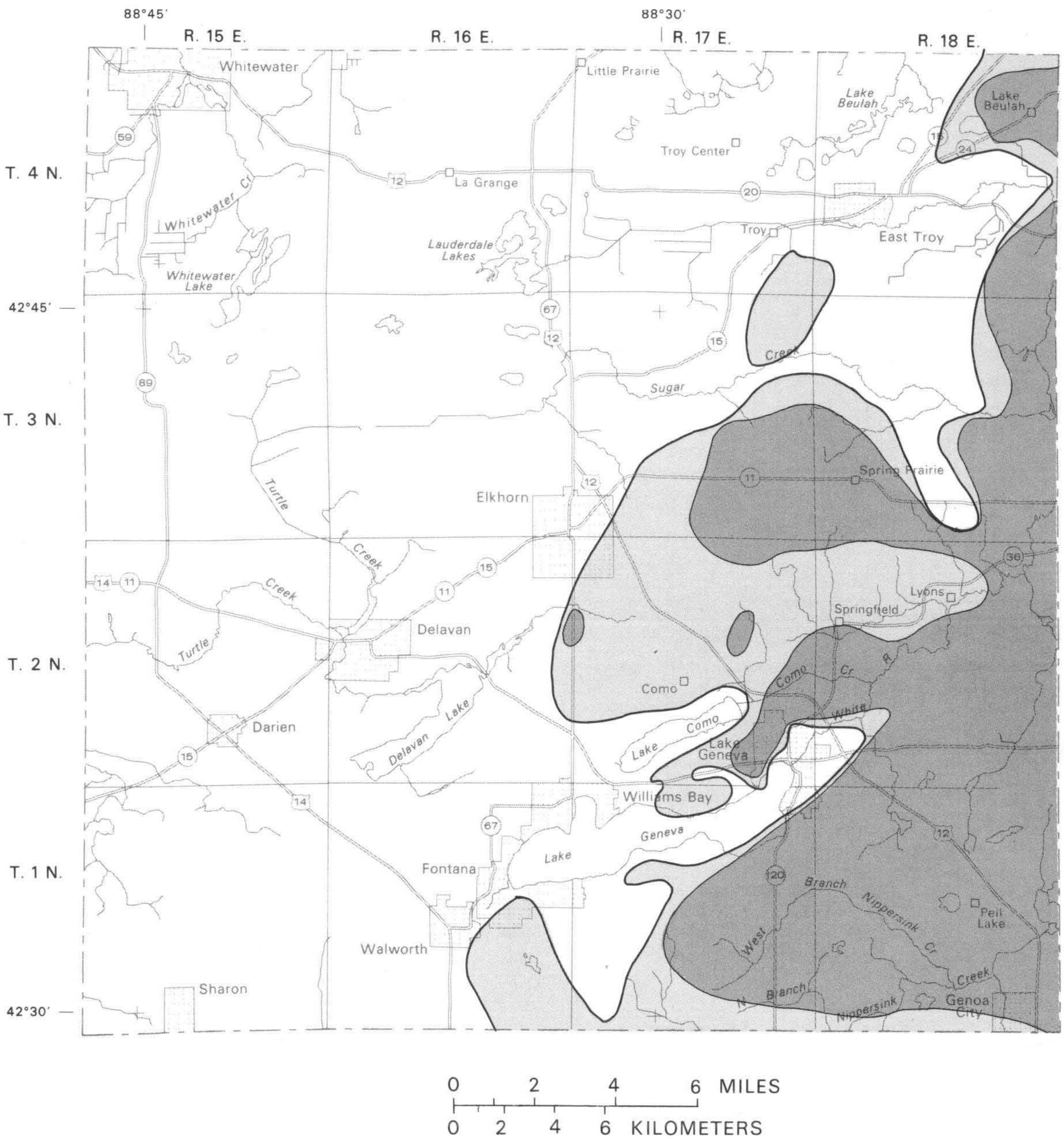
The hydraulic conductivity of the Galena-Platteville aquifer was estimated from specific-capacity information from about 90 wells in the aquifer. Values ranged from about 1 ft/d (0.3 m/d) to more than 130 ft/d (40 m/d).



EXPLANATION

——— 50 ——— Line of equal saturated thickness of Niagara aquifer
Zero thickness marks the limit of the aquifer. Interval 50 feet (15 meters)

Figure 11. Saturated thickness of the Niagara aquifer.



EXPLANATION

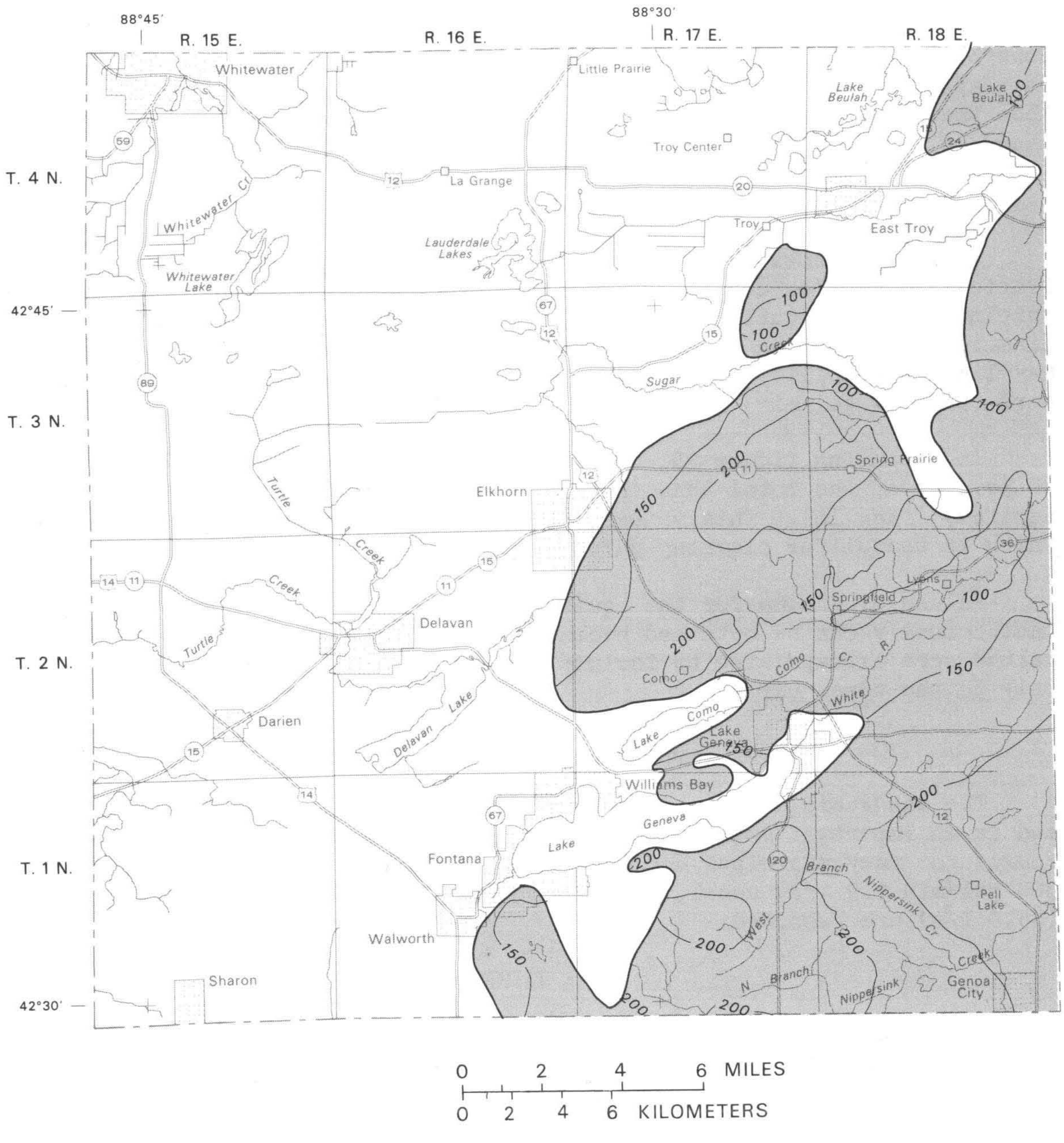
Probable well yields

Chances of more than 100 gallons per minute (6.3 liters per second) are poor

Chances of 100-500 gallons per minute (6.3-32 liters per second) are good

Boundary of saturated Niagara aquifer

Figure 12. Probable well yields from the Niagara aquifer.



EXPLANATION

150 — Line of equal total head
Shows total head above the base of the Niagara aquifer in 1973. Interval 50 feet (15 meters)

Area of Niagara aquifer

Figure 13. Total head for the Niagara aquifer.

Most wells in the Galena-Platteville aquifer are finished as shallow as possible. The hydraulic-conductivity values estimated from specific-capacity data apply to the upper part of the aquifer, which is likely to be more permeable than the lower part because it is more fractured and contains more solution channels.

PROBABLE WELL YIELDS

Figure 15 shows the well yields that may be expected from the Galena-Platteville aquifer and is based on the hydraulic conductivity and saturated thickness of the aquifer. The yields shown are based on wells 1 ft (0.3 m) in diameter, penetrating and open to the entire thickness of the aquifer. Recharge may limit the ability of a well or well field to provide sustained yields of more than 500 gal/min (32 l/s).

In preparing figure 15, drawdowns caused by pumping wells were limited to 40 percent of the total head (height of the water table above the bottom of the aquifer) (fig. 16). This is a reasonable but arbitrary limitation of drawdown which is useful for planning purposes.

Values of yields for the aquifer shown on the map may be higher than those that actually can be obtained because the estimated hydraulic conductivity values were extrapolated to include the entire aquifer, whereas they may apply only to the upper part.

THE SANDSTONE AQUIFER

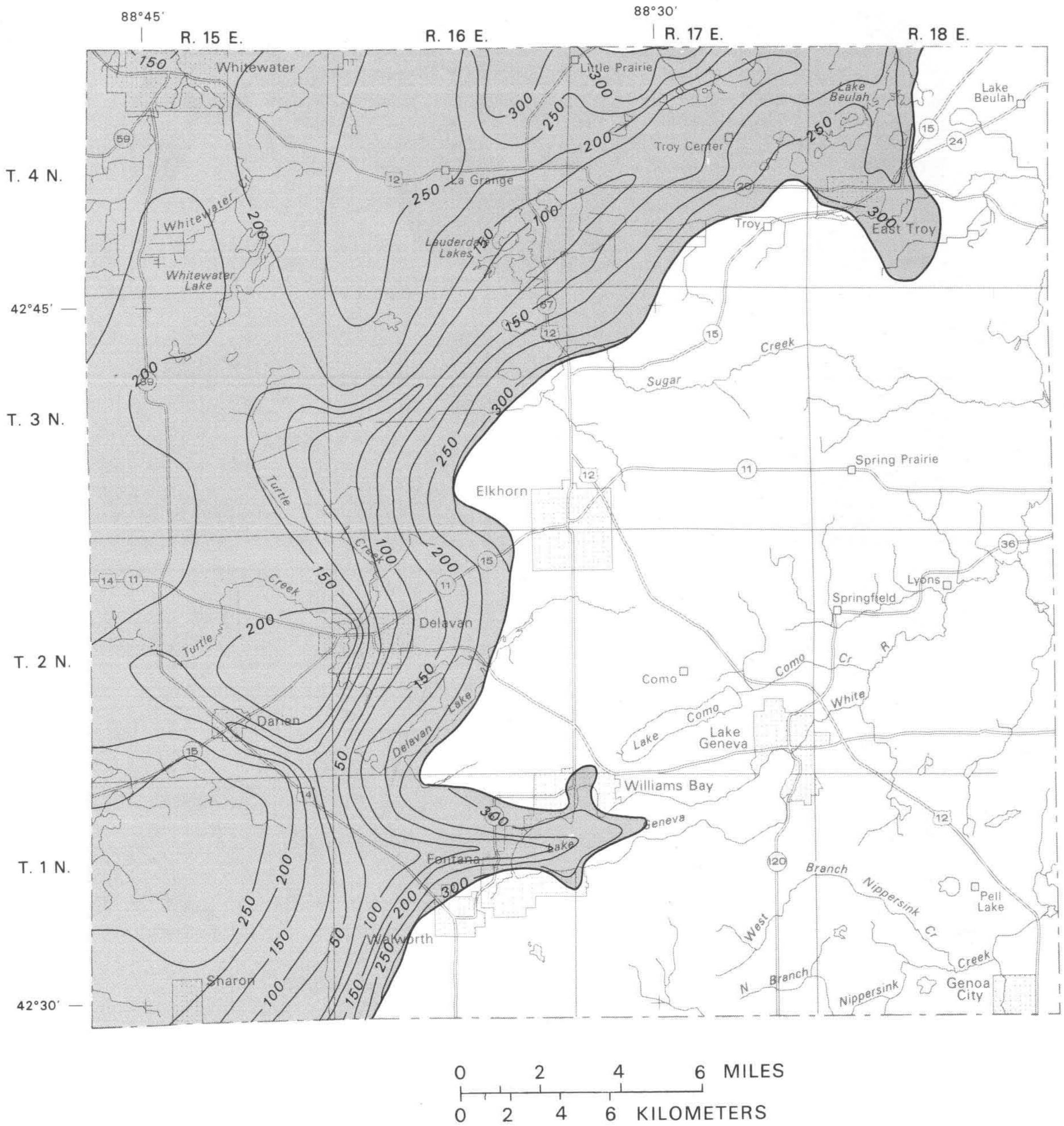
The sandstone aquifer underlies southeastern Wisconsin and adjacent Illinois and is an important source of water. In Walworth County it is the principal source for many municipal and industrial supplies. Most wells pump between 300 gal/min (19 l/s) and 1,000 gal/min (63 l/s); yields as high as 1,350 gal/min (85.0 l/s) are reported.

THICKNESS

The saturated thickness of the sandstone aquifer in Walworth County ranges from less than 800 ft (240 m) in the northwestern part of the county to more than 2,200 ft (670 m) along the eastern county line (fig. 17). The Galena-Platteville unit is considered to be a part of the sandstone aquifer only in those areas where it is overlain by the Maquoketa Shale; therefore, there is a change in thickness of about 300 ft (90 m) in the aquifer thickness at the western limit of the shale.

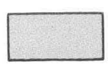
HYDRAULIC CONDUCTIVITY

The hydraulic conductivity of the sandstone aquifer was estimated from specific-capacity information from 14 wells finished in the aquifer. Values ranged from less than 2.7 ft/d (0.82 m/d) to more than 4.7 ft/d (1.4 m/d), where the Maquoketa Shale is missing, and from less than 1.3 ft/d (0.40 m/d) to more than 2.7 ft/d (0.82 m/d), where the shale is present. Estimates include the Galena-Platteville unit in the sandstone aquifer, where the Maquoketa Shale is present.



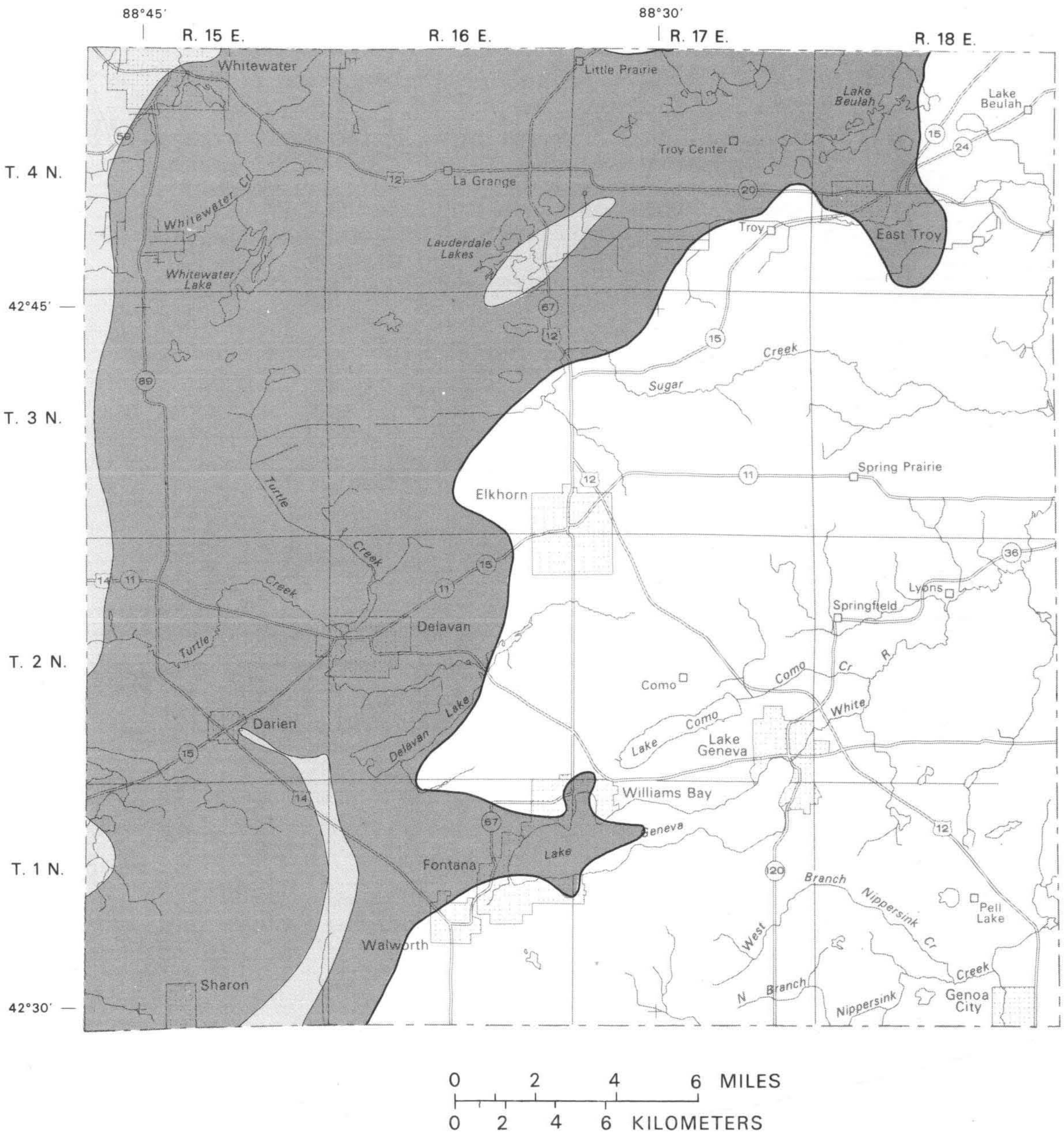
EXPLANATION

Line of equal saturated thickness of Galena-Platteville aquifer
Interval 50 feet (15 meters)



Area of Galena-Platteville aquifer

Figure 14. Saturated thickness of the Galena-Platteville aquifer.



EXPLANATION

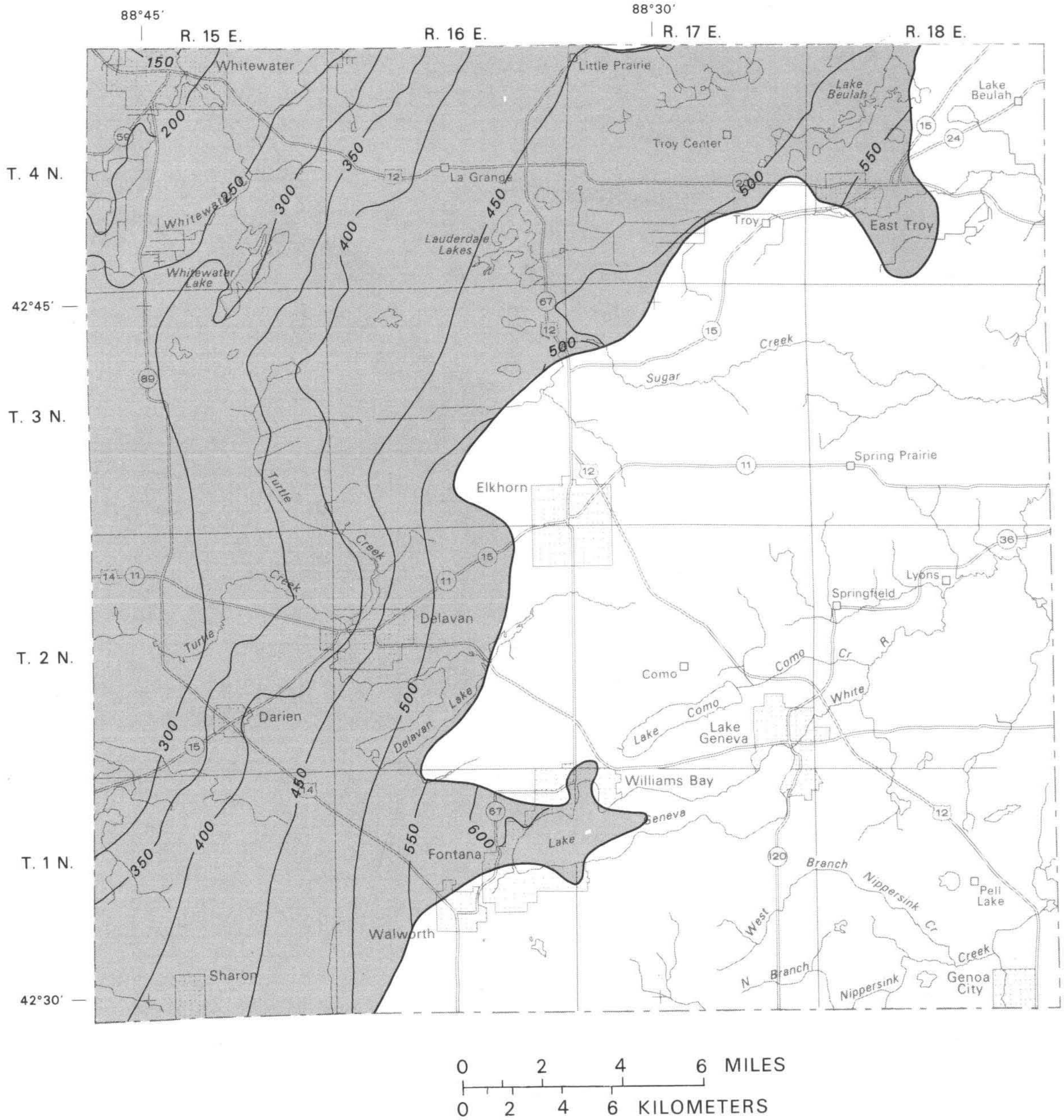
Probable well yields

Chances of 100-500 gallons per minute (6.3-32 liters per second) are good

Chances of more than 500 gallons per minute (32 liters per second) are good

Boundary of Galena-Platteville aquifer

Figure 15. Probable well yields from the Galena-Platteville aquifer.

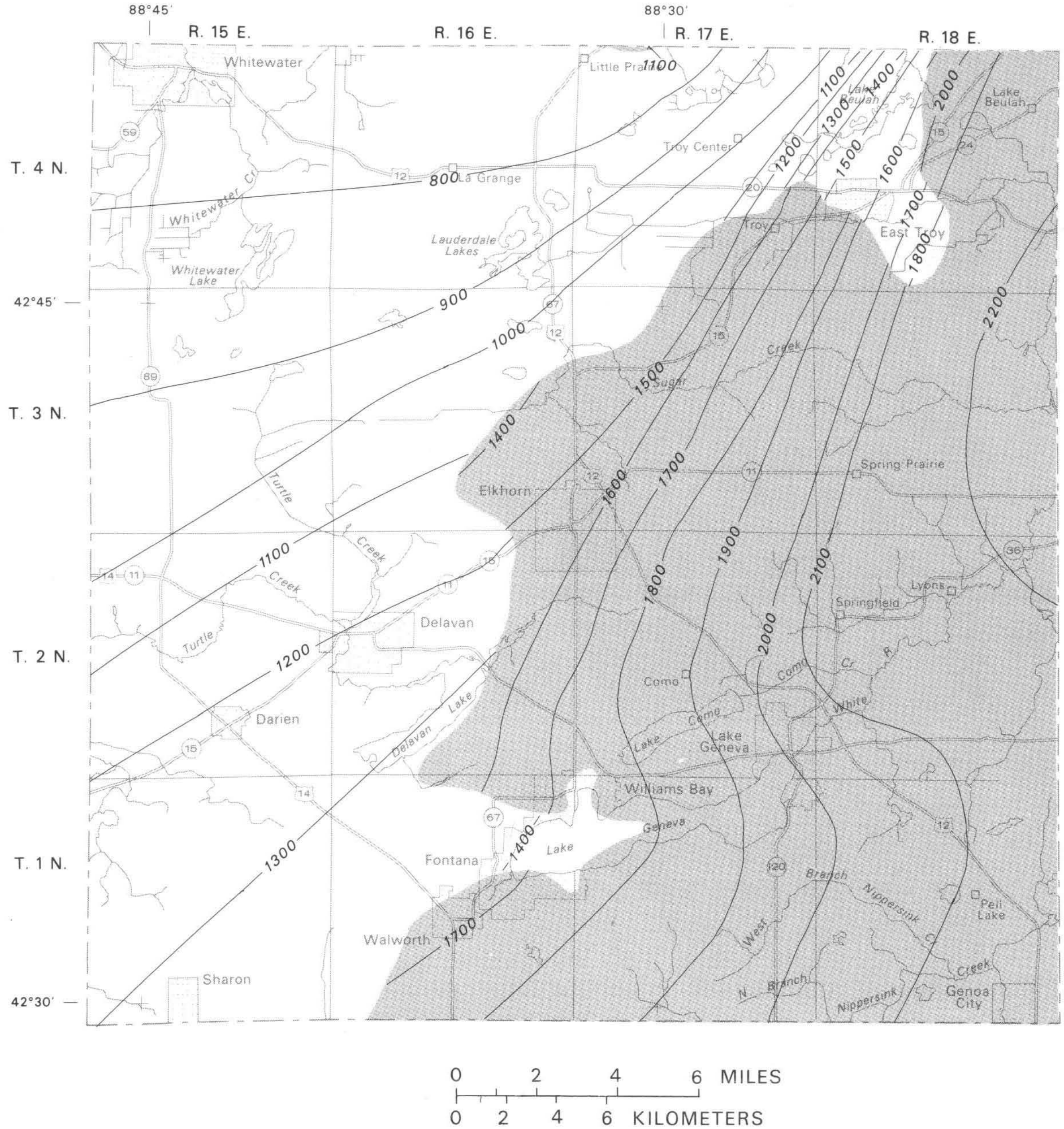


EXPLANATION

400 — Line of equal total head
Shows total head above the base of Galena-Platteville aquifer in 1973. Interval 50 feet (15 meters)

Area of Galena-Platteville aquifer

Figure 16. Total head for the Galena-Platteville aquifer.



EXPLANATION

1200 — Line of equal saturated thickness of sandstone aquifer
Interval 100 feet (30 meters)

Area where Maquoketa Shale confines sandstone aquifer

Figure 17. Saturated thickness of the sandstone aquifer.

These values show that the permeability of the sandstone aquifer is much more uniform than that of the other three aquifers in Walworth County.

POTENTIOMETRIC SURFACE

The potentiometric surface map (fig. 18) shows the altitude to which water rose in wells in the sandstone aquifer as of 1971. In Walworth County it ranged from 900 ft (270 m) south of Whitewater to less than 600 ft (180 m) along the eastern county line (fig. 18). The general slope of the surface is downward from the ground-water divide in the western part of the county toward pumping centers in the urban area of eastern Wisconsin and Illinois. Some distortion of the surface is caused by local pumping from the sandstone aquifer, such as at Darien and Elkhorn.

PROBABLE WELL YIELDS

Large well yields can be developed from the sandstone aquifer because of its great thickness and total head. The total head in November 1971 ranged from about 900 ft (270 m) in the northwest corner of the county to more than 2,200 ft (670 m) in the eastern part of the county.

Based on hydraulic conductivity and saturated thickness of the sandstone aquifer, yields of 1,000 gal/min (63 l/s) can be obtained anywhere in the county without excessive drawdowns (more than 40 percent of the total head). This is assuming 12-in (0.30-mm) diameter wells open to the full thickness of the aquifer.

WATER QUALITY

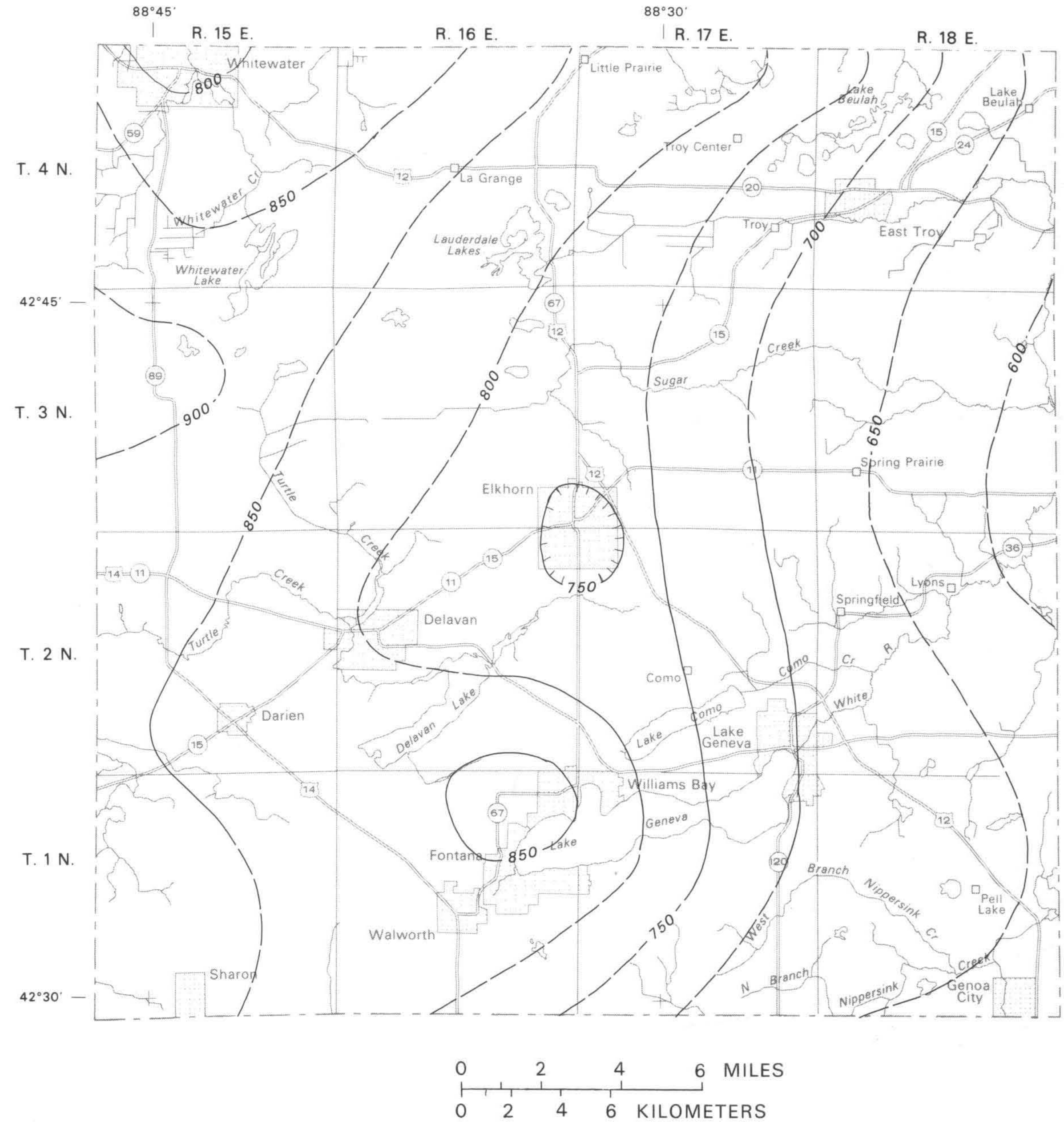
GROUND-WATER QUALITY

The quality of ground water in Walworth County generally is good; however, some water has chemical characteristics that make it objectionable or unsuitable for domestic or industrial uses. Some chemical constituents that determine the quality of ground water and its suitability for certain uses are dissolved-solids, iron, manganese, and nitrate concentrations. Hardness also determines the suitability of ground water for some uses. The known range of concentration of these parameters is shown for each aquifer in figure 19.

DISSOLVED SOLIDS

Dissolved-solids concentration is a measure of the total mineralization of water and is reported as milligrams per liter (mg/l). An upper limit of 500 mg/l for dissolved solids is recommended by the U.S. Public Health Service (1962, p. 7) because higher amounts create taste problems. These standards apply only to drinking water and water-supply systems used by interstate carriers and others subject to Federal quarantine regulations; however, they have been voluntarily accepted by the American Water Works Association and most State departments of public health as criteria for public water supplies.

In Walworth County the dissolved-solids concentrations for most water from the sand-and-gravel, Niagara, Galena-Platteville, and sandstone aquifers are less than the recommended limit.



EXPLANATION

750 — Potentiometric contour

Dashed where approximately located. Contour interval 50 feet (15 meters). Datum is mean sea level

Figure 18. Potentiometric surface of the sandstone aquifer, November 1971.

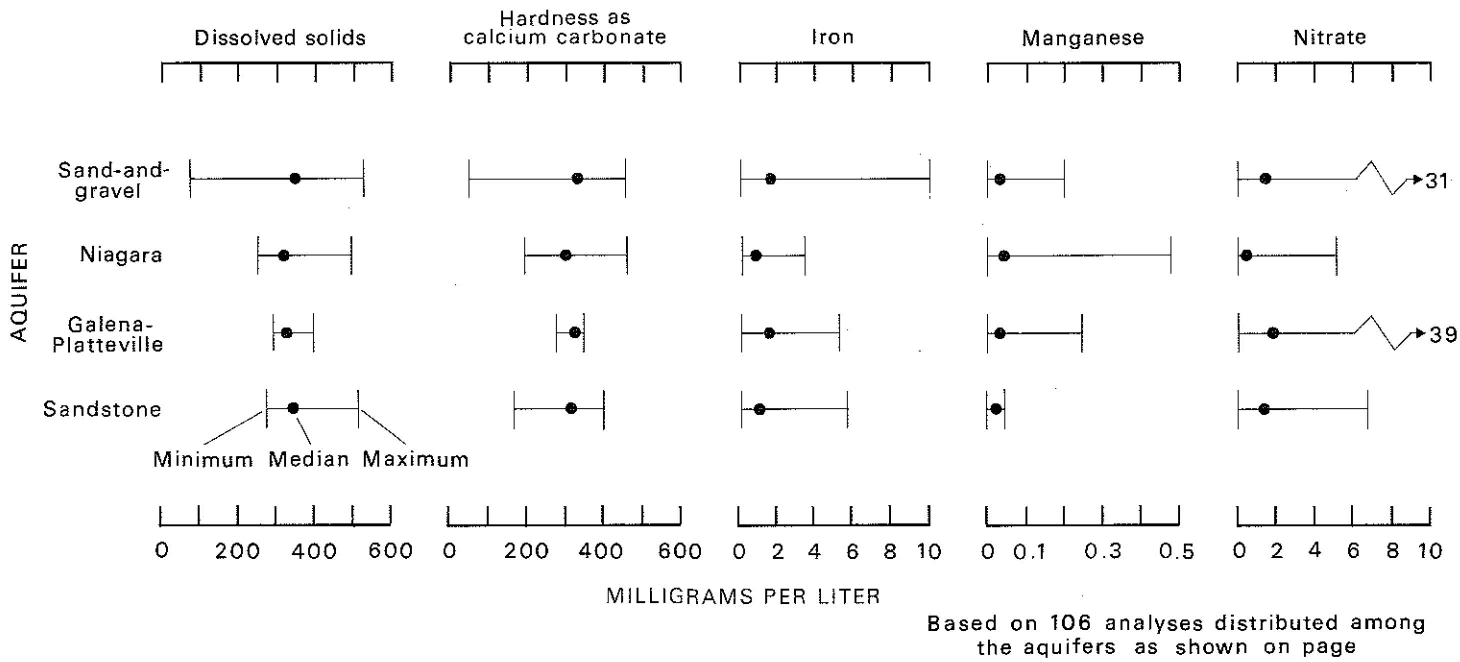


Figure 19. Comparison of concentration of selected chemical constituents and hardness in water from principal aquifers.

Chemical analyses of water from the sand-and-gravel aquifer indicate that the dissolved-solids concentrations range from less than 100 mg/l to more than 500 mg/l in the south-central part of the county near the village of Walworth. The median concentration is 346 mg/l (fig. 19).

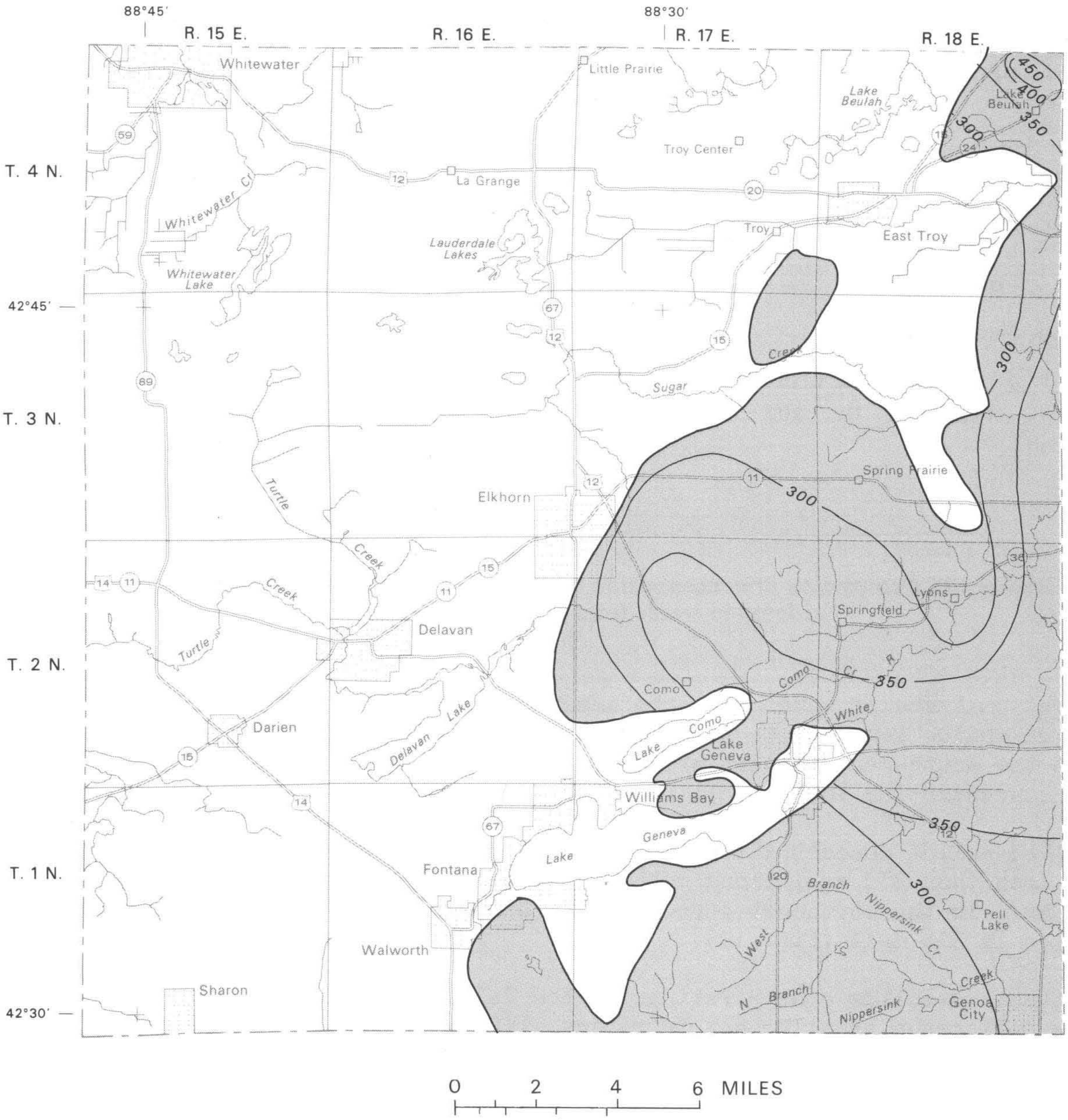
Dissolved-solids concentrations in the Niagara aquifer in Walworth County range from less than 300 mg/l along much of the western border of the aquifer to nearly 500 mg/l in the northeast corner of the county (fig. 20). The median concentration is 318 mg/l (fig. 19).

The dissolved-solids concentrations in the Galena-Platteville aquifer shows very little difference areally, but increases slightly toward the south and east, ranging from less than 300 mg/l in the northeast to more than 375 mg/l near Williams Bay (fig. 21). The median concentration is 327 mg/l (fig. 19).

Extremes in dissolved-solids concentrations in the sandstone aquifer occur at East Troy. The highest value is more than 500 mg/l in a well finished in the St. Peter Sandstone (700 ft or 210 m deep), and the lowest value is less than 300 mg/l in a well finished in Cambrian sandstone (1,500 ft or 460 m deep). Values of dissolved solids in the rest of the aquifer are fairly uniform. The median concentration is 341 mg/l (fig. 19).

HARDNESS

Hardness in water is associated with the formation of insoluble residues with heating or the addition of soap. These residues are usually compounds of calcium and magnesium, which are the elements that are generally responsible for

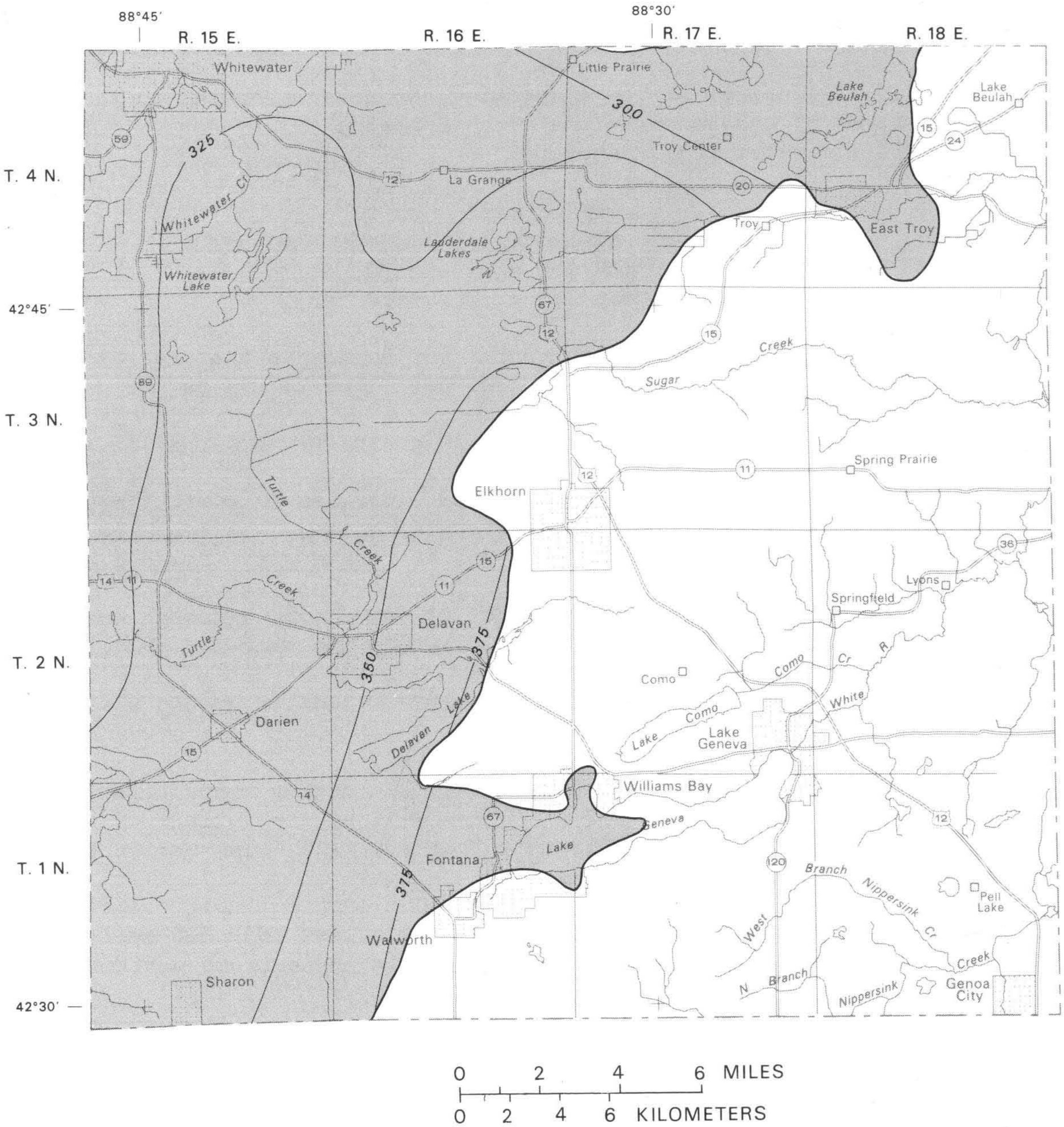


EXPLANATION

——— 350 ——— Line of equal dissolved-solids concentrations
Interval 50 milligrams per liter

[shaded box] Area of Niagara aquifer

Figure 20. Dissolved-solids concentrations for water from the Niagara aquifer.



EXPLANATION

350 — Line of equal dissolved-solids concentrations
Interval 25 milligrams per liter

Area of Galena-Platteville aquifer

Figure 21. Dissolved-solids concentrations for water from the Galena-Platteville aquifer.

hardness. Calcium and magnesium are dissolved from almost all rocks and soils, but the highest concentrations usually are in water that has been in contact with limestone, dolomite, or gypsum. Dolomite is abundant in both the bedrock and glacial drift of Walworth County.

The U.S. Geological Survey classifies hardness according to the following table, in terms of the amount of calcium carbonate or its equivalent that would be formed if the water were evaporated:

0- 60 mg/l - soft,
61-120 mg/l - moderately hard,
121-180 mg/l - hard, and
more than 180 mg/l - very hard.

Hardness is often reported in grains per gallon in the water-softening industry. The conversion from milligrams per liter to grains per gallons is:

1 milligram per liter = 17.12 grains per U.S. gallon.

Hardness is objectionable because hard water leaves a scaly deposit on the insides of pipes, steam boilers, and hot-water heaters; it requires more soap than soft water to make a good lather; and it roughens clothes and hands.

In Walworth County most ground water is very hard, although some localized areas of hard and moderately hard water occur in the sand-and-gravel aquifer. The dissolved constituents that are responsible for hardness (calcium, magnesium, and bicarbonate) make up most of the dissolved solids in ground water in the county.

Hardness of water from the sand-and-gravel aquifer ranges from less than 100 mg/l locally to more than 450 mg/l in a well at the village of Walworth. Hardness for most of the county is more than 300 mg/l. The median value is 330 mg/l (fig. 19).

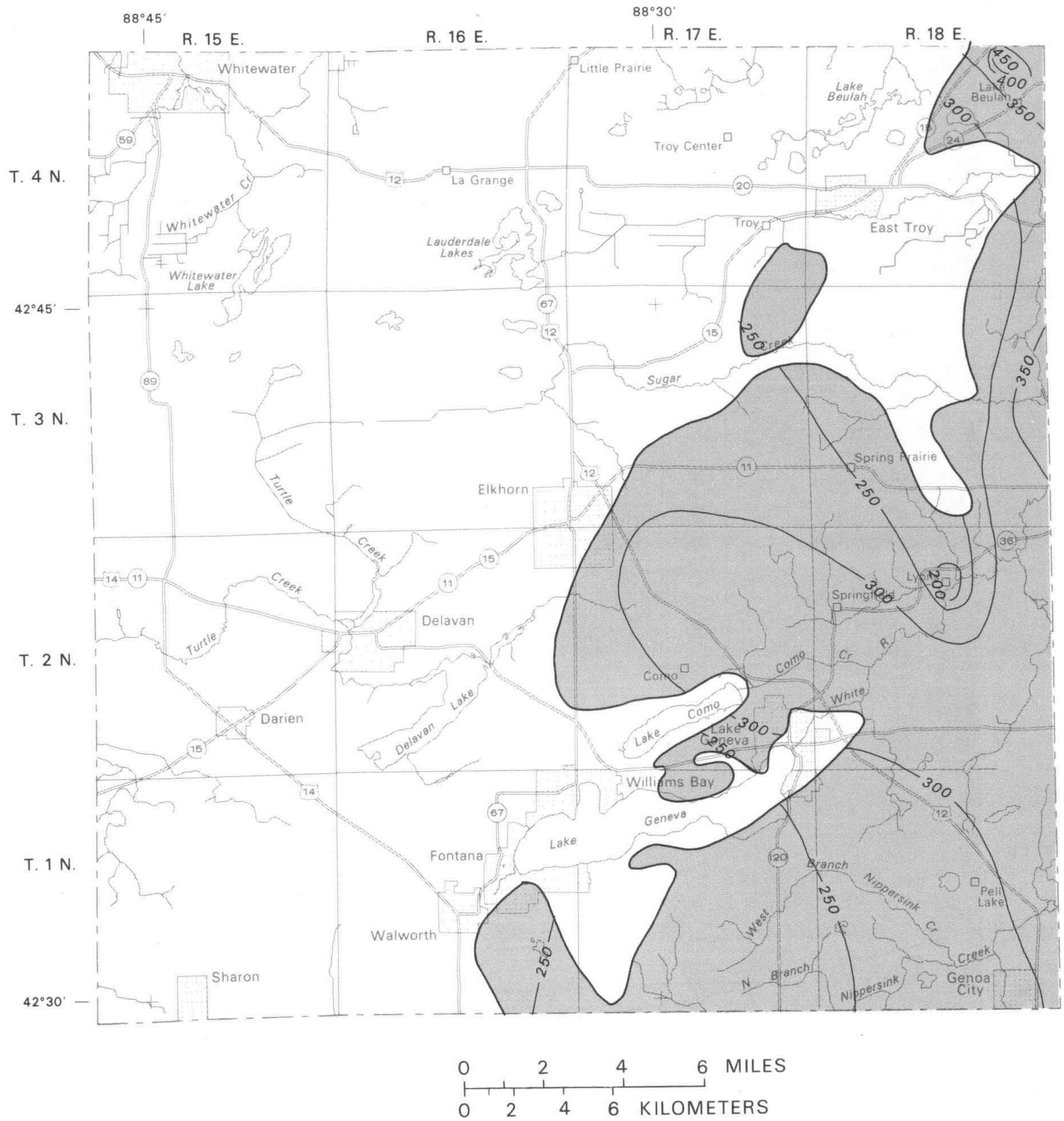
In the Niagara aquifer hardness ranges from less than 200 mg/l northeast of the city of Lake Geneva to more than 450 mg/l in the extreme northeast corner of the county (fig. 22). The median value is 300 mg/l (fig. 19).

Hardness of water in the Galena-Platteville aquifer ranges from less than 300 mg/l northwest of Delavan and in the north-central part of the county to more than 350 mg/l near Williams Bay and Fontana (fig. 23). Like the dissolved-solids concentration, the range in hardness in this aquifer is very small, and differences within the county are not very significant. The median value is 317 mg/l (fig. 19).

Hardness for the sandstone aquifer ranges from less than 200 mg/l southwest of the city of Lake Geneva to more than 400 mg/l near East Troy. The median value is 307 mg/l (fig. 19).

IRON AND MANGANESE

The concentrations of iron and manganese also affect the desirability of water for domestic and industrial uses. Iron is dissolved from many rocks and



EXPLANATION

300 — Line of equal hardness as calcium carbonate
Interval 50 milligrams per liter

Area of Niagara aquifer

Figure 22. Hardness as calcium carbonate for water from the Niagara aquifer.

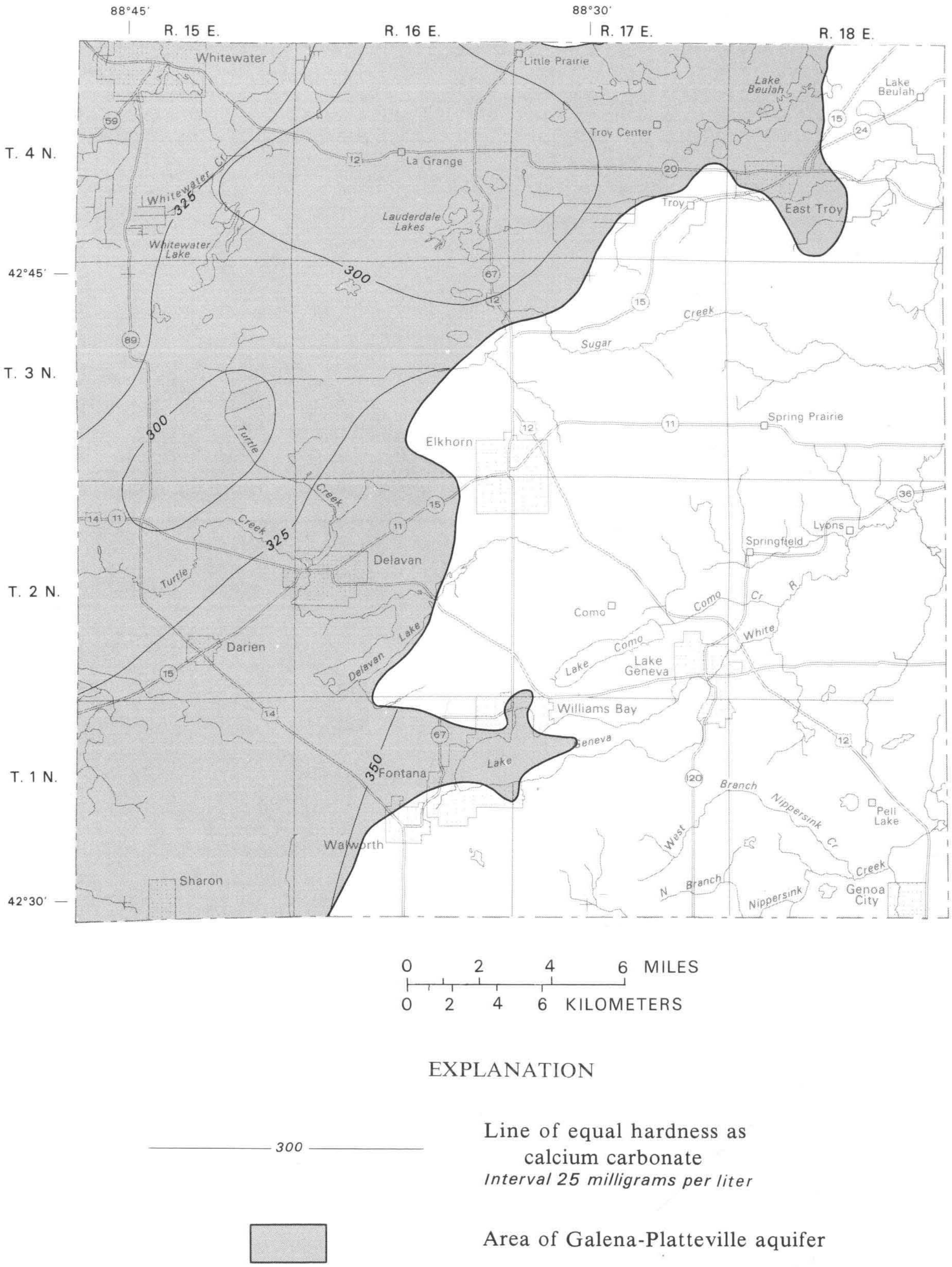


Figure 23. Hardness as calcium carbonate for water from the Galena-Platteville aquifer.

soils. On exposure to air, iron in nonacidic water oxidizes and settles out of solution. In concentrations as low as 0.3 mg/l, iron causes reddish-brown stains on porcelain or enameled ware, on fixtures, and on fabrics washed in the water. Manganese also is dissolved from rocks and resembles iron in its chemical behavior and occurrence in water. Manganese is especially objectionable in water used in laundry work and textile processing. Concentrations as low as 0.2 mg/l may cause dark brown or black stains on fabrics and porcelain fixtures. Water containing objectionable quantities of iron often contains appreciable quantities of manganese. Upper limits of 0.3 mg/l for iron and 0.05 mg/l for manganese have been recommended by the U.S. Public Health Service (1962, p. 7).

High iron and manganese concentrations (more than 0.3 mg/l and 0.05 mg/l, respectively) occur in all aquifers in Walworth County (fig. 19). Iron concentrations in the sand-and-gravel aquifer range from 0 to 10 mg/l. The median concentration of 1.7 mg/l is considerably above the 0.3 mg/l recommended limit. Manganese concentrations in the sand-and-gravel aquifer range from 0 to 0.2 mg/l. However, the median concentration of 0.03 mg/l for this aquifer is below the recommended limit of 0.05 mg/l. Iron concentrations in the Niagara aquifer range from 0.04 to 3.5 mg/l. The median concentration of 0.97 mg/l is well above the 0.3 mg/l recommended limit. Manganese concentrations in the Niagara aquifer range from 0 to 0.48 mg/l. The median concentration of 0.04 mg/l is less than the recommended limit of 0.05 mg/l. Iron concentrations in the Galena-Platteville aquifer range from 0.05 to 5.3 mg/l. The median concentration of 1.8 mg/l is considerably above the 0.3 mg/l recommended limit. Manganese concentrations in the Galena-Platteville aquifer range from 0 to 0.24 mg/l. The median concentration of 0.03 mg/l is less than the recommended limit of 0.05 mg/l. Iron concentrations in the sandstone aquifer range from 0.05 to 4.8 mg/l. The median concentration of 1.1 mg/l is well above the recommended upper limit of 0.3 mg/l. Manganese concentrations in the sandstone aquifer range from 0 to 0.04 mg/l. The median concentration of 0.02 mg/l is below the recommended limit of 0.05 mg/l.

NITRATE

Nitrate in water is considered a final oxidation product of nitrogen-containing matter. Nitrate concentrations of several milligrams per liter may indicate pollution by sewage or other organic matter. The effect of nitrate on industrial use of water is practically negligible; however, many studies by health officers and medical research scientists have shown that excess nitrate in drinking water is a contributing factor or perhaps the main cause of a condition in infants known as methemoglobinemia. The U.S. Public Health Service has set 45 mg/l (1962, p. 7) as the upper limit for nitrate.

In Walworth County nitrate is not a problem, although some pollution of ground water is suggested by well water having nitrate concentrations exceeding the background concentration of 3.0 mg/l. As used here, the background concentration is the upper limit of the modal range, as determined by Cotter and others (1969) for the Rock-Fox River basin. Median concentrations for all aquifers are less than the background concentration of 3.0 mg/l (fig. 19).

Wells in the sand-and-gravel aquifer are susceptible to pollution if they are shallow, inadequately cased, or poorly located and constructed. Of 48 sand-and-gravel aquifer wells with analyses for nitrate, only 2 showed a nitrate concentration above the recommended upper limit, but 17 showed values higher than the background concentration of 3.0 mg/l.

If overlying unconsolidated deposits are thin or permeable, improperly constructed wells finished in limestone or dolomite are susceptible to pollution because fractures and solution cavities allow rapid passage of water from surface sources of pollution. Of the 25 wells sampled in Walworth County, water from 1 in the Niagara aquifer and from 5 in the Galena-Platteville aquifer exceeds the background concentration of nitrate, but none exceeds the recommended upper limit of 45 mg/l.

The sandstone aquifer, because of its great depth below the surface, is less susceptible to pollution than the others. Nitrate concentration of water from 2 of the 17 wells sampled exceeds the background concentration; none approaches the recommended limit of 45 mg/l.

OTHER CHEMICAL CHARACTERISTICS

In addition to those described above, analysis of several other chemical constituents and properties were made. Table 2 summarizes these measurements by aquifer and is based on analyses from the Wisconsin State Laboratory of Hygiene and the U.S. Geological Survey. There were analyses from 54 wells in the sand-and-gravel aquifer, 15 wells in the Niagara aquifer, 14 wells in the Galena-Platteville aquifer, and 23 wells in the sandstone aquifer.

SURFACE-WATER QUALITY

The surface-water-quality map (fig. 24) shows the specific conductance range, in micromhos, of streams in Walworth County during a dry period (June 26-28, 1972) when streamflow was maintained largely from ground-water inflow. Specific conductance is a measure of the electrical conductivity of water and is related to the amount of minerals dissolved in the water. In Walworth County it can be approximately related to dissolved solids by the equation:

$$\text{dissolved solids} = \text{specific conductance} \times 0.57.$$

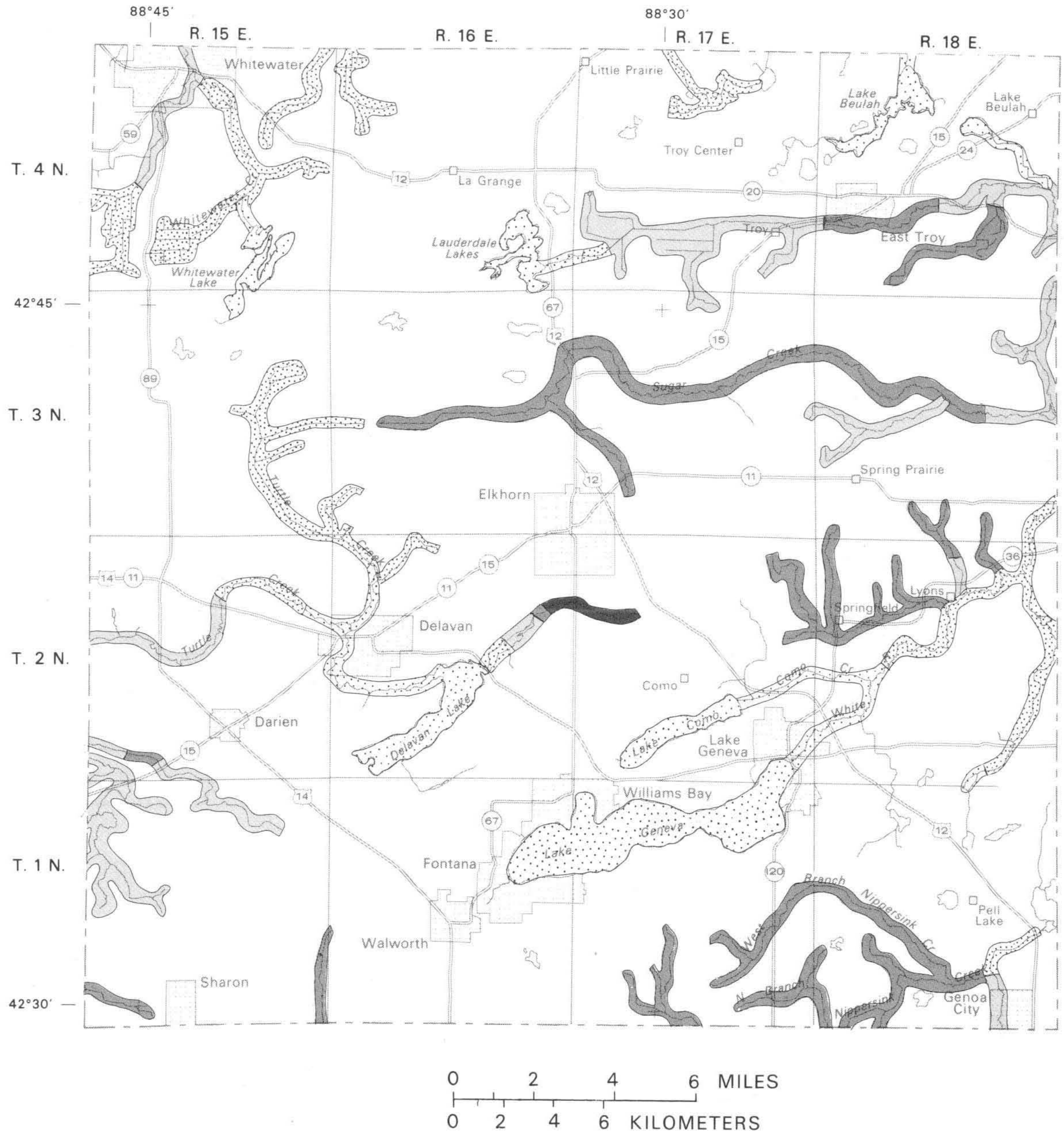
Many streams or stream segments within the county have a higher or lower conductance than that common to the ground water in the area through which they flow. Dissolved solids and conductance of streams discharging from lakes are lower than the regional ground-water inflow because biologic activity and chemical precipitation within lakes remove some of the dissolved solids. Runoff stored in lakes is low in dissolved solids, which may also account for the low conductance of water discharging from the lakes. Streams with specific conductance higher than that of the regional ground-water inflow reflect contamination by waste-water discharge. The areas of contamination extend downstream from the source until diluted by ground-water inflow.

Conductivity of streams during periods of low flow (ignoring reaches of streams influenced by lakes and by waste-water discharge) generally reflect the dissolved-solids concentration of water in shallow aquifers.

Table 2.--Additional constituents and properties of water from the sand-and-gravel, Niagara, Galena-Platteville, and sandstone aquifers

(Chemical analysis in milligrams per liter except pH and temperature, as shown)

Aquifer		Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Noncarbonate hardness as calcium carbonate	pH (standard units)	Temperature (°C)
Sand-and-gravel	Minimum	2.3	20	1.2	1.9	0.8	37	0.4	0.5	0.0	0.0	6.9	9.0
	Median	18	76	36	5.1	1.2	370	18	3.5	.2	22	7.6	11
	Maximum	26	108	49	88	4.3	466	73	108	1.0	127	8.1	14
Niagara	Minimum	9.6	35	26	.7	.7	323	.6	7.0	.2	.0	7.2	10
	Median	18	57	35	6.6	16	364	7.5	2.0	.2	3	7.6	10
	Maximum	26	100	52	60	24	466	67	19	1.0	82	8.0	10
Galena-Platteville	Minimum	14	61	19	.0	.7	310	.2	.0	.2	.0	7.2	10
	Median	17	68	32	4.4	1.4	362	9.3	2.0	.2	18	7.5	12
	Maximum	21	84	39	22	6.7	440	34	15	.4	84	7.9	14
Sandstone	Minimum	8.7	37	18	1.8	1.0	293	0	.0	.1	.0	7.2	10
	Median	13	72	34	10	2.0	393	12	2.2	.3	2.4	7.5	12
	Maximum	18	83	46	75	5.9	442	63	14	.8	68	7.8	14



EXPLANATION

Specific conductance of surface water, in micromhos per centimeter at 25 degrees Celsius

Less than 500

500-600

600-700

700-800

Greater than 800

Figure 24. Surface-water quality during low flow.

GROUND-WATER PUMPAGE AND USE

About 6.6 Mgal/d (0.29 m^3/s) of water was pumped from the four aquifers in Walworth County in 1971. This water was used for residential, industrial, commercial, institutional, and municipal purposes.

PUMPAGE

Pumpage in Walworth County in 1971 from the sand-and-gravel and sandstone aquifers accounted for about 94 percent of the total pumpage, and pumpage from the Niagara and Galena-Platteville aquifers accounted for about 6 percent. The pumpages are tabulated below:

Aquifer	1971 pumpage (Mgal/d)	Percent
Sand and gravel	3.5	53
Niagara	.2	3
Galena-Platteville	.2	3
Sandstone	2.7	41
Total	6.6	100

Ten municipalities and corporations accounted for 5.05 Mgal/d (0.221 m^3/s) or 76 percent of all water pumped in the county in 1971. The average daily pumpages were:

Organization	1971 pumpage (Mgal/d)
City of Whitewater	1.27
City of Lake Geneva	.93
City of Delavan	.63
Village of East Troy	.49
City of Elkhorn	.48
Village of Walworth	.32
Libby, McNeill, and Libby, Inc.	.28
Village of Fontana	.27
Village of Williams Bay	.26
Club Land Development Corp. (Playboy Club)	.12
Total	5.05

USE

The amount of water used daily in 1971 for residential, commercial, industrial, and municipal purposes is shown below:

	Amount used 1971 (Mgal/d)	Percent
Residential, public supply	1.56	23
Residential, private supply	1.1	17
Commercial, public and private supply	1.2	18
Industrial, public and private supply	1.3	20
Institutional, private supply	.2	3
Municipal	1.27	19
Total	6.6	100

Residential water use includes all household uses. In addition, it includes farm uses such as stock watering and equipment washing. Public-supply residential use is water used by residences on a public or private water-distribution system serving five or more homes. Water used by homes and farms with their own source of supply is considered private-supply residential use.

About 40 percent of all water pumped in 1971 was for residential use, and most of the water came from the sand-and-gravel aquifer. Residential use by aquifer is tabulated as follows:

Aquifer	Residential use: Public supply (Mgal/d)	Residential use: Private supply (Mgal/d)
Sand-and-gravel	0.92	0.7
Niagara	.00	.1
Galena-Platteville	.00	.2
Sandstone	.64	.0
Total	1.56	1.0

This tabulation shows the relative importance of the different aquifers for public and private residential supplies.

The sand-and-gravel, Niagara, and Galena-Platteville aquifers occur at relatively shallow depths and are capable of yielding sufficient water for residential use. The sand-and-gravel and sandstone aquifers, which are capable of yielding large water supplies, are the only aquifers used for public distribution systems in the county.

Commercial use refers to water used by a business establishment that does not fabricate or produce a product. Filling stations, retail stores, and restaurants are examples of such establishments. Commercial water use accounted for 18 percent of the water pumped in 1971.

Industrial use refers to water used in a plant that manufactures or fabricates a product. Industrial water may be used to cool machinery, provide sanitary facilities for employees, air-condition the plant, or water the grounds at the plant. Industrial water use accounted for 20 percent of the water used in Walworth County in 1971.

Institutional use refers to water used in the maintenance and operation of institutions such as schools, hospitals, rest homes, and prisons. Owners of institutions may be individuals, corporations, churches, or governmental units. Private-supply institutional use is the only type tabulated. Use by institutions served by public supplies is included under municipal water use. Self-supplied institutional use accounted for 3 percent of the water used in Walworth County in 1971.

Municipal water use is water pumped by municipalities but not sold to customers. It includes use in flushing water lines, fire fighting, sprinkling, use in municipal buildings and institutions, and water lost in the distribution system due to leaks. In 1971, 19 percent of the water used in the county was for municipal use.

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