Geology and Ground-Water Resources of Dane County, Wisconsin

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1779-U

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

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By DENZEL R. CLINE

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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from glacial drift than in water from the other rock units. The temperature of ground water discharged from wells generally ranges between 50° and 52° F in Dane County.

Ground water is the principal source of water for all uses in Dane County. Of the 35 million gallons per day used in the county in 1959, 60 percent was used for municipal purposes, 15 percent for industrial and commercial purposes, 15 percent for rural domestic and stock purposes, and 10 percent for miscellaneous purposes. The Madison metropolitan area used about 25 million gallons per day in 1959, or 73 percent of the total water used in the county. About 80 percent of the total water used for municipal purposes in the county was used in the Madison metropolitan area. It is estimated that the amount of ground water used in Dane County will double by 1980.

INTRODUCTION

PURPOSE AND SCOPE

The purpose of the ground-water investigation of Dane County, Wis., was to determine the occurrence, movement, quantity, quality, and availability of ground water in the unconsolidated deposits and the underlying bedrock. The relationships between ground water and surface water were studied in general in Dane County and in detail in the Madison metropolitan area. An analysis was made of the hydrologic system of the Yahara River valley and of the effects of ground-water pumpage on that system.

The basic data for this report are available for inspection at the offices of the U.S. Geological Survey, Ground Water Branch, and the Wisconsin Geological and Natural History Survey, 175 Science Hall, Madison, Wis. The location of wells for which information is available is shown in plate 1.

The study of the ground-water resources of Dane County was begun in 1956 and was carried on in cooperation with the University of Wisconsin Geological and Natural History Survey. W. K. Summers assisted in the investigation from 1959 to 1961. The work was under the immediate supervision of W. J. Drescher, district engineer, and his successor C. L. R. Holt, Jr., district geologist.

DESCRIPTION OF THE AREA

Dane County is in southern Wisconsin (pl. 2), midway between Lake Michigan and the Mississippi River. Madison, the State capital and the county seat, is in the center of the county about 75 miles west of Milwaukee, Wis., and is about 40 miles north of the Illinois-Wisconsin State line.

According to the U.S. Bureau of the Census, the population of Dane County in 1960 was 222,095 of which about 160,000 lived in the Madison metropolitan area and 126,706 lived in the city of Madison.

PHYSIOGRAPHY

The total area of Dane County is 1,233 square miles of which 40 square miles is covered by lakes. Western Dane County is hilly and well drained, whereas the eastern two-thirds of the county is rolling to moderately hilly and poorly drained and contains many lakes and swamps.

Most of the streams in Dane County originate within the county (pl. 2) and are tributary to either the Wisconsin River or the Rock River systems. These drainage systems are separated by a major topographic divide which trends in a northeast-southwest direction across the northwestern part of the county (fig. 7). The Wisconsin River system drains the northwest one-fifth of the county, and the Rock River system drains the remainder. The Yahara River system, tributary to the Rock River, drains about two-fifths of the county. Both the Wisconsin River and the Yahara River originate outside Dane County—the Wisconsin River in northern Wisconsin and the Yahara River in southern Columbia County.

Dane County has 26 lakes covering 35 acres or more according to the Wisconsin Conservation Department (1958, p. 9). The levels of the large lakes in the Yahara River system are maintained at nearly constant altitudes by dams.

For convenience the county has been divided in this report into five areas which have distinctive physiographic features. The physiographic areas are: the Wisconsin River valley area, the valley and ridge area, the moraine area, the Yahara River valley area, and the drumlin and marsh area (pl. 2).

The broad Wisconsin River valley area is a part of the Driftless Area of southwestern Wisconsin. The valley averages about 4 miles in width and is mostly covered by marsh. The valley walls are steep and have as much as 320 feet of relief in less than 0.1 mile. The lowest altitude in the county, 721 feet above mean sea level, is at the Wisconsin River, and the highest altitude in the county, 1,488 feet above mean sea level,[1] is only 12 miles to the south at Blue Mounds.

The valley and ridge area is also part of the Driftless Area and, in general, has the greatest relief of the county. As described by Whitson and others (1917, p. 6), "This part of the county is rolling to rough and hilly, and is marked by undulating to rolling ridge lands, steep valley walls with numerous rock ledges outcropping, and rather narrow valley bottoms."

The dominant topographic features in the valley and ridge area are Blue Mounds and Military Ridge (pl. 2). Military Ridge roughly parallels the Wisconsin River and is the surface-water drainage divide.

[1] The higher western summit of Blue Mounds (1,716 ft), is just outside the county.

It has "* * * a short, steep, northern slope toward the Wisconsin and a long, gentle descent southward * * *," according to Martin (1932, p. 62).

The moraine area contains several moraines, which are nearly parallel elongated hills of glacial drift. These hills are rugged and trend in a general north-south direction across the county (pl. 2). They are cut by several deep, steep-walled valleys that have comparatively flat bottoms less than 1 mile wide. These valleys once drained the melt waters of glaciers. The moraine area is generally poorly drained and has many small kettles, some of which contain landlocked lakes. Most of the kettles are less than 20 feet deep, although some are more than 60 feet deep.

The Yahara River valley area has an irregular topography that is flat and rolling to hummocky and hilly. The area generally has less relief and gentler slopes than does the western part of the county. Lakes Mendota, Monona, Waubesa, Kegonsa, and Wingra dominate the valley; their physical characteristics are listed in table 1. Generally the lowlands adjacent to the lakes and the Yahara River are marshy, whereas the uplands in this physiographic area are well drained. Some drumlins (elongated hills) occur in the area.

The drumlin and marsh area in eastern and northern Dane County is moderately hilly and has much flat to rolling land between the hills. The area has many drumlins that are alined in a northeast-southwest direction. Much of the lowlands around the drumlins is marsh. About 35 square miles of wetlands, or one-half of the wetlands in Dane County in 1959, are in this area (Wisconsin Conservation Department, 1961).

TABLE 1.—*Physical characteristics of Lakes Mendota, Monona, Waubesa, Kegonsa, and Wingra, Dane County, Wis.*

[Data from Birge and Juday (1914, p. 11–29) except as indicated]

Lake	Location	Miles		Area (sq mi)	Maximum depth (feet)	Mean depth (feet)	Length of shoreline (miles)	Altitude of lake surface
		Length	Width					
Mendota	Tps. 7–8 N., R. 9 E.	5.9	4.6	15.2	84	40	20	[1] 849
Monona	T. 7 N., Rs. 9–10 E.	4.1	2.4	5.4	74	28	13	[1] 845
Waubesa	Tps, 6–7 N., R. 10 E.	4.2	1.4	3.2	36	16	8.6	[1] 845
Kegonsa	T. 6 N., Rs. 10–11 E.	3.0	2.2	4.9	32	15	9.6	[1] 842
Wingra	T. 7 N., R. 9 E.	[1] 1.3	[1] .5	[1] .5	14		[1] 3	[1] 848

[1] Taken from U.S. Geol. Survey quadrangle maps of Madison (1959) or Evansville (1906).

CLIMATE

The climate of Dane County is typically continental—the summers are warm and the winters are cold. The average annual temperature at Madison is 46.2° F and ranges from an average of 17.7° F in January to an average of 72.7° F in July. During each of 4 winter months, December through March, the mean monthly temperature is below 32° F. The growing season extends generally from late April to mid-October and averages 175 days.

The precipitation varies widely during the year. The maximum average monthly precipitation occurs in June, and the minimum average precipitation occurs in February. Generally 3 to 4 inches of precipitation per month occurs during May through September. Most of this precipitation is associated with thunderstorms. Between 1 and 2 inches of precipitation per month generally occurs during November through February. The total yearly precipitation averages 31.2 inches, which includes an average annual snowfall of 37.8 inches, or about 7 inches precipitation.

Climatological data was obtained from two U.S. Weather Bureau stations at Madison and from several substations in the county. The annual averages of climatological data for Madison are representative of those for Dane County.

PREVIOUS INVESTIGATIONS

Many previous geologic and hydrologic studies included all or parts of Dane County, Wis. Of general interest are the works of Irving (1877), Weidman and Schultz (1915), Whitson and others (1917), Alden (1918), Martin (1932), Bean (1949), and Hayl and others (1959). Various specialized studies have been made by the faculty and students of the University of Wisconsin, and by State and Federal agencies in Madison. An early phase of this investigation was an intensive study of the ground-water resources of upper Black Earth basin (Cline, 1963).

NUMBERING SYSTEM

A system of letters and numbers is used to locate and designate wells and rock-sampling sites in Wisconsin. The first part of the numbering system consists of two letters that designate the county; for example, Dn indicates that the well is in Dane County. The middle part of the system, set off by hyphens, consists of the township, range, and section numbers, respectively. The last part of the system is the serial number, assigned in the order that the well was inventoried or the sample was collected in the county. Rock-sampling sites are distinguished from wells by the letter "R" prefixed to the serial number. The number for well Dn–8/6/26–11 shows that the well is in Dane County, in T. 8 N., R. 6 E., sec 26, and was the 11th well inventoried (fig. 1). Only the serial numbers are shown on maps in this report.

ACKNOWLEDGMENTS

The collection of data for this report was facilitated by the cooperation of well owners, well drillers, local officials, and others. Acknowl-

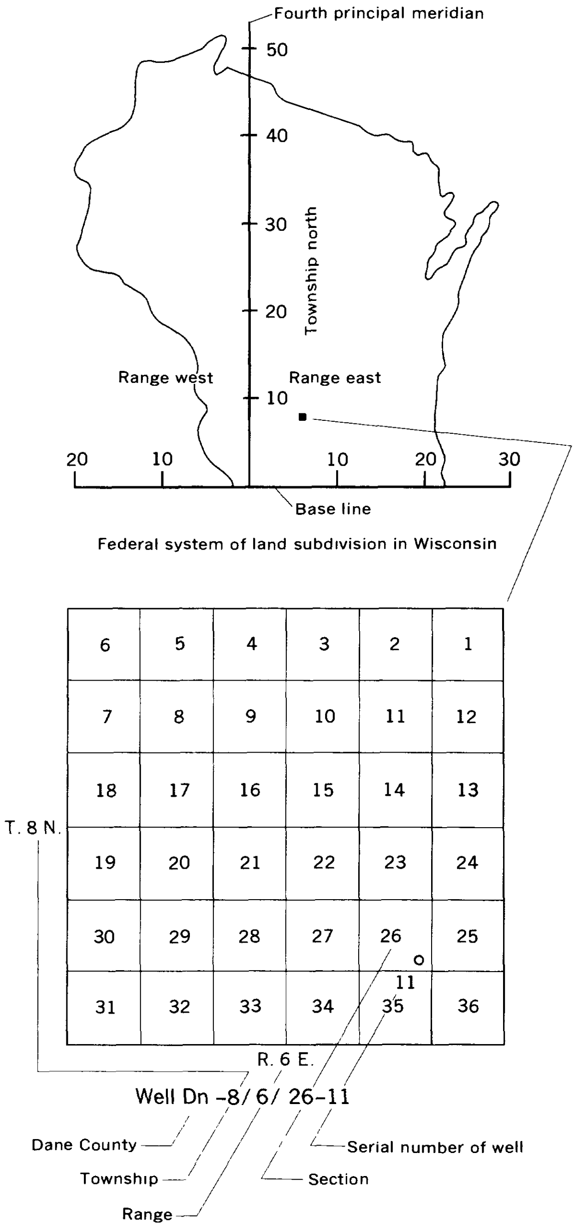


FIGURE 1.—Well-numbering system in Wisconsin.

edgment is made to G. M. Randall for data in northwestern Dane County. Special acknowledgment is made to the Wisconsin State Board of Health for supplying well records and for the use of a deep-well thermometer, to the Wisconsin State Laboratory of Hygiene for

chemical analyses of water samples, to the Public Service Commission for pumpage records, and to the city of Madison Water Department for their assistance.

Acknowledgment is made to G. F. Hanson, State Geologist, for his review of the report.

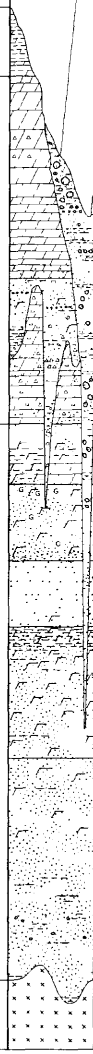
GEOLOGY

The rocks from which Dane County obtains its water supply are sandstones, dolomites, and shales of Cambrian and Ordovician ages and sand and gravel deposits of Quaternary age (fig. 2). The rocks of Cambrian age, principally sandstone and dolomite, were deposited in shallow seas on an uneven and arched surface of igneous and metamorphic rocks of Precambrian age. Dolomite of the Prairie du Chien Group of Ordovician age was deposited on the rocks of Cambrian age. A long period of emergence and erosion followed, leaving an uneven surface that locally has a relief of as much as 200 feet in half a mile. The St. Peter Sandstone of Ordovician age was deposited on the irregular surface. Dolomite of the Platteville, Decorah, and Galena Formations (Platteville-Galena unit) and the Maquoketa Shale, all of Ordovician age, were subsequently deposited. Dolomite and shale of Silurian and Devonian age were probably deposited in Dane County, as indicated by evidence in other parts of Wisconsin, but were subsequently eroded away. The present bedrock geology of the county is shown in plate 3.

The rocks in Dane County dip gently to the south, southeast, and southwest, forming the central part of a southward-plunging arch, called the Wisconsin Arch. The Precambrian surface slopes 10 to 30 feet per mile to the east, south, and west (fig. 3), and the overlying sedimentary strata dip 10 to 15 feet per mile in the same directions (pl. 4, and fig. 4). The sedimentary rocks thicken toward the south and, particularly, toward the southeast and southwest.

After the deposition of the sedimentary rocks, erosion over a long period produced a bedrock surface having a maximum relief of 1,000 feet in Dane County. Erosion has reduced the thickness of the sedimentary rocks in the Wisconsin River valley to about 300 feet; however, about 1,600 feet of sedimentary rocks remains at Blue Mounds.

In Pleistocene time continental glaciers advanced across the eastern two-thirds of Dane County from the northeast to the southwest, transporting enormous quantities of rock material frozen in the ice. This unconsolidated material was dumped on the land surface by the melting glaciers, and thus formed the present-day surface that contains glacial features such as kettles, moraines, and drumlins and that is poorly drained in much of the area. Glacial drift covers most of the bedrock except in the Driftless Area in the west one-third of Dane



SYSTEM	ROCK UNIT		STRATIGRAPHIC THICKNESS (feet)		LITHOLOGY	WATER-YIELDING CHARACTERISTICS
QUATERNARY	Pleistocene and Recent deposits		0-370		Clay, silt, sand, gravel, boulders, peat, muck, and marl, sorted to unsorted, stratified to unstratified	Outwash sand and gravel locally an important aquifer Yields small to large quantities of water Deposits other than outwash may yield small to moderate quantities of water where not situated above the water table
	UNCONFORMITY					
ORDOVICIAN	Maquoketa Shale		[1] 100		Shale, blue-gray and brown-gray, dolomitic	Not an aquifer in Dane County
ORDOVICIAN	Platteville, Decorah, and Galena Formations, undifferentiated		315		Dolomite, yellow, gray, brown, and blue Chert (△) in middle part	Yields small quantities of water from fractures and solution channels Generally situated above the water table except in west central Dane County
ORDOVICIAN	St Peter Sandstone		0-200	120-220	Sandstone, very fine to coarse-grained, white to red or brown, dolomitic in places, some conglomerate, siltstone, and shale, particularly in lower part	Locally yields small to moderate quantities of water
	UNCONFORMITY					
ORDOVICIAN	Prairie du Chien Group		0-200		Dolomite, light gray, buff, cherty, sandy	Locally yields small to moderate quantities of water from fractures and solution channels
CAMBRIAN	Trempealeau Formation		30-125	650-1100	Sandstone, fine to medium-grained light gray to yellow-gray, dolomitic, siltstone, dolomite, sandy	Principal aquifer Yields large quantities of water Dresbach Group generally yields the most water
CAMBRIAN	Franconia Sandstone		70-155		Sandstone, very fine to fine grained, white to yellow brown, dolomitic, glauconitic (G), coarse grains in basal part	
CAMBRIAN	Galesville Sandstone	Dresbach Group	35-130		Sandstone, medium- to fine-grained, white to yellow-gray	
CAMBRIAN	Eau Claire Sandstone	Dresbach Group	50-310		Sandstone, very fine to medium grained, light gray and yellow gray dolomitic, upper part contains shale and siltstone	
CAMBRIAN	Mount Simon Sandstone	Dresbach Group	220-455		Sandstone, very fine to very coarse grained, light-gray, some silty and shaly layers, coarse grained in lower part, somewhat dolomitic in upper part	
	UNCONFORMITY					
PRE-CAMBRIAN	Crystalline rocks		Unknown		Mostly rhyolite, granite, and basalt	Relatively impermeable Not an aquifer

[1] Full stratigraphic thickness not present in county

FIGURE 2.—Lithology and water-yielding characteristics of rock units in Dane County, Wis.

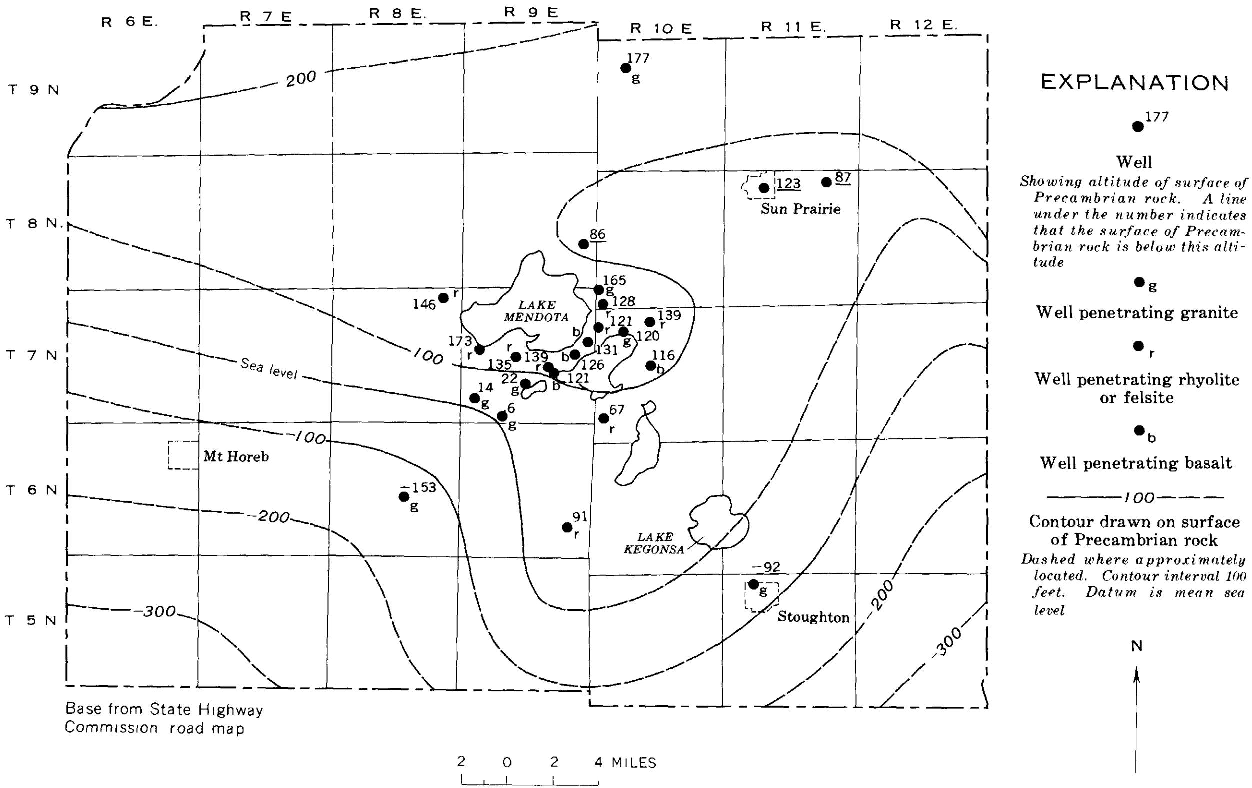


FIGURE 3.—Contour lines showing configuration of the Precambrian surface and Precambrian rock penetrated by wells in Dane County, Wis.

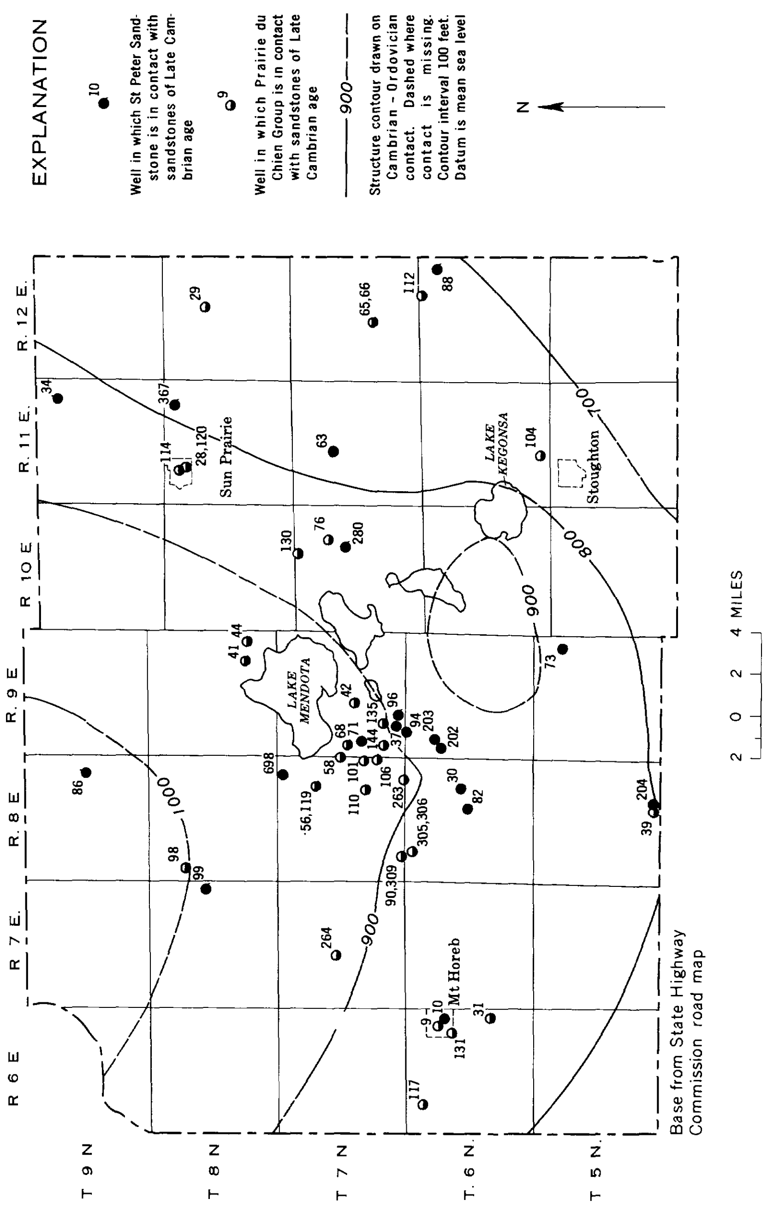


Figure 4.—Generalized structure contours showing configuration of the Cambrian-Ordovician contact, Dane County, Wis.

County (pls. 4 and 2). Glacial and alluvial deposits of Quaternary age (Pleistocene and Recent ages) occur in the valleys in the Driftless Area, and windblown silt, called loess, thinly blankets the entire area.

The glaciers and their meltwaters eroded the bedrock, although the amount of change in Dane County was probably minor. The glaciers ground off the tops of ridges and gouged out the valleys and, in places, formed depressions in the bedrock surface. Thwaites (1953, p. 18) said "* * * basins in the bed rock surface exist which are difficult to account for except by glacial excavation; * * *." Glacial melt water draining from the ice front cut narrow notches through saddles on the topographic divides when the drainage outlets were blocked by ice and glacial deposits.

The drainage system that has formed in Recent times in the glaciated part of Dane County generally conforms to the preglacial drainage pattern, although the present topography has much less relief than the preglacial topography (pl. 4). Both the preglacial drainage and topography in the glaciated area were similar to the present drainage and topography in the Driftless Area.

BEDROCK UNITS AND THEIR WATER-YIELDING CHARACTERISTICS

PRECAMBRIAN ROCKS

Rocks of Precambrian age underlie Dane County at depths ranging from 500 to 1,000 feet below land surface and extend downward to great depths. Rhyolite, granite, and basalt are the principal Precambrian rock types penetrated by wells (fig. 3). These rocks are not water yielding and form the base of the ground-water reservoir in Dane County.

Buried ridges of Precambrian rock, which reduce the thickness of the overlying saturated rock, may occur in Dane County. A quartzite ridge, which has a relief of 700 feet in 1 mile, is known to occur 3 miles east of Dane County.

Thwaites (1931, 1940, 1957) mapped an east-west-trending fault in the Precambrian rocks in southern Dane County. The author did not find sufficient evidence to confirm the fault (fig. 3).

CAMBRIAN SYSTEM

The rocks of Late Cambrian age consist mostly of sandstone, but some of the sandstones are shaly, silty, and dolomitic, and some contain interlayered shale, siltstone, and dolomite (fig. 2). Impure sandstones are more common in the upper part of the division. The term "sandstones of Cambrian age" as used in this report includes all of the rocks of Late Cambrian age.

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The average stratigraphic thickness (thickness between the underlying and overlying consolidated rock units) is about 800 feet. The greatest thicknesses are about 1,000 feet in the southeastern part of the county and 1,100 feet in the southwestern part.

Erosion has cut into sandstones of Cambrian age in many places in the county. Recent and Pleistocene drainage has eroded the sandstones particularly in the northwest and in the Yahara River valley (pl. 3). Erosion during pre-St. Peter time cut channels through the Prairie du Chien Group into sandstones of Cambrian age and thus allowed the St. Peter Sandstone to be deposited in contact with the sandstones of Cambrian age. The minimum thickness of the sandstones of Cambrian age is about 300 feet in the Wisconsin River valley and 380 feet in a well in Madison (Dn–8/10/31–125) (fig. 3 and pl. 5).

The sandstones of Cambrian age are considered in this report to be a single water-yielding unit and consist of five formations. The oldest and most deeply buried formation is the Mount Simon Sandstone, and successively overlying it are the Eau Claire Sandstone and the Galesville Sandstone. These three formations comprise the Dresbach Group. Next in ascending order are the Franconia Sandstone and the Trempealeau Formation (fig. 2).

MOUNT SIMON SANDSTONE

The Mount Simon Sandstone is predominantly a well-cemented medium-grained sandstone that contains very fine to very coarse sand. The upper part is partly dolomitic and is finer grained than the lower part.

The measured thickness of the Mount Simon Sandstone ranges from 223 feet at Sauk City (adjacent to the northwest corner of Dane County) to 455 feet at the village of Verona (well Dn–6/8/22–316), and the unit is probably thickest in the southeast and southwest corners of the county. The thickness varies greatly locally; for example, in the Madison area the thickness ranges from 240 feet at well Dn–7/9/13–48 (Madison east well of the main station group) to 427 feet at well Dn–7/9/32–96 (Madison unit 10).

Much of the variation in thickness of the Mount Simon Sandstone is caused by the unevenness of the Precambrian surface. The sandstone occurs everywhere in the county, except possibly where knobs of Precambrian rock extend above the top of the formation. The Mount Simon Sandstone has probably not been eroded since Cambrian time, as logs of wells that show the deepest erosion indicate that the Eau Claire Sandstone was penetrated beneath the glacial drift (well Dn–8/10/31–74) (pl. 4).

EAU CLAIRE SANDSTONE

The Eau Claire Sandstone is a fine- to medium-grained dolomitic sandstone that contains much very fine sand and silt. Shale and siltstone occur extensively in the upper part of the formation and only locally in the lower part.

The Eau Claire and Mt. Simon Sandstones are distinguished only with difficulty in the subsurface. The Eau Claire is characteristically finer grained, dolomitic, and shaly and silty in contrast with the Mt. Simon, which may contain granules up to 4 mm in diameter and which is only locally dolomitic and shaly. Commonly the Eau Claire grades imperceptibly into the Mt. Simon (fig. 2).

The stratigraphic thickness of the formation varies greatly within short distances, and both the maximum and minimum stratigraphic thicknesses occur in Madison; 310 feet at well Dn–8/10/31–53 (Madison unit 7) and 50 feet at well Dn–7/9/18–715 (Madison unit 14). The Eau Claire Sandstone has been partly eroded in the preglacial Yahara and Wisconsin River valleys. At well Dn–8/10/31–125, in Madison, only 40 feet of the Eau Claire Sandstone remains beneath the glacial drift. This well is only 0.7 mile from the maximum known thickness of the sandstone in Dane County.

GALESVILLE SANDSTONE

The Galesville Sandstone is predominantly a medium- to fine-grained sandstone that ranges in stratigraphic thickness from 35 feet at De Forest (well Dn–9/10/17–301) to 130 feet in the Madison area (wells Dn–6/8/14–30 and Dn–7/10/6–50, Madison unit 3). The Galesville Sandstone is not normally dolomitic or shaly, nor does it contain silt. The absence of these materials distinguishes it from the underlying Eau Claire Sandstone. Preglacial erosion has removed all or part of the formation in places. The sandstone is covered by glacial deposits and is not exposed at the surface in Dane County.

FRANCONIA SANDSTONE

The Franconia Sandstone is divided into upper and lower parts on the basis of lithology. The upper part is known locally as "greensand" due to its high content of green glauconite pellets. It consists of very fine- to fine-grained dolomitic and glauconitic sandstone which includes some silt and medium sand. The lower part of the formation is fine to coarse grained and is only locally dolomitic and glauconitic. The presence of dolomite, glauconite "greensand", and very coarse sand grains and granules in the lower part of the Franconia Sandstone distinguish this unit from the underlying Galesville Sandstone (fig. 2).

The stratigraphic thickness of the Franconia Sandstone ranges from 70 feet near Lake Kegonsa (well Dn–6/10/22–338) to 155 feet at Sun Prairie (well Dn–8/11/5–28) and is between 100 and 120 feet in more than one-half of the wells that penetrate the entire formation. Preglacial erosion has removed the formation in northwestern Dane County and the Yahara River valley.

Pre-St. Peter erosion has locally removed the overlying Trempealeau Formation so that the St. Peter Sandstone overlies the Franconia Sandstone in Madison (well Dn–7/9/32–96, Madison unit 10) (pl. 4), in Middleton (well Dn–7/8/2–698), and near Sun Prairie (well Dn–8/11/2–367).

TREMPEALEAU FORMATION

The Trempealeau Formation consists of sandstone, siltstone, and dolomite. The upper part is mostly a fine- to medium-grained locally dolomitic sandstone; the middle part is a siltstone that is dolomitic to very dolomitic, commonly sandy, and locally shaly; and the lower part is dolomite which is commonly sandy and may locally consist of very dolomitic sandstone. The lower part of the Trempealeau is very dolomitic or consists of dolomite containing very little glauconite "greensand." The underlying Franconia Sandstone is glauconitic and only moderately to slightly dolomitic.

The thickness of the Trempealeau Formation ranges from 30 feet near Stoughton (well Dn–6/11/33–104) to 125 feet in Verona (well Dn–6/8/15–82). St. Peter Sandstone overlies the Trempealeau Formation in several places as a result of pre-St. Peter erosion (fig. 4).

WATER-YIELDING CHARACTERISTICS OF THE SANDSTONES OF LATE CAMBRIAN AGE

The sandstones of Cambrian age form the principal aquifer and are the major source of water for wells in Dane County. Ground water moves through interconnected pore spaces, along bedding planes, and through fractures. Locally, fractures are abundant and large and are the principal channels of movement.

Water may be obtained from all units of the sandstone aquifer, although some units yield more water than do others. The Galesville and Mount Simon Sandstones of the Dresbach Group contain less silt, shale, and dolomite than do the other formations and yield the largest amounts of water. The Eau Claire Sandstone of the Dresbach Group and the Franconia Sandstone yield moderate amounts of water, and the Trempealeau Formation yields the least amount of water.

The specific capacity (gallons per minute per foot of drawdown) of a well is an indication of the rate at which an aquifer will yield water to wells. Factors governing the specific capacity of a well are: the permeability of the rock, the length of uncased hole or the extent to which the aquifer is penetrated, the stage of development of the well, the amount of encrustation on the walls of the well, and the rate and length of time of pumping.

In general, the specific capacity of a well increases as the depth of the uncased hole is increased. In the following table this tendency is exemplified by the specific capacities for two wells that were tested at different depths as the wells were being drilled.

Dn-6/8/22-316		Dn-7/10/16-87 (Madison unit 9)	
Uncased hole (feet)	Specific capacity gpm per ft	Uncased hole (feet)	Specific capacity gpm per ft
369	8.5	105	4.4
629	10	630	21
974	14	730	24

A municipality or other user of large quantities of ground water may generally expect to obtain 200 to 400 gpm (gallons per minute) from a well that penetrates only a few hundred feet of the sandstones of Cambrian age. A well that penetrates the full thickness of the aquifer may yield 1,000 to 2,000 gpm.

Development of wells penetrating the sandstones of Cambrian age, by shooting with dynamite and pumping, generally increases the specific capacity. For example, well Dn-7/10/16-87 (Madison unit 9) was tested before and after shooting and pumping. The well was reportedly pumped for 8½ hours at 1,444 gpm before shooting and had a specific capacity of 16½ gpm per foot of drawdown. After four shots the well was pumped for 8 hours at 1,517 gpm and had a specific capacity of 18 gpm per foot of drawdown. After six more shots the well was pumped for 10 hours at 770 gpm and had a specific capacity of 24 gpm per foot of drawdown. Shooting was probably more effective than pumping in the development of this well. The specific capacities of seven public supply wells, for which information is available before and after shooting, reportedly increased from 2 to 8 gpm per foot of drawdown.

Specific capacities for most of the high-capacity wells tapping consolidated formations in Dane County are listed in table 2. Significantly, most of the wells that obtain water from the Dresbach Group have the highest specific capacities.

TABLE 2.—*Specific capacities of wells in consolidated rock in Dane County, Wis.*

[Length of test: Asterisk (*) indicates days]

Well	Thickness of formation penetrated (feet)								Length of uncased hole below water level [1] (feet)	Length of test (hours)	Pumping rate (gpm)	Specific capacity
	Ordovician			Cambrian								
	Platteville-Galena unit	St. Peter Sandstone	Prairie du Chien Group	Trempealeau Formation	Franconia Sandstone	Galesville Sandstone	Eau Claire Sandstone	Mount Simon Sandstone				
Dn-7/7/3-145					88	90			178	26	500	125
9/10/17-301					60	35	178		273	37	200-380	63
7/9/18-715					63	50	50	425	588	46	4,200	51
8/10/33-84					7	60			67	1	50	50
7/10/34-312				40	100	100	190	10	440	8	919	46
7/10/20-300					4	90	195	85	374	30	870-1,300	40
8/9/35-40					22	50	65		137			40
6/9/7-203		72	0	25	115	40			252	1	350	39
6/10/3-13					28	85	205	75	393		395	36
8/11/2-367					9		607		616	46	145-1,002	32
7/10/8-54					25	115	195	315	650	75	[2] 1,965	30
7/9/22-51						56	240	265	561	*30		28
7/9/30-144						85	280	355	720	8	1,915	26
6/8/14-30				77	105	130	175	115	602	14	376	25
7/8/10-93					29	50	57		136	50	600	25
7/10/16-87				10	100	90	205	325	730	10	1,770	24
8/9/25-372					2	85	265	296	648	40	2,400	24
7/10/34-111					15	120	80	15	230	8	1,000	23
7/10/27-108				11	100	85	20		216	12	220	23
7/10/27-697					102	105	35		242	30	1,370	23
7/10/4-139					9	80	165	358	612	6	2,155	23
7/9/21-52							254	265	519		2,000	22
7/9/19-64					15	100	35		150		400	22
8/11/5-114				45	130	85	215	195	670	30	1,500	21
7/10/16-87					10	90	205	325	630	10	1,652	21
7/9/32-96						110	190	427	727	34	1,520	21
8/11/5-28				76	155	65	215	120	631			20
5/8/34-204				41	120	110	31		302	8	599	20
7/9/23-47							138	370	508	*30		20
8/10/31-53					69	60	310	245	684			20
6/8/15-82		46	0	125	105	60	240	81	657			20
8/10/31-75							130	295	425	24	1,550	19
8/10/31-53							242	245	487		1,750	19
7/9/13-49							10	250	260	*30		19
7/10/17-109					65	95	71		231	8	517	18
7/8/2-698					80	125	533		738	2	2,257	17
7/10/10-307					86	95	215		396	105	1,001	17
8/6/26-38							43	209	252		1,080	16
8/9/26-8					25	55	275	288	643		750	16
7/9/21-52							254	265	519	*30		16
7/10/21-146					9	105	192		306	24	609	15
6/8/22-316				39	120	100	260	455	974	22	983-1,048	14
9/10/17-370							180		180	14	350	14
7/10/34-695				25	105	115	15		260	24	1,170	13
7/10/8-54							165	315	480			13
7/9/28-46						83	215	410	708	*30		13
7/10/9-105					45	50	200		295	11	275-697	13
7/10/4-311					44				44	24	50	13
7/9/19-71				42	100	56			198	1	70	12
5/9/12-73				19	90	80	85		274		747	11
9/8/14-86					83	75			158	10	400	11
6/8/22-316				39	120	100	260	110	629	9	713-1,003	10
7/8/11-119					122	120	215	30	487	12	700	10
7/10/15-280		45	0	10	110	55	20		240	12	329	10
8/9/25-44					80	41			121		225	10
8/12/10-29					85	117			202	10	350	9.5
7/12/21-66				35	95	45	260	112	547		250	9.2
7/8/11-205							250		250	8	712	8.7
7/9/13-7							505		505	*30		8.5
6/8/22-316				39	120	100	110		369	7	300-500	8.5
5/11/5-79					59	50	205	415	729	6	585	7.7
6/12/2-112		55	75	60	26				216	1	69	7.7
6/9/26-122						105	195	415	715			7.5
6/9/7-202				59	100	40			199		60	7.5
7/10/6-50						72	235	275	582	*30		7.3

See footnotes at end of table.

TABLE 2.—*Specific capacities of wells in consolidated rock in Dane County, Wis.*—Continued

Well	Thickness of formation penetrated (feet)								Length of uncased hole below water level[1] (feet)	Length of test (hours)	Pumping rate (gpm)	Specific capacity
	Ordovician			Cambrian								
	Platteville-Galena unit	St. Peter Sandstone	Prairie du Chien Group	Trempealeau Formation	Franconia Sandstone	Galesville Sandstone	Eau Claire Sandstone	Mount Simon Sandstone				
Dn-7/11/9-63	------	------	------	------	83	40	70	------	193	------	217	7
7/10/7-273	------	------	------	------	------	------	77	------	77	------	150	6.8
7/8/11-56	------	------	------	190		10	------	------	200	------	------	6.2
6/6/12-10	------	137	0	85	130	50	127	------	529	10	298	5.5
7/10/30-121	------	------	------	------	------	48	190	360	598	*30	------	5.2
7/9/13-45	------	------	------	------	------	------	223	258	481	*30	------	5.0
8/10/20-60	------	------	------	------	------	------	92	------	92	------	------	5.0
9/10/8-33	------	------	------	------	109	15	------	------	124	72	10	5.0
7/9/25-80	------	------	------	------	35	83	18	------	136	------	24	5
6/6/24-31	------	107	------	------	------	------	------	------	107	------	25	5
8/9/34-77	------	------	------	------	------	16	------	------	16	------	15	5
7/9/13-48	------	------	------	------	------	------	276	240	516	*30	------	4.9
7/10/16-87	------	------	------	15	90	------	------	------	105	------	120	4.4
7/9/33-62	------	------	------	------	77	36	------	------	113	10	140	4.1
7/8/36-91	------	------	------	67	110	70	------	------	247	------	60	4.0
6/10/22-338	------	------	------	14	70	55	15	------	154	4	100	3.8
7/7/16-264	------	------	------	12	------	------	------	------	12	4	10	3.3
6/6/12-9	------	------	198	82	125	80	95	------	580	------	------	3.2
7/8/26-110	------	------	10	75	75	------	------	------	160	------	30	3.0
8/10/19-115	------	------	------	------	------	------	[3]0	------	[3]0	------	30	3.0
7/10/11-76	------	------	------	64	85	------	------	------	149	8	50	2.9
7/9/1-102	------	------	------	------	7	101	33	------	141	------	12	2.4
6/11/33-104	------	------	------	------	------	82	------	------	82	------	42	2.1
7/9/32-37	------	------	------	20	105	30	------	------	155	------	150	1.5
6/6/5-117	------	95	5	------	------	------	------	------	100	1	5	.5
7/8/32-90	31	0	45	------	------	------	------	------	76	------	10	.4
6/8/5-306	------	------	13	35	------	------	------	------	48	1	25	.2

[1] Excludes rocks of Precambrian age.
[2] Last 10 hr only at this rate.
[3] Water enters at open end of casing.

ORDOVICIAN SYSTEM

PRAIRIE DU CHIEN GROUP

The Prairie du Chien Group of Ordovician age overlies the sandstones of Cambrian age (fig. 2) and is composed mostly of dolomite that is generally dense, massive, and hard. The Prairie du Chien is the oldest geologic unit in Wisconsin that contains chert and the only one in which the chert commonly contains small spherical oolites. In addition to chert, shale partings and sandy zones are common in the group, and a thin sandstone unit occurs in places in the middle part. Some algal reefs occur, and these structures together with erosion and lack of laterally traceable beds make it difficult to correlate beds within the Prairie du Chien. The Prairie du Chien Group is distinguished from the underlying Trempealeau Formation on the basis of dominant lithology. Distinction between dolomites of the two units is based on the occurrence of chert in the Prairie du Chien Group and on the absence of chert in the Trempealeau Formation.

The dolomite of the Prairie du Chien Group is more resistant to weathering and erosion than is the underlying sandstone. It caps many of the hills, particularly in the central and northwestern parts of the county (pl. 3).

Between the Prairie du Chien Group and the overlying St. Peter Sandstone is an unconformity having large local relief. The maximum known thickness of the Prairie du Chien Group in the county, 203 feet at well Dn–6/6/12–9 in Mt. Horeb, is only 0.4 mile from where the group is missing entirely (well Dn–6/6/12–10). The Prairie du Chien Group overlies the sandstones of Cambrian age in 34 wells and is missing in 19 wells (fig. 4).

In several areas, T. 6 N., R. 9 E., T. 7 N., R. 8 E., and T. 9 N., R. 11 E., the Prairie du Chien Group is directly overlain by the Platteville-Galena unit. The St. Peter Sandstone was probably never deposited in these areas.

The combined thickness of the Prairie du Chien Group and the St. Peter Sandstone is generally consistent but thins from west to east across the county. In the western part of the county (well Dn–6/6/12–9) the combined thickness is 217 feet, whereas to the east the combined thickness is 120 feet (well Dn–7/10/11–76) (pl. 4). Where the St. Peter Sandstone cuts into the sandstones of Cambrian age the stratigraphic thickness of the St. Peter Sandstone is greater than the combined thickness of the Prairie du Chien Group and the St. Peter Sandstone.

Water moves through joints, cracks, and solution channels in the rocks of the Prairie du Chien Group. The yield of water from adjacent wells may vary greatly because of the irregular distribution and poor interconnection of openings.

Wells penetrating the Prairie du Chien Group generally yield only small amounts of water but locally may yield moderate amounts. The specific capacities for wells penetrating the Prairie du Chien Group are very low. Of six wells that obtain water from this group, three had specific capacities of less than 1 gpm per foot of drawdown (table 2).

Water occurs in the rocks of the Prairie du Chien Group mainly in the southwestern and eastern parts of the county. The group is generally unsaturated in other areas, particularly in northwestern and central Dane County.

ST. PETER SANDSTONE

The St. Peter Sandstone was deposited unconformably on the deeply eroded surface of dolomite in the Prairie du Chien Group and in some areas on sandstones of Cambrian age. St. Peter Sandstone crops out mainly in southern and eastern Dane County (pl. 3), and the thickest sections of sandstone are located in pre-St. Peter valleys, whereas the sandstone is thin or absent on the tops of the pre-St. Peter ridges. A line of wells that show the St. Peter Sandstone to be in contact with the sandstones of Cambrian age extends from the central part of T. 6 N., R. 8 E., to the southwest corner of T. 7 N., R. 9 E. (fig. 4). This line of wells indicates the possible location of one of the pre-St. Peter valleys.

St. Peter Sandstone in Dane County consists mostly of sandstone and partly of conglomerate, siltstone, and shale. The sandstone is mostly fine and medium grained but varies from very fine to coarse, contains much chert and some dolomite fragments, and is dolomitic in places. The conglomerate is composed generally of white chert pebbles and other material derived from underlying formations in a matrix of sandstone and shale. The chert in the St. Peter Sandstone was probably weathered and eroded from the Prairie du Chien Group. The shale, commonly red, occurs mostly in the basal part of the formation and is called "red ochre" by some drillers. The entire formation is variable in lithology both vertically and laterally, but generally the lower part of the formation in pre-St. Peter valleys is the most variable.

As a result of the wide variation in lithology and the presence of the shale at the base, the permeability of the formation is low. The formation will yield the largest amounts of water in areas that have the thickest saturated section, generally in pre-St. Peter valleys, contain the least amount of fine-grained material, and have the largest lateral extent of thick coarse-grained sandstone.

Small to moderate supplies of water can be obtained from the St. Peter Sandstone where it is saturated, mainly in the southwestern, southern, and eastern parts of the county. Generally the specific capacities of wells that obtain water from this unit are not large. Of the seven wells that obtain water from the St. Peter Sandstone, two obtain their water principally from this formation. The specific capacities for these two wells are 5 and 0.5 gpm per foot of drawdown (table 2).

PLATTEVILLE, DECORAH, AND GALENA FORMATIONS, UNDIFFERENTIATED

The Platteville-Galena unit lies on the St. Peter Sandstone, except in the few places where it lies on the Prairie du Chien Group, and consists mostly of dense dolomite that is generally thin bedded in the lower part and massive in the upper part. The Platteville-Galena unit is distinguished from the underlying St. Peter Sandstone on the basis of the difference in dominant lithology. Limestone occurs locally in the lower part of the unit and chert occurs in the upper part.

The Platteville-Galena unit is 315 feet thick at Blue Mounds in western Dane County, the only area in the county where the full sequence occurs. Erosion has removed part or all of the unit elsewhere. The unit crops out mainly in southwestern and eastern Dane County (pl. 3).

Water in the Platteville-Galena unit moves principally through cracks, joints, and solution channels, and these opening are irregular in distribution. In general, the unit is unsaturated except along the high ridge from Blue Mounds to Mount Horeb. Although water can be obtained from wells in the lower or saturated part of the unit, the specific capacities would probably be very low (table 2). Most wells in the Mount Horeb area cannot obtain sufficient water for domestic and stock needs from the Platteville-Galena unit and, therefore, obtain water from the underlying St. Peter Sandstone.

MAQUOKETA SHALE

The Maquoketa Shale is mostly a dolomitic shale but contains some beds of dolomite. This formation is approximately 100 feet thick and occurs only as an eroded remnant on the top of Blue Mounds (pls. 3 and 4). Because of its lithology, location, and small extent, the Maquoketa Shale is not considered to be an aquifer in Dane County.

UNCONSOLIDATED DEPOSITS AND THEIR WATER-YIELDING CHARACTERISTICS

QUATERNARY SYSTEM

Deposits of Quaternary age in Dane County vary greatly in thickness and lithology within short distances. The irregularity of the relief of the bedrock surface causes much of the variation in thickness. The configuration of this surface, shown by contours in plate 5, is nearly the same as the present land surface in the western one-third of the county, except in the deeper valleys where unconsolidated material of considerable thickness was deposited by glacial melt waters. In the glaciated part of the county, drift covers most of the bedrock to varying depths (pl. 4), although bedrock crops out in many places (pl. 5). The Wisconsin and Yahara River valleys are the deepest preglacial valleys in the county and contain the thickest deposits of drift. The maximum known thickness of drift in the county is 372 feet in well Dn–8/10/31–125 in Madison.

A deep depression, apparently formed by glacial erosion, occurs in eastern Madison in the preglacial Yahara River valley (pl. 5). The lowest known altitude of the bedrock surface in this depression is 486 feet in well Dn–8/10/31–125. The depression may be considered as a bedrock basin rather than as part of the preglacial Yahara River valley because the deepest part of the basin is about 100 feet below the valley bottom in Dane County.

The deposits of Quaternary age in Dane County consist of unconsolidated loess, marsh deposits, glacial lake deposits, outwash and alluvium, morainal deposits, and undifferentiated glacial deposits (table 3). Marsh and alluvial deposits were formed principally during Recent time. The distribution of the unconsolidated deposits and the rock sampling sites are shown in plate 2. A more detailed map of the deposits of Quaternary age is shown by Alden (1918, pl. 3).

Loess deposits lie directly on the bedrock on the slopes and hills of the Driftless Area in western Dane County and generally overlie other unconsolidated deposits over the remainder of the county. The thickness of the loess is generally 0 to 10 feet, although some wells have penetrated as much as 20 feet. The loess is generally not saturated.

Loess is composed mostly of angular silt-size particles. A particle-size distribution curve for loess (sample Dn–8/12/17–R10) shows that 70 percent of the particles are in the silt-size range (fig. 5).

TABLE 3.—*Lithology and water-yielding characteristics of the deposits of Quaternary age in Dane County, Wis.*

Unit	General description	Maximum thickness (feet)	Water-yielding characteristics
Loess	Silt with some clay and a little sand; unstratified.	20	Generally unsaturated; does not yield water to wells.
Marsh deposits	Peat and muck.	50	Generally saturated; not used as a source of water for wells in Dane County.
Glacial lake deposits	Clay, silt, sand, and marl; sorted and stratified.	50	Sand may yield small quantities of water.
Outwash and alluvium	Mostly sand and gravel, sorted and stratified.	250	Yield small to large quantities of water. Black Earth Creek valley and the Wisconsin River valley are the most favorable areas for obtaining large yields.
Morainal deposits	Mostly sandy till, consisting of clay, silt, sand, gravel, and boulders; unsorted and unstratified.	220	Isolated lenses of sand and gravel may yield small quantities of water to wells.
Undifferentiated glacial deposits	Clay, silt, sand, gravel, and boulders; unstratified to stratified and unsorted to sorted.	372	Yield small quantities of water. Thick sections of sand and gravel in buried valleys may yield moderate to large quantities of water.

Marsh deposits in Dane County (pl. 2) consist of peat and muck, which average about 5 feet in thickness. Generally, the thickness is less than 20 feet; however, a State Highway Commission of Wisconsin boring went through 50 feet of peat in the Door Creek Marsh in the SE¼SE¼, sec. 30, T. 7 N., R. 11 E. (R. F. Robinson, written communication 1961). In the Madison area most of the marsh deposits have been covered with fill dirt (fig. 12). Generally the water table is near the land surface in the marsh deposits, but these deposits are not used as a source of water.

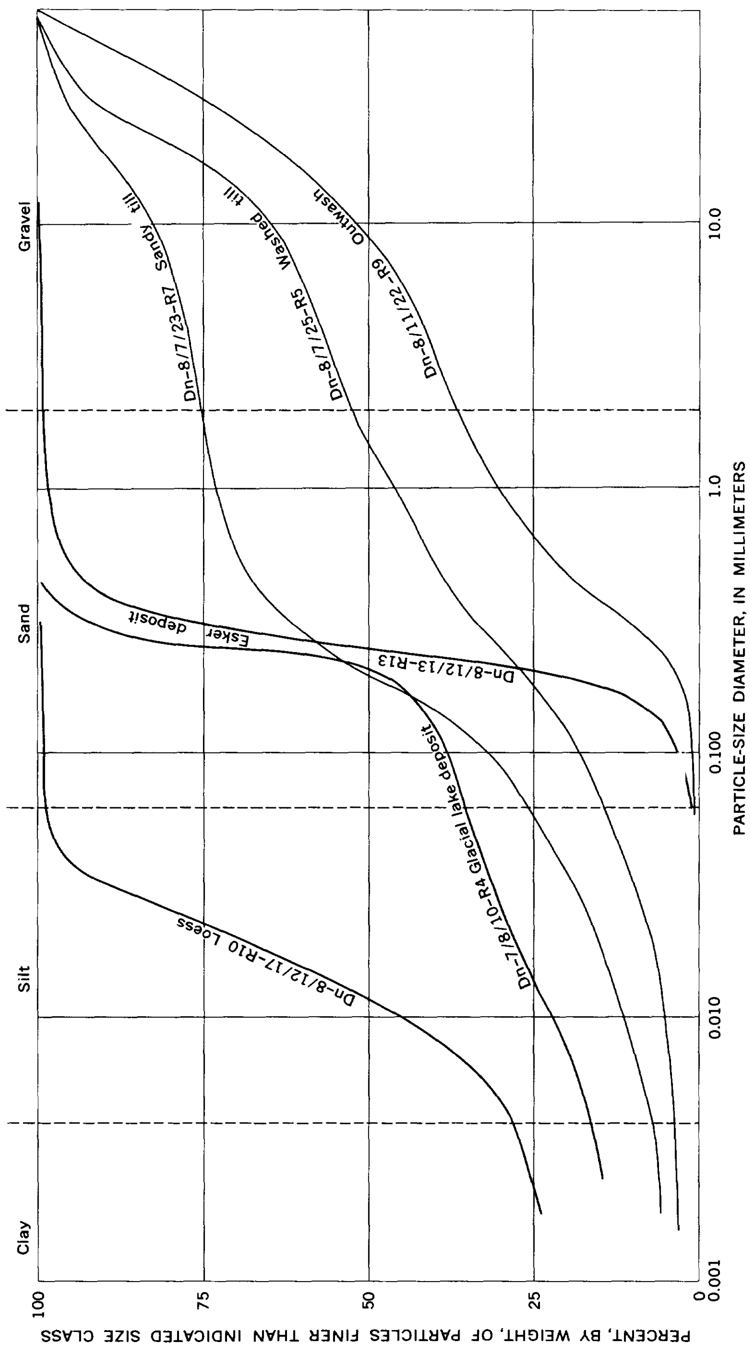

FIGURE 5.—Particle-size-distribution curves of selected deposits of Quaternary age in Dane County, Wis.

Glacial-lake deposits, consisting of stratified and well-sorted clay, silt, sand, and marl, are generally less than 50 feet thick and crop out in only a small part of the county (pl. 2). The deposits are much more extensive than the map shows because they are generally overlain by younger marsh deposits or by existing lakes. The particle-size distribution curve of sample Dn–7/8/10–R4 from a glacial lake deposit shows that 60 percent of the particles consists of fine and medium sand and the remainder consists of clay and silt (fig. 5).

Although wells in glacial lake sand may produce as much as 50 gpm of water, generally they will yield only a few gallons per minute.

Deposits of outwash and alluvium in Dane County are generally in stream valleys and in abandoned drainageways (pl. 2); some outwash and alluvium may be found in buried bedrock valleys. The thickest and most extensive deposits are in the Wisconsin River valley where the outwash and alluvium are more than 200 feet thick. The deposits are more than 100 feet thick in Black Earth Creek valley and in the Sugar River valley. Outwash and alluvium also occur in the valley extending from Madison to Verona and in the valley occupied by Fish and Crystal Lakes in northwestern Dane County.

The outwash and alluvium consist mostly of stratified and sorted sand and gravel. Some of the outwash contains boulders in the eastern two-thirds of the county. A particle-size distribution curve of coarse outwash (sample Dn–8/11/22–R9) is shown in figure 5. Rocks that were too large to collect for analysis, an estimated 15 percent of the deposit, were excluded from the sample. The curve shows that this sample is mostly gravel and has a wide range of particle sizes. In Black Earth Creek valley the deposits of outwash and alluvium appear to become finer grained with increasing distance westward from the limit of glaciation. In the Wisconsin River valley, the deposits appear to be dominantly sand.

The outwash and alluvium are generally excellent sources of ground water and yield small to large quantities of water, depending on the saturated thickness, coarseness, and sorting of the sediments. Well Dn–8/6/4–371 in the outwash of the Wisconsin River valley is reported to yield 633 gpm and to have a specific capacity of 10 gpm per foot of drawdown. Well Dn–7/7/3–32 in outwash in the Black Earth Creek valley is reported to yield 112 gpm and to have a specific capacity of 24 gpm per foot of drawdown. Substantially higher yields may be obtained from properly screened and developed wells penetrating a maximum thickness of the saturated sand and gravel aquifer.

The morainal deposits that form the Johnstown, Milton, and Brooklyn moraines (pl. 2) consist mostly of sandy till. Till is composed of unsorted and unstratified clay, silt, sand, gravel, and boulders but locally contains some minor deposits of stratified sand and gravel. A sample of sandy till in Dane County (Dn–8/7/23–R7) contains 49 percent sand and has a very wide range of particle sizes, as shown in a particle-size distribution curve (fig. 5). A sample of washed sandy till (Dn–8/7/25–R5) is intermediate in lithology between sandy till and outwash. Note that the particle-size distribution curve for the washed till falls between the curves for sandy till and outwash (fig. 5).

The thickness of the morainal deposits is highly variable. Several wells in the morainal deposits penetrated more than 150 feet of glacial drift before penetrating bedrock, and one well (Dn–9/7/5–672) penetrated 220 feet of drift without entering bedrock.

The morainal deposits generally yield little water, although isolated lenses of sand and gravel may yield small amounts of water to wells. In the past, dug wells have obtained a few gallons per minute from the morainal deposits. At the present, wells are generally drilled through the morainal deposits into bedrock or into buried outwash deposits.

The undifferentiated glacial deposits that cover large areas of the northeastern half of Dane County are of mixed composition and origin and form drumlins, moraine (mostly ground moraine), kames, crevasse fills, and eskers (pl. 2). Buried valleys may contain outwash.

The drumlins and ground moraine are composed of sandy till similar to sample Dn–8/7/23–R7 (fig. 5), whereas the kames, crevasse fills, and eskers are composed of sorted and stratified clay, silt, sand, and gravel. A particle-size distribution curve of well-sorted sand from an esker (sample Dn–8/12/13–R13, fig. 5) shows that 89 percent of the sample is composed of fine and medium sand.

The undifferentiated glacial deposits are thickest in the buried valleys. The maximum known thickness of these deposits is 372 feet at well Dn–8/10/31–125 in Madison. Most of the drift in this well is clay, silt, and very fine sand. Wells that penetrate the undifferentiated glacial deposits rarely penetrate more than 100 feet of sand and gravel.

The undifferentiated glacial deposits generally yield small amounts of water to wells but may yield moderate to large amounts of water where thick deposits of sand and gravel occur in buried valleys.

The thickest saturated deposits of Quaternary age are generally the areas most favorable for obtaining large amounts of water. The preglacial Wisconsin and Yahara River valleys contain more than 200 feet of saturated drift (pls. 5 and 6). The drift in the Yahara River valley contains more clay and silt than sand and gravel. The only place where the thickness of the saturated drift is known to exceed

300 feet is in the bedrock basin (pl. 5) in sec. 31, T. 8 N., R. 10 E. (See pl. 6.) Most of the county contains less than 100 feet of saturated drift.

The specific capacities for 30 wells in sand and gravel of Quaternary age average 4.1 gpm per foot of drawdown and range from 1 to 24 gpm per foot of drawdown (table 4). Wells tapping sand and gravel in the Black Earth Creek valley have the highest specific capacities.

TABLE 4.—*Specific capacities of wells in sand and gravel of Quaternary age in Dane County, Wis.*

Well	Depth of well (feet)	Length of screen (feet)	Length of test (hours)	Pumping rate (gpm)	Specific capacity (gpm per ft)
Dn-5/10/7 -655	110	[1] 0	5	15	4
21-657	73	[1] 0	1	20	5
30-660	88	[1] 0	1	15	8
5/11/ 5-652	50	3	1	8	4
16-596	49	[1] 0	1	21	1
17-586	164	[1] 0	1	10	2
18-591	114	[1] 0	1	10	2
21-589	144	[1] 0	1	10	5
22-588	64	3	1	7	1
27-584	131	[1] 0	1	10	5
32-582	98	[1] 0	1	10	5
33-580	97	5	1	10	2
5/12/25-299	158	10	13	175	8
571	78	2	1	21	4
36-262	142	[1] 0	4	10	1
6/10/ 9-561	90	4	8	7	1
10-555	160	[1] 0	24	6	2
14-548	104	[1] 0	12	6	1
23-542	170	[1] 0	4	10	1
6/11/29-533	55	[1] 0	1	6	2
536	47	2	6	10	5
30-537	60	[1] 0	1	10	5
32-530	173	8	12	10	1
7/ 7/ 3-32	49	6	5	112	24
11-231	99	[1] 0	30	26	13
7/12/33-447	81	[1] 0	3	12	3
8/ 6/ 4-371	110	4	--------	633	10
15-233	193	5	6	22	1
8/11/ 2-428	106	2	10	20	5
9-423	95	10	35	10	2

[1] Water enters open end of casing.

GROUND WATER

OCCURRENCE AND MOVEMENT

Most of the ground water in Dane County is derived from precipitation that falls in the county. When rain falls or snow melts, some runs off into streams, some seeps into the ground, and most evaporates or is transpired by plants—a process called evapotranspiration. The water that percolates downward to the zone of saturation is called recharge and becomes ground water.

The zone of saturation is where all the available void space in the rock are filled with water, and the water is under pressure equal to or greater than atmospheric pressure. The surface of the zone of saturation is the water table and is the level at which water stands in nonpumping wells under unconfined conditions. Under artesian (confined) conditions the water level in a well is above the top of the aquifer.

In Dane County, the ground-water reservoir consists of water-saturated rocks of Cambrian, Ordovician, and Quaternary ages and has as a base the surface of the rocks of Precambrian age. These saturated rocks may be considered as a single ground-water reservoir or aquifer in most places in Dane County.

Ground water occurs under water-table and artesian conditions in Dane County. Glacial till partially confines the ground water under a small hydrostatic pressure in many places in the eastern two-thirds of the county, whereas water-table conditions prevail in the western part of the county. Ground water in the sandstones of Cambrian age generally is partially confined. The upper part of the sandstone is unsaturated in some places, particularly in the northwest quarter of the county.

Ground water moves through rock in response to gravity from points of higher head (water levels indicate head) to points of lower head, the rate of movement being proportional to the hydraulic gradient and the permeability of the rock. The hydraulic gradient is the ratio between the difference in head and the distance the water moves along the path of travel. Permeability indicates the ease with which water can move through the rock and is determined by the size, shape, and interconnection of voids in the rock. Voids consist of pore space, fractures, and solution channels.

Permeability of rocks and movement of ground water in Dane County are generally greater parallel than perpendicular to the rock's bedding. Rock strata having low permeability—such as clay, shale, and dolomite—retard the vertical movement of water by confining the water under pressure in the more permeable underlying rocks. Water can move through these strata, but more slowly than through sand, gravel, and sandstone.

Rock fractures or joints in Dane County may be important as paths of ground-water movement. Probably much of the vertical movement of ground water is along fractures, especially in the less permeable zones. A current-meter test of a 500-foot well in sandstones of Cambrian age in McFarland (Dn–7/10/34–312) showed that nearly all the water came from a 5-foot section of dolomitic siltstone at the base of the Trempealeau Formation. The water was moving into the well along a fracture or solution channel. An aquifer test of a well in western Madison (Dn–7/9/18–715, Madison unit 14) showed a hydraulic interconnection between the Dresbach Group and the overlying Franconia Sandstone, whereas a test of a well in southwest Madison (Dn–7/9/30–144, Madison unit 12) showed little interconnection between the Dresbach Group and overlying formations. Fracturing probably accounts for the hydraulic interconnection between formations at well Dn–7/9/18–715.

Shale occurs locally in the Eau Claire Sandstone and is a partial barrier to the vertical circulation of water. A temperature profile of a well in Verona (Dn–6/8/22–316) shows a more rapid temperature change across a 35-foot shaly zone in the Eau Claire Sandstone than above and below the shaly zone. This temperature change indicates that at this well the shale retards movement of water between the overlying and underlying sandstones. Water is partially confined in some zones in the dolomite of the Prairie du Chien Group, and water levels in wells tapping different zones may differ by as much as 50 feet. A well in the dolomite may tap several water-yielding zones, each having a different hydrostatic pressure (water level). Some of the water-yielding zones may even be perched, separated from a lower saturated zone by an unsaturated zone.

Vertical movement of water through the St. Peter Sandstone is generally good, except in the basal part of the unit where shale and poorly sorted material retard the movement of water. In places where the St. Peter Sandstone rests directly on the sandstones of Cambrian age, the circulation of ground water between the two units is more rapid than in places where the Prairie du Chien Group is present.

Circulation of water through the Platteville-Galena unit is poor and occurs principally through fractures and solution channels.

Circulation of water through outwash and alluvium is generally good; however, silts and clays or poorly sorted material, if present, will retard the movement. Circulation of water between sand and gravel deposits and bedrock is generally good, unless retarded by material that has low permeability.

Although all the saturated rock units are considered as one groundwater reservoir, at some places the units may act as separate, but closely related, aquifers between which leakage takes place. Leakage can take place where differences in head occur between shallow and deep zones. Differences in head between units may be large and can occur where steep hydraulic gradients, induced by large topographic

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relief or pumpage, move ground water much more rapidly along the bedding than the water can move vertically across the bedding.

In the Blue Mounds-Mount Horeb area, water levels are much higher in wells tapping the Platteville-Galena unit than in wells tapping the St. Peter Sandstone. Water levels are in turn higher in wells in the St. Peter Sandstone than in wells in the sandstones of Cambrian age. The differences in head are caused by steep hydraulic gradients which are induced by large topographic relief. The piezometric map (pl. 7) is not contoured above 1,040 feet in this area because of the large difference in water levels and the scarcity of observation wells.

In southwest Madison water levels in wells tapping the St. Peter Sandstone, Prairie du Chien Group, and upper part of the sandstones of Cambrian age are higher than in wells tapping the Dresbach Group. The water level in well Dn–7/9/30–144 (Madison unit 12), which is 986 feet deep, is about 100 feet lower than the water levels in nearby wells, which are 70 to 295 feet deep (pl. 7). The difference in head is caused by the steep hydraulic gradient induced by heavy pumping of wells.

Water levels that are lower in the deep formations than in the shallow formations indicate that water is moving downward and recharging the deep formations. Conversely, water levels that are higher in the deep formations than in the shallow formations indicate that water is moving upward and discharging from the deep formations. Some of the water obtained from the deep Madison municipal wells is from local recharge in the Madison area, as shown by the changes in the water level in well Dn–7/9/16–266, which responds both to pumping from the deep city well and to recharge from precipitation (figs. 6 and 10). During 1959, although pumping of the city well continued, the water level in well Dn–7/9/16–266 stopped declining and started to rise in response to recharge from the above-normal precipitation (fig. 6).

Ground water moves through the aquifer from points of recharge, such as high areas, to points of discharge, such as springs, streams, lakes, wells, and drainage ditches. The piezometric surface (a surface to which water from a given aquifer will rise under its full head) in Dane County in April–May 1960 is shown in plate 7. Contours are lines of equal altitude on this surface. Ground water moves from points of higher altitude on the piezometric surface to points of lower altitude along a path that crosses the contour lines at right angles.

The piezometric surface, in general, is a subdued replica of the topography, the water levels being deep under the hills and ridges and shallow in the valleys. On the piezometric map, the high and low

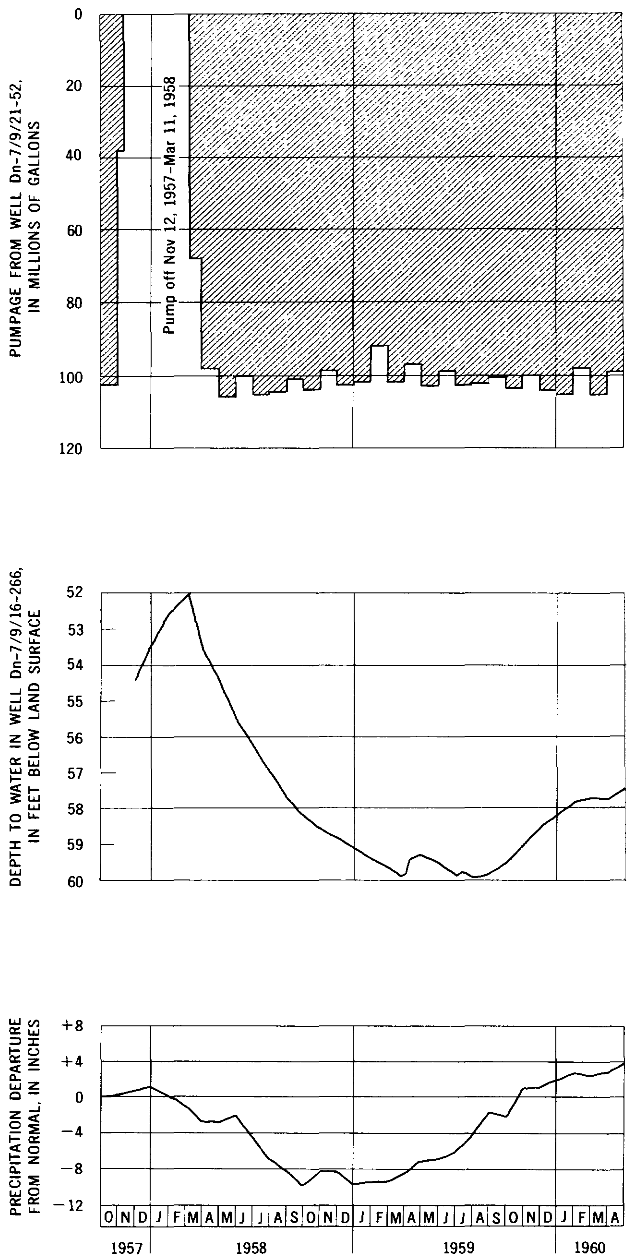

Figure 6.—Water pumped from well Dn–7/9/21–52, hydrograph of well Dn–7/9/16–266, and cumulative departure from normal monthly precipitation at North Hall, Madison, Wis., October 1957 to April 1960.

areas coincide generally with the high and low topographic areas, respectively. In the glaciated part of Dane County, however, the piezometric surface does not correspond as closely to the topography as it does in the rest of the county. The glacial deposits are partially confining, and the relief of the land surface is less in the glaciated part of the county than it is in the unglaciated part.

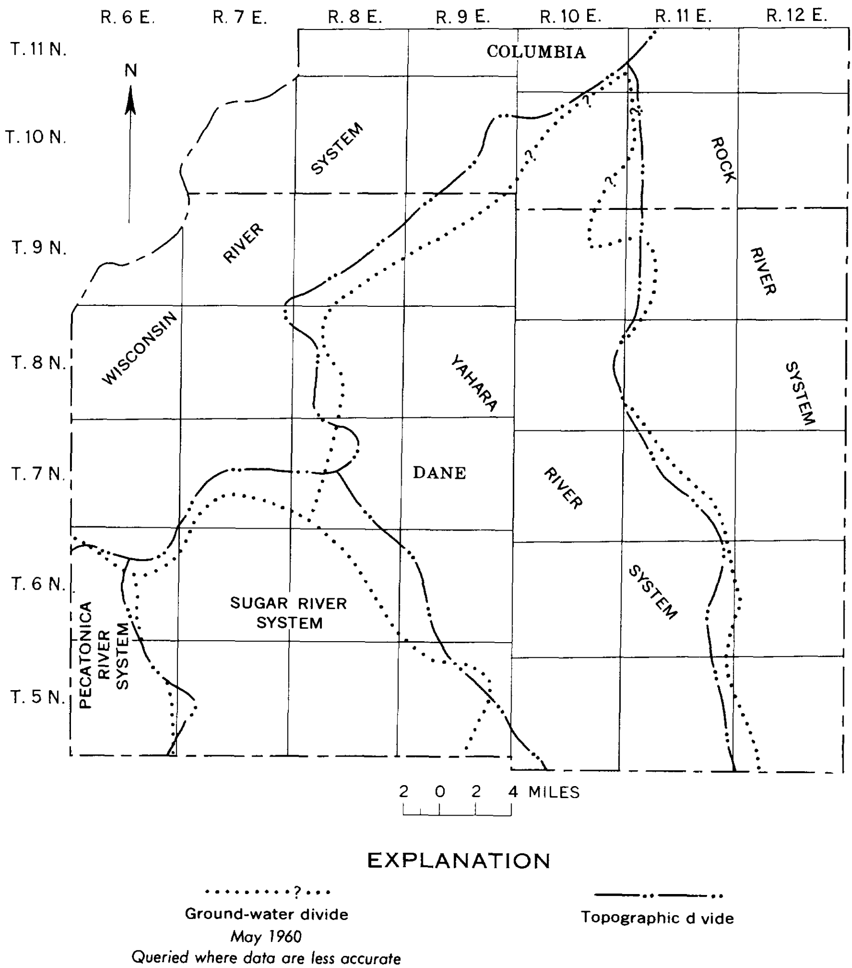

FIGURE 7.—Ground-water and topographic divides in Dane County and southern Columbia County, Wis.

The major ground-water divides in Dane County (pl. 7 and fig. 7) are the boundaries of the ground-water basins in the county. The proximity of the ground-water divides to the topographic divides (fig. 7) shows that ground water and surface runoff are discharged from approximately the same areas. Ground water moves from a divide toward an area of discharge, generally a stream. For example, ground water moves from the divide near the village of Dane northwest toward the Wisconsin River and southeast toward the Yahara River and Lake Mendota.

The ground water being discharged in the Madison area is derived solely from the Yahara River ground-water basin (fig. 7). The basin, generally coincident with the topographic divide, extends a few miles into Columbia County. The maximum distance that ground water has moved to the Madison area is about 20 miles.

Pumping creates a cone of depression in the piezometric surface that can shift the ground-water divide and thus changes the configuration of the piezometric surface and diverts ground water from one area to another. Pumping from the Madison area may be partly responsible for the difference between the ground-water and topographic divides in T. 6 N., R. 8 E. (fig. 7). The shifting of the ground-water divide to the southwest means that ground water that formerly moved to the Sugar River system is intercepted and is now part of the Yahara River system.

Movement of ground water under natural conditions is extremely slow. In Dane County, ground water moves a few feet or less per day except near pumping wells. Movement of a few tenths of a foot per day is common.

In Madison, ground water moves toward the lakes and Yahara River, except for areas of pumpage where movement is toward the wells. Cones of depression in the piezometric surface surround high-capacity wells (pl. 7). The elongated cone of depression between Lakes Mendota and Monona indicates local movement of water from the lakes toward the wells. The pumping of deep wells also affects the movement of water in shallow sand and gravel deposits near Lake Mendota. For example, a shallow test hole in glacial silt and sand about 540 feet from Lake Mendota, in the center of sec. 15, T. 7 N., R. 9 E., on the University of Wisconsin campus, had water levels that ranged from 4 to 5 feet below the water level of Lake Mendota. At this location, water is moving out of Lake Mendota into the glacial drift and sandstone. The fact that ground-water levels are higher than the lake level at the west end of Lake Mendota indicates that ground water is discharging into the lake. Generally ground water discharges into the lakes except near areas of heavy pumping.

Ground-water and surface-water levels are closely related as shown by the almost simultaneous rises and declines of the water levels in well Dn–7/9/16–303 and Lake Mendota (fig. 8). The well is about 250 feet from the lake (pl. 8) and in sandstones of Cambrian age. Water

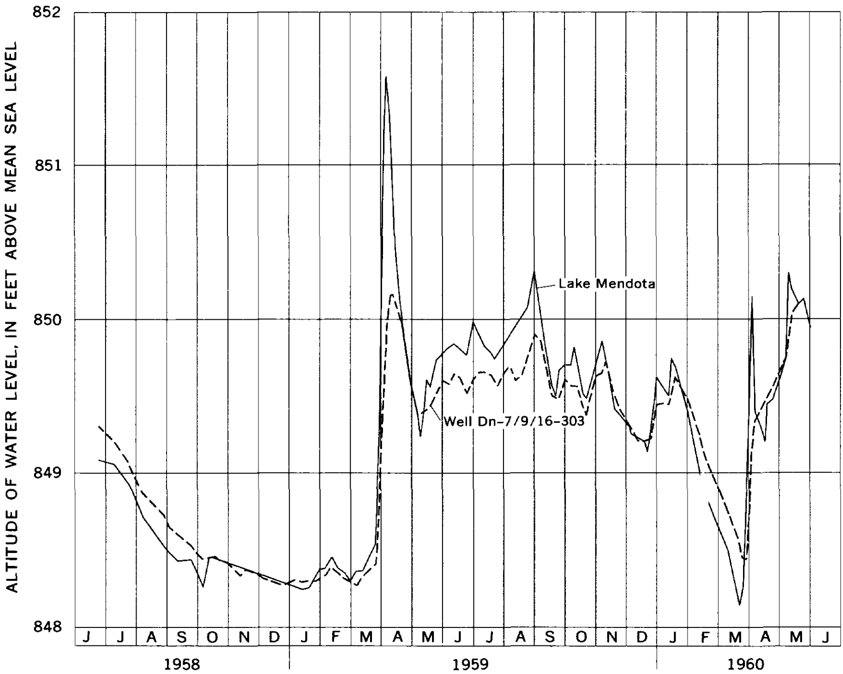

FIGURE 8.—Hydrograph of well Dn–7/9/16–303 and stage of Lake Mendota, Madison, Wis., June 1958 to May 1960.

moves back and forth between the aquifer and the lake, as shown by the alternately higher water levels in the well and the lake.

DISCHARGE

The ground-water reservoir is depleted continuously by discharge and is replenished intermittently by recharge. When discharge exceeds recharge, water is released from storage and ground-water levels decline. When recharge exceeds discharge, water goes into storage and water levels rise. Discharge equals recharge if, over a period of time, the net change in water levels is zero.

Ground water is discharged naturally in Dane County by springs and seeps into streams, lakes, and ditches and by evapotranspiration, and is discharged artificially by pumping from wells.

Ground-water discharged from Dane County is estimated to be about one-fifth of the average annual precipitation of 31 inches, or about 6 inches of water. Ground-water discharge by streamflow averages about 5 inches of water per year over the county. The net loss of ground water by underflow out of the county is estimated to be one-half inch per year. Ground-water discharge by evapotranspiration is estimated to be about one-half inch per year, and although most of the water pumped by wells is discharged into streams, a small amount is lost.

SPRINGS

Most of the water discharged from springs becomes part of streamflow. The majority of the 229 springs inventoried in 1958–59 in Dane County by the Wisconsin Conservation Department (written communication) are in the southern part of the county. Thirteen of the springs discharged more than 200 gpm, 10 between 100 and 200 gpm, and the remainder less than 100 gpm. The largest discharge was reported to be more than 2,000 gpm from a cluster of springs near the southwest end of Lake Waubesa.

STREAMS AND LAKES

The ground water discharged in Dane County goes mostly to streams and lakes and makes up the largest part of the streamflow. The annual streamflow from the county is estimated to average about 600 cfs (cubic feet per second), or approximately 390 mgd (million gallons per day), based on an average of 6½ inches of runoff over the county. Measurements of streamflow of Black Earth and Mount Vernon Creeks, during 1955–61, indicate that the base flow (ground-water contribution) varies between 60 and 95 percent of the total annual flow. If one assumes that about three-fourths of the annual streamflow from the county is ground-water discharge, then the annual ground-water contribution to the streams is about 450 cfs—about 290 mgd or about 5 inches of runoff over the county.

An overall relationship of long-term trends exists between the streamflow of the Yahara River, measured near the village of McFarland at the gage at the outlet of Lake Waubesa, precipitation at Madison, and the ground-water level in a well near Sun Prairie (fig. 9). When annual precipitation exceeds the long-term yearly average, the water level in well Dn–9/11/34–4, rises, and when precipitation is less than the long-term average the water level declines. Although streamflow may increase rapidly within a brief time after an increase in precipitation and a rise in water levels, a long-term increase in streamflow is generally in evidence after increases in precipitation and ground-water levels (fig. 9).

The discharge of ground water to streams is continuous and is reflected by a decline in ground-water levels except during short periods of recharge. In well Dn–8/6/26–11 (fig. 10), the declines of the water level, following the rises due to recharge, suggest that ground water is moving away from the area, principally toward a nearby stream.

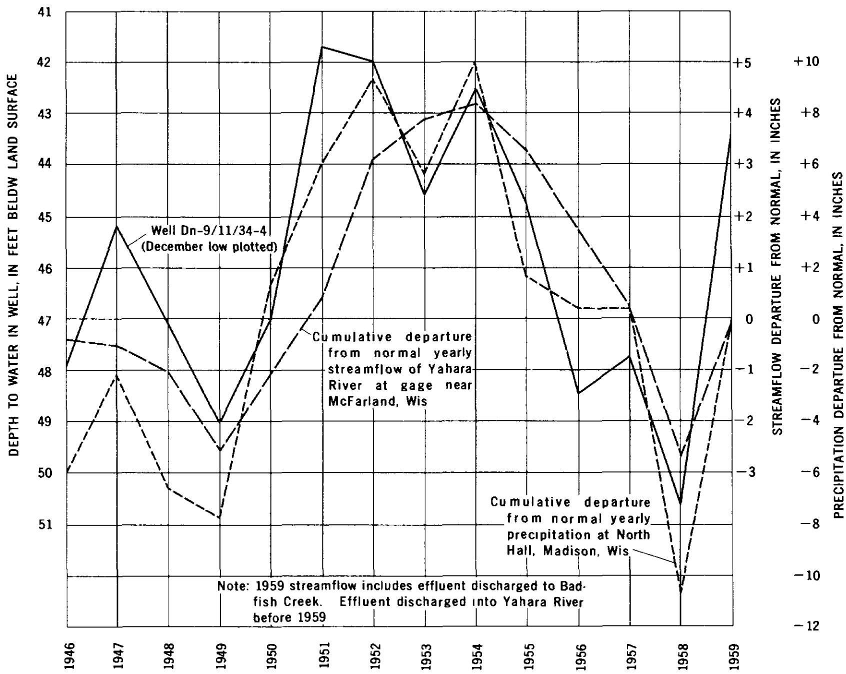

FIGURE 9.—Cumulative departure from normal yearly precipitation and streamflow in the upper Yahara River basin, Wisconsin, and hydrograph of well Dn-9/11/34-4, 1946–59.

EVAPOTRANSPIRATION

Water is lost to the atmosphere by evapotranspiration. In general, evaportranspiration is greatest over surface-water bodies, less in areas where the water table is near the land surface, and least in areas where only soil moisture can be discharged to the atmosphere. The evapotranspiration rate from that part of the Yahara River basin covered largely by lakes and marshes is about equal to the precipitation (fig. 16).

Evapotranspiration from soil moisture depends on the amount and distribution of precipitation and the availability of ground water, and is greatest where the water table is near the land surface. In these areas the difference between precipitation and potential evapotranspiration (the rate at which water is transpired by vegetation that is never short of water) is in part made up of ground water. Ground-water discharge by evapotranspiration occurs between May and October and is greatest between June and August when temperatures are high and vegetation is abundant (fig. 11).

Ground-water discharge by evapotranspiration was computed to be about one-half inch per year over the county on the assumptions that

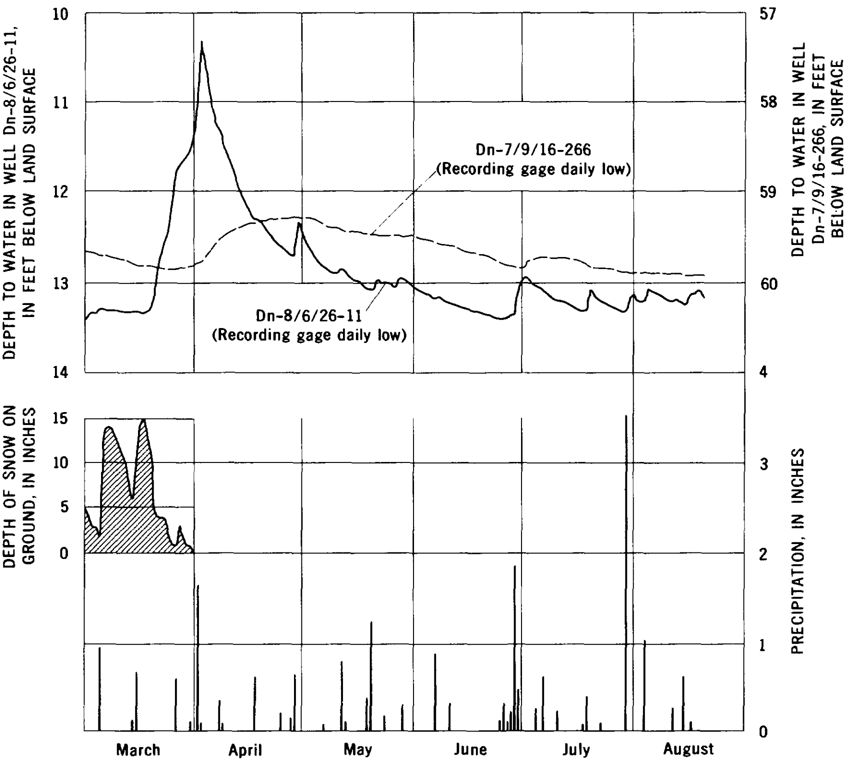

FIGURE 10.—Hydrographs of wells Dn-8/6/26-11 and Dn-7/9/16-266, snow on the ground at Traux Field, and daily precipitation at North Hall, Madison, Wis., March 1 to August 20, 1959.

the entire difference of 4.6 inches between evapotranspiration and precipitation (fig. 11, this report; Thornthwaite and others, 1958, p. 47) was made up of ground water in areas (excluding lakes) where the water table lies within 10 feet of the land surface and that no ground water is discharged by evapotranspiration from areas where the water table lies more than 10 feet below the surface.

Evapotranspiration of ground water occurs principally from marshes and lowlands along streams, where the water is near or at the surface, and it is probably greater in the eastern part of the county than in the western part because the water table in the eastern part is near the land surface over more of the area. Areas covered by marshes have been considerably decreased by ditching and draining and by filling, particularly in the Madison area (fig. 12). Dane County contained only about 70 square miles of wetlands in 1959 as compared with about 105 square miles in 1939 and with a much more extensive area in the 1840's, according to the Wisconsin Conservation Department (1961).

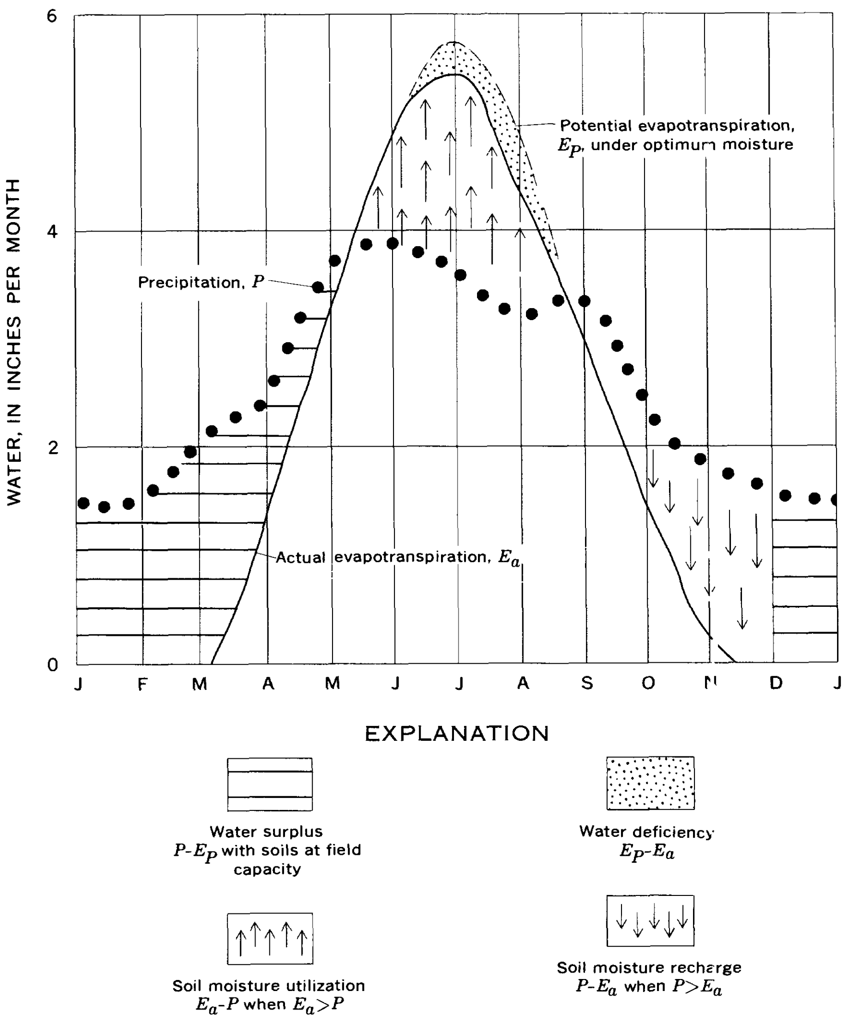

Figure 11.—The water balance at Madison, Wis. Adapted from Thornwaite, Mather, and Carter (1958).

Draining the marshes and covering the land surface with manmade structures change the hydrologic regimen slightly. For example, draining the marshes increases streamflow because evapotranspiration is decreased. Thus, if 1 square mile of marsh is drained and put into crops, streamflow is increased by about 0.4 cfs, or about 6 inches of runoff per year—an amount equal to the difference between a rate of evaportranspiration from a free water surface of about 31 inches per year (fig. 16) and a rate of potential evapotranspiration from a land

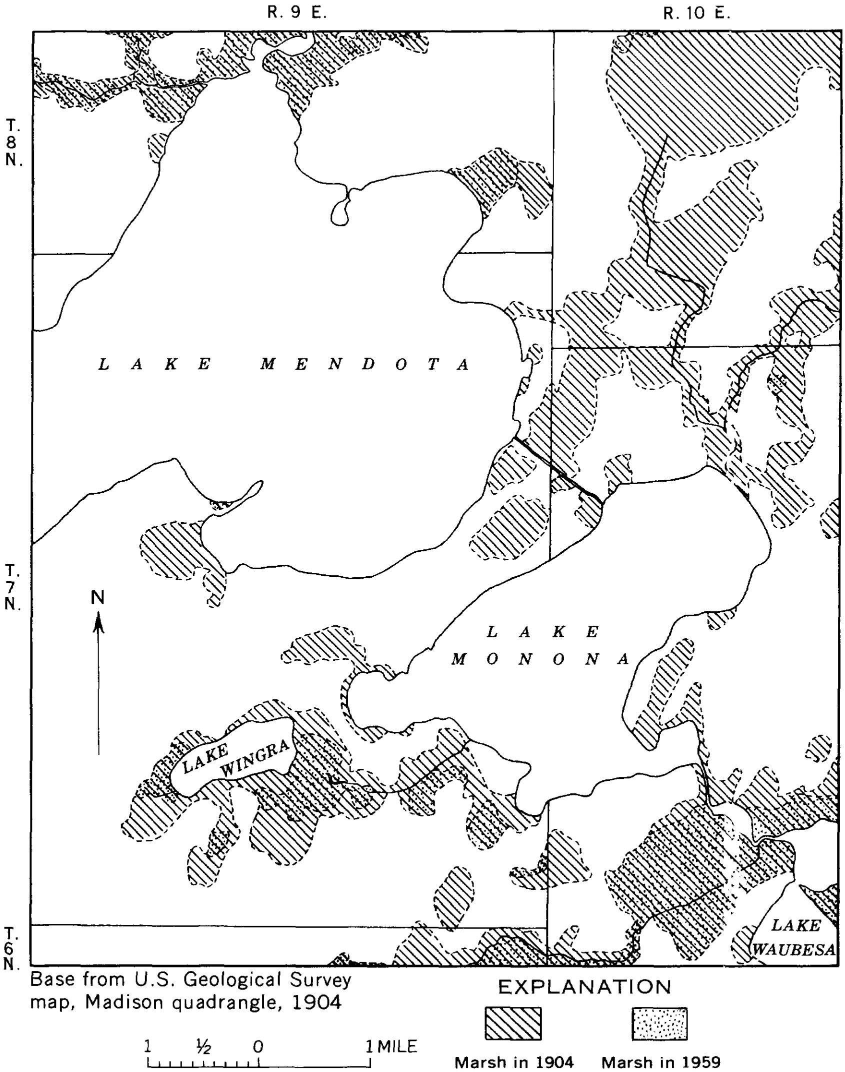

FIGURE 12.—The extent of marsh in 1904 and 1959 in the Madison area, Wisconsin.

surface covered with vegetation of 25 inches per year (Thornthwaite and others, 1958, p. 47).

PUMPAGE

Ground-water pumpage in Dane County has increased rapidly in the last 30 years (1930–60), especially in the Madison metropolitan area (fig. 13). Pumpage records show that the total pumpage of ground water in the county increased from 16 mgd in 1931 to 35 mgd in 1959. The total pumpage in 1959 was equal to about 10 percent of the average annual streamflow in all the streams leaving the county. A projection of the increase of past pumpage and population indicates

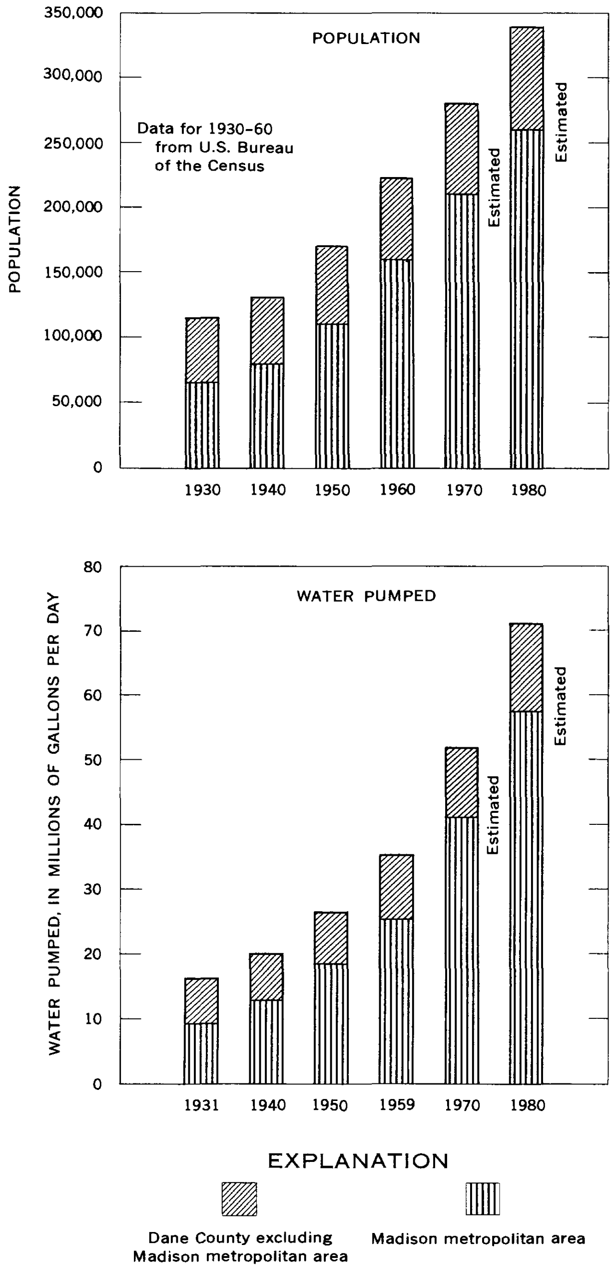

FIGURE 13.—Population and pumped water in Dane County, Wis., 1930–80. Estimated population and pumpage from Dane County Citizen's Planning Committee, 1961.

that the use of ground water will double again by 1980, possibly reaching 71 mgd (Dane County Citizens' Planning Committee, 1961; fig. 13 this report).

Since 1931, pumpage in the Madison metropolitan area has increased rapidly, while pumpage in the remainder of Dane County has increased only slightly (fig. 13). In 1931, 9½ mgd were pumped in the Madison area, or 58 percent of the total pumpage in the county. By 1959, 25 mgd were pumped in the area, or 73 percent of the county pumpage. The distribution of the pumpage in the county in 1959 is shown in figure 14. By 1980, pumpage in the Madison area will probably be about 58 mgd, or about 80 percent of the total pumpage in Dane County.

Before December 1958, the treated effluent from the Madison metropolitan area was discharged into the Yahara River at the north end of Lake Waubesa.

Of the 25 mgd pumped from wells in the Madison metropolitan area in 1959, about 21 mgd was discharged into Badfish Creek in southern Dane County as effluent, 1½ mgd was discharged from Nevin Fish Hatchery as streamflow into the Yahara River, and the remainder (2½ mgd) was lost to evapotranspiration and consumptive use or seeped into streams, lakes, and the ground-water reservoir. Most of this pumpage was from wells located upstream from the outlet of Lake Monona within a circular area about 10 miles in diameter (pl. 8).

Water levels in the vicinity of pumping wells rise and decline in response to changes in pumping (fig. 6). For example, the city of Madison well, Dn–7/9/21–52 (Madison unit 6), which had been pumping for about 6 months, was turned off on November 12, 1957, and the water level in well Dn–7/9/16–266, 1,900 feet away (pl. 8), rose at least 2.5 feet in 4 months. After pumping was resumed on March 11, 1958, water levels in well Dn–7/9/16–266 declined 8 feet in a year. Because pumping of the city well (Dn–7/9/21–52) since March 1958 continued to be relatively constant, the water level in well Dn–7/9/16–266 approached a state of stability, and natural changes in recharge and discharge became noticeable.

The two areas of heaviest pumping in the Madison metropolitan area (pl. 8) are the Madison main station wells (Dn–7/9/13–7, –45, –48, and –49) and the Oscar Mayer & Co. wells (Dn–8/10/31–74, –75, and –125). The deepest cones of depression shown on the piezometric map (pl. 7) are in these areas and are caused by large withdrawals of water from small areas. The water levels in each of these two deep cones are about 60 feet lower than they were before pumping began. Pumping of other wells in the vicinity has deepened the cones slightly (pl. 8), but water levels in the Madison area have not been lowered

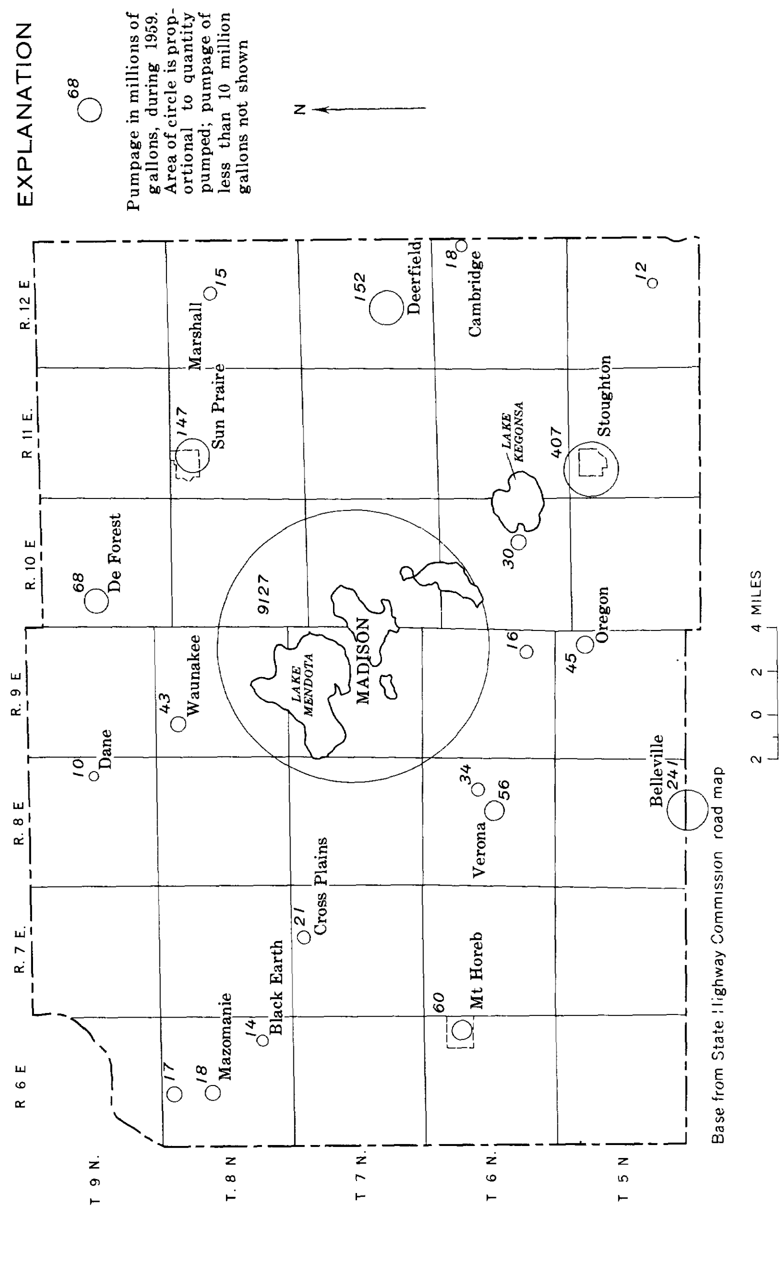

FIGURE 14.—Ground water pumped in 1959 in Dane County, Wis.

enough to make pumping levels excessive or to dewater the aquifer significantly.

In Madison, the lowering of ground-water levels through pumpage may have helped to reduce the extent of marshes (fig. 12). The discharge of ground water into marshes is reduced by the lowering of water levels. Where discharge has ceased, surface-water runoff that has accumulated in the marshes may recharge the ground-water reservoir.

The flow of the Yahara River in the Madison metropolitan area is reduced by pumpage from wells that locally intercepts ground-water discharge to Lakes Mendota and Monona. The water pumped in the Madison metropolitan area is diverted as treated effluent out of the upper Yahara River basin and is emptied into the lower part of the same basin by way of the Badfish Creek. The flow of the Yahara River in the upper part of the basin is reduced by an amount approximately equal to the pumpage of the Madison metropolitan area, unless additional water is captured by shifting the ground-water divides.

Pumpage from wells in the Madison metropolitan area in 1958 was about 25 percent of the 29-year average annual streamflow (97.5 mgd) of the Yahara River at the outlet of Lake Waubesa, and was estimated to be about 35 percent at the outlet of Lake Monona. The estimate of the discharge from Lake Monona is based on work by Lenz (1944) and a comparison of several discharge measurements from Lake Mendota and Lake Waubesa.

The pumping of 4,200 gpm for 46 hours from well Dn–7/9/18–715 (Madison unit 14) in western Madison stopped the flow of Spring Harbor Creek and reduced the flow of several springs. The creek, 440 feet from the well, flowed 12 gpm before the pumping test. One of the springs, 1,300 feet from the well, was reduced in flow from 95 gpm before the pumping test to 22 gpm at the end of pumping. The decrease in the flows of the spring and creek show that ground water had been diverted from its normal course of discharging into streams and lakes when it was discharged from wells.

Increased pumpage and the placing of many large-capacity wells around the lakes might in the future drastically reduce the discharge of water into the lakes. Increased pumpage around Lake Monona would affect Lake Mendota little because Lake Monona is downstream; however, increased pumpage around Lake Mendota would affect both lakes.

RECHARGE

Precipitation is the principal source of recharge to the ground-water reservoir in Dane County. A small amount of ground water enters Dane County as underflow from Columbia and Iowa Counties. The amount of recharge varies with amount and intensity of precipitation, slope of land surface, geology, soil moisture, frost in the ground, and water stored as snow and ice.

The intensity and amount of rainfall affect the amount of recharge to a ground-water reservoir. Much of the water from a high-intensity rain may run off directly to streams instead of contributing to recharge. Gentle rains of long duration generally supply the most recharge to the ground-water reservoir. For example, the water level in well Dn–7/9/16–266 (fig. 10) did not respond to the high-intensity rain of July 29; however, it did respond to the precipitation at the end of June, when rains—equal in amount to the July 29 rain—occurred over a 7-day period.

In areas of steep slopes, runoff is more rapid and recharge is generally less than in areas having gentle slopes or poor drainage.

In general, shallow water levels in wells in unconfined aquifers respond more quickly to recharge from precipitation than do deep water levels in wells in confined aquifers. The magnitude of water-level fluctuations is generally less in wells near streams than in wells that are distant from streams. For example, the magnitude of the fluctuations in well Dn–8/6/26–11, about 600 feet from a stream, was about 2 feet during 1957–60, whereas the magnitude in well Dn–9/11/34–4, 1½ miles from a stream, was about 14 feet (fig. 15). The actual magnitudes are somewhat greater, as only the monthly low water levels are shown in figure 15.

When soil moisture is deficient, water from precipitation may replenish the soil moisture instead of percolating downward to the water table. Soil moisture is generally deficient in the summer, when evapotranspiration exceeds precipitation, and is generally replenished in the autumn (fig. 11).

In winter, there is generally little recharge, and water levels decline because water is stored as frost in the ground and as snow and ice on the land surface. In Dane County the ground is usually frozen from about the first of December through most of March, a period during which the average monthly temperature is below 32° F. Snow on the ground is generally present over the same period.

Generally, most recharge occurs in the spring after the temperature rises above freezing. Water from the melting of snow and frost in the ground and from spring rains rapidly recharges the ground-water body and results in rising water levels (figs. 10 and 15). Spring rains occur when soil moisture is at a maximum and evapotranspiration is near a minimum.

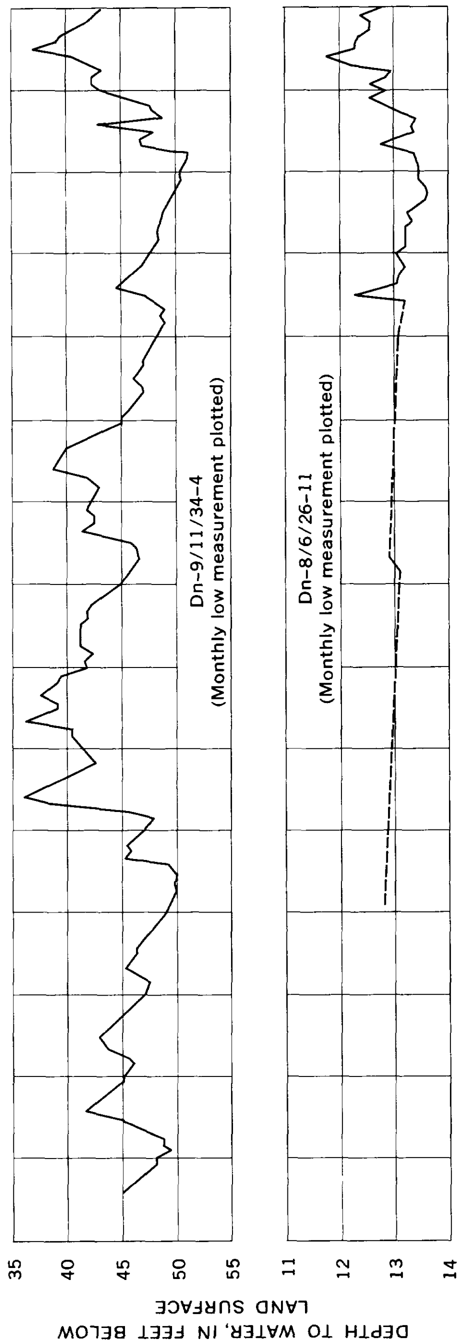

FIGURE 15.—Hydrographs of wells Dn-9/11/34-4 and Dn-8/6/26-11, Dane County, Wis., 1946-60.

Recharge in Dane County equals discharge, about 6 inches, if storage remains generally constant. Although storage varies seasonally and to some extent from year to year, water levels indicate that there has been no significant net change in storage (fig. 15). Thus, recharge to the ground-water reservoir in Dane County is estimated to be about 6 inches, or about one-fifth of the average annual precipitation.

In the upper Yahara River basin, an estimate of recharge to the ground-water reservoir can be made by comparing the amount of ground water moving across the 870-foot piezometric contour of the basin to the amount of precipitation falling in the area between the boundary of the basin and the 870-foot contour (fig. 16). The amount of precipitation that becomes recharge is about one-fifth of the average annual precipitation. Thus, the amount of recharge to the ground-water reservoir in the upper Yahara River basin is estimated to be about 6 inches.

WATER BUDGET OF UPPER YAHARA RIVER BASIN

A generalized water budget of the upper Yahara River basin, north of the outlet of Lake Waubesa (fig. 16), shows the amount of water in various environments in the hydrologic cycle and indicates in a general way the relationships between different components of the hydrologic cycle in the basin. The total amount of water entering the basin by precipitation equals the total amount leaving the basin by evapotranspiration, by streamflow, and by underflow. Evapotranspiration losses are about 80 percent of precipitation for the basin. Ground-water underflow leaving the upper Yahara River basin is negligible because of the nearly flat hydraulic gradient downstream.

AQUIFER TESTS

Several aquifer tests were made in Madison to determine the hydraulic characteristics of the sandstones of Cambrian age. The hydraulic characteristics of an aquifer can be used to determine the effects of pumping on water levels in wells at different distances from a pumped well for various times and rates of pumping, and to determine the volume and velocity of water moving through the aquifier. These determinations are made by using mathematical equations derived for an ideal aquifer model selected to correspond to the actual aquifer.

The hydraulic characteristics are commonly expressed as the coefficients of transmissibility and storage. The coefficient of transmissibility is expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide and extending the full saturated height of the aquifer, under a hydraulic gradient of 1 foot per foot. The coefficient of storage

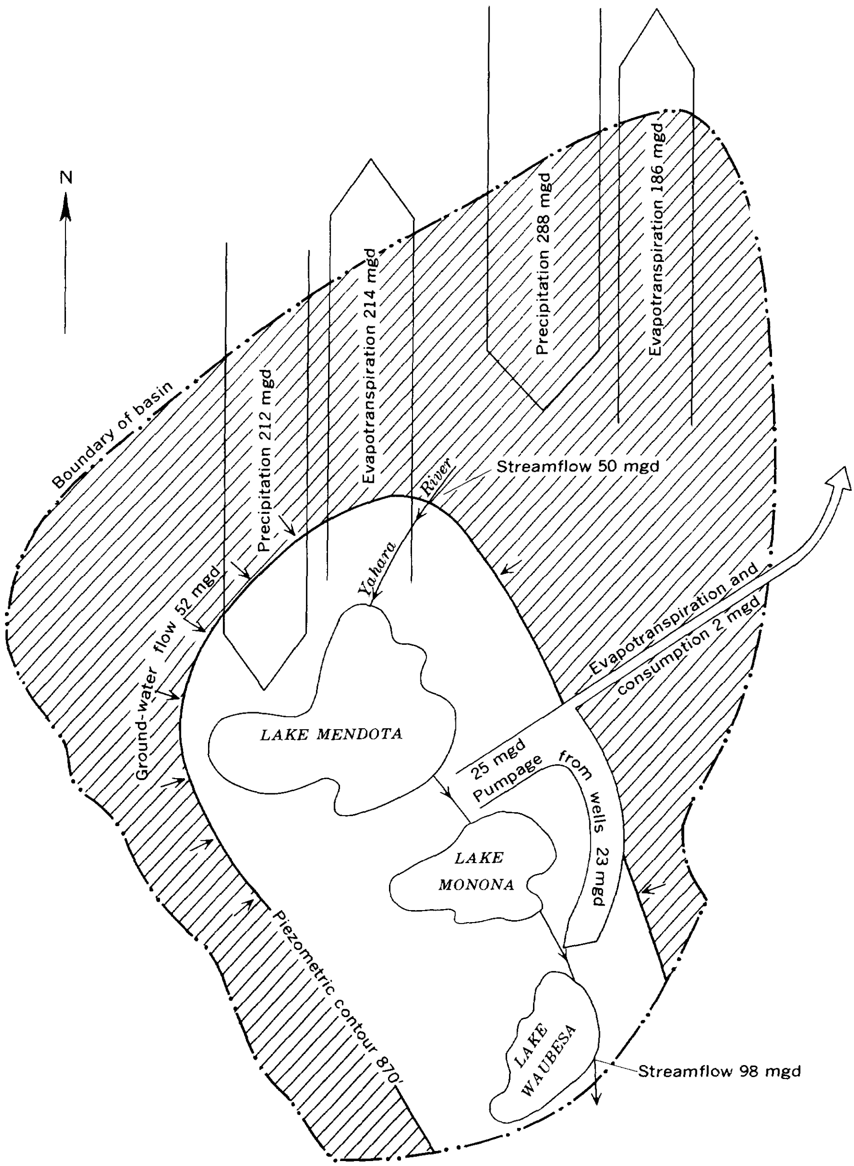

FIGURE 16.—Generalized water budget of upper Yahara River basin, Wisconsin, 1931–58.

of an aquifer is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The aquifer tests were made by first pumping wells at uniform rates and measuring the rates of drawdown in the pumped wells and in other nearby wells and then stopping the pumps and measuring the rates of recovery.

Data from the tests were analyzed by use of the nonequilibrium formula (Theis, 1935) in which it is assumed that the aquifer is infinite in areal extent, homogenous and transmits water in all directions with equal ease, and confined between impermeable beds. Other assumptions are that the coefficients of transmissibility and storage are constant, the discharging well penetrates the entire thickness of the aquifer, and the discharged water is released from storage instantaneously with decline in head. Because these conditions are never fully met in nature, judgment must be used in deciding the validity of the results. Only one test gave credible results, although several other tests gave qualitative information.

The coefficients of transmissibility and storage for the sandstones of Cambrian age, determined on the basis of data obtained from pumping well Dn–7/9/30–144 (Madison unit 12) in southwestern Madison and from measuring the effects on water levels in two observation wells, are as follows:

Observation well	Distance from pumped well (feet)	Coefficient of transmissibility gpd per ft		Coefficient of storage	
		Drawdown	Recovery	Drawdown	Recovery
Dn–7/9/30–144 (Madison unit 12)	0	47, 200	40, 700	--------	--------
7/9/31–201	3, 450	58, 000	47, 200	0. 00038	0. 00044
7/9/32–96 (Madison unit 10)	7, 650	49, 200	48, 400	. 00037	. 00031
Average		48, 500		. 00038	

Well Dn–7/9/30–144 was pumped at a rate of 1,975 gpm for 24 hours. Wells Dn–7/9/30–147, –150, –151, Dn–7/9/31–154, –155, and Dn–7/9/32–37 (pl. 8) did not respond to the pumping because they obtained water from formations that overlie the Dresbach Group. The distance of these wells from the pumping well ranged from 1,600 to 5,450 feet.

Tests performed by pumping wells Dn–7/10/4–139 (Madison unit 11), Dn–7/10/9–105, and Dn–7/10/16–87 (Madison unit 9) indicate that the coefficient of transmissibility is lower in eastern Madison than it is in southwestern Madison at well Dn–7/9/30–144. Tests of wells Dn–7/9/18–715 (Madison unit 14) and Dn–7/9/21–52 (Madison unit 6) in western Madison near Lake Mendota indicate that the coefficient of transmissibility may be higher near the lake. Recharge from Lake

Mendota and fractures in water-yielding strata probably are factors contributing to the higher yields.

Values of 40,000 gpd per ft (gallons per day per foot) for the coefficient of transmissibility and 0.0004 for the coefficient of storage were chosen as being representative for the sandstones of Cambrian age in the Madison area. The theoretical drawdown of water levels at various distances from a well pumping 500 gpm and 2,000 gpm after 30 days, 1 year, and 10 years is shown in figure 17. The curves are based on the assumption that all water is withdrawn from storage and do not show the effects of recharge. This figure can be used in Dane County to predict effects of pumping on water levels in wells and in the Madison area to indicate drawdown for short distances and times. Recharge and discharge boundaries, if present, must be considered.

Comparison of the observed water-level decline with the calculated decline in the cone of depression between Lakes Mendota and Monona in the vicinity of the main station group of wells indicates that most of the water withdrawn from the aquifer is locally derived. For example, the observed decline 2,000 feet from the center of the cone is 10 to 15 feet (after 80 years of pumping) (pl. 7), whereas the calculated decline, if one assumes that all water is withdrawn from storage, would be 80 feet (after 20 years of pumping).

Many artesian aquifers are bounded by semipermeable beds that can transmit large quantities of water under a steep hydraulic gradient. The equation for head declines in a leaky aquifer (Hantush and Jacob 1955, p. 95–100 and Hantush, 1956, p. 702–714) should be used to predict water-level declines in such an aquifer.

The leaky aquifer equation was derived for an ideal homogeneous and isotropic aquifer of infinite areal extent overlain by a homogeneous semiconfining bed of uniform thickness above which a water table or water surface is maintained at a constant level. Use of the leaky aquifer model requires a knowledge of the coefficients of transmissibility and storage for the aquifer and the coefficient of leakage (the vertical permeability of the semiconfining bed divided by the thickness of the bed) for the aquifer system.

The leaky aquifer model may be used to represent the sandstones of Cambrian age in parts of the Madison area. The drift and upper part of the sandstones, which are cased off in the large-discharge wells, act as a semiconfining bed. The water table in the drift is maintained at an approximately constant level by the lakes and marshes in the area. The water tables does decline a few feet at some distance from the lakes or wetlands when water is pumped from the sandstones of Cambrian age. This decline can probably be ignored for predictions made from the leaky aquifer model.

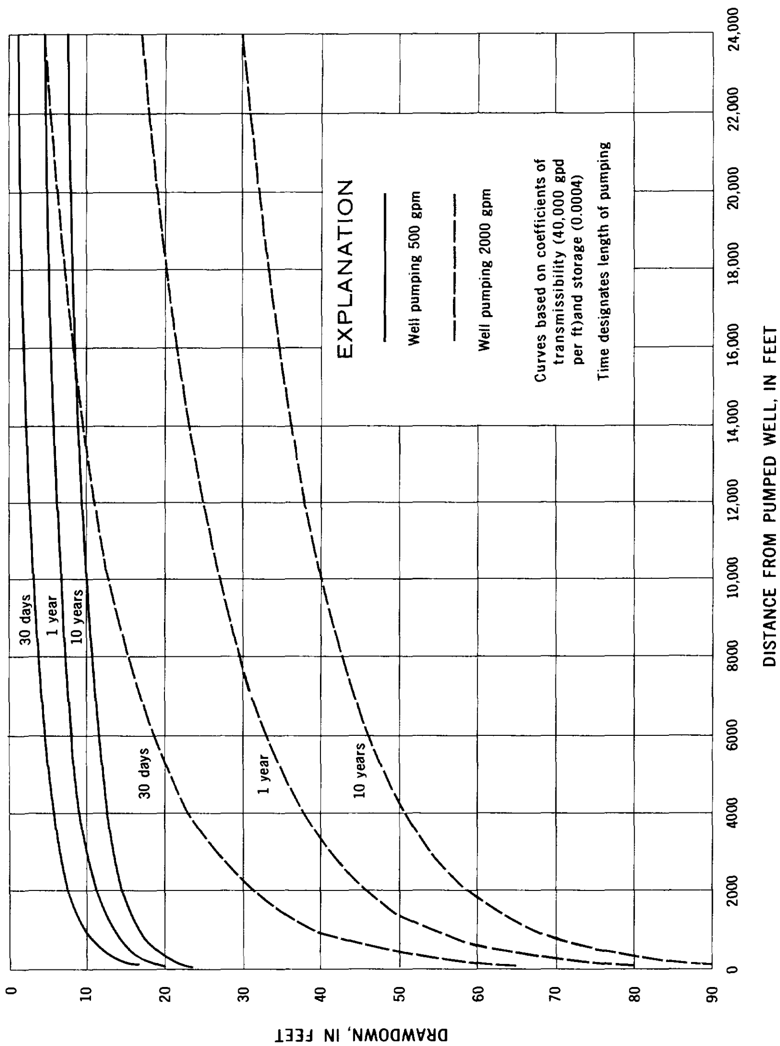

FIGURE 17.—Theoretical distance-drawdown curves determined for pumping from the sandstones of Late Cambrian age at Madison, Wis. (Not adjusted for boundaries.)

Rough estimates of the leakage coefficient have been determined for two areas in Madison. One estimate was made from an analysis of the drawdown cone resulting from pumping of the municipal wells in the main station group (wells Dn–7/9/13–7, –45, –48, and –49), and the other was made from water-level data collected at well Dn–7/9/16–266 during an aquifer test on well Dn–7/9/21–52 (Madison unit 6). The analyses indicate a vertical permeability of the confining bed materials of about 0.2 gpd per sq ft in the vicinity of the main station group, and of about 0.1 gpd per sq ft in the vicinity of well Dn–7/9/21–52. The vertical permeability may be higher in the vicinity of Spring Harbor, where springs and a small stream were affected during a test on well Dn–7/9/18–715 (Madison unit 14).

When a well in a leaky aquifer is pumped, the cone of depression expands until the differences in head between the artesian aquifer and the overlying water table are great enough to induce recharge at a total rate equal to the well discharge. Once the induced recharge equals the well discharge, the cone of depression ceases to expand (reaches equilibrium), provided sufficient water is available to maintain a constant level in the unconfined aquifer and to perennially supply the artesian aquifer.

The distribution of drawdown at equilibrium in leaky aquifers is shown in figure 18. The equation used for computing the curves shown (Hantush, 1956, p. 707–711) assumes that the water table does not respond to pumping in the artesian aquifer. For most of the Madison area, this assumption seems to be reasonable because the water table is maintained at approximately constant levels by lakes and swamps. The vertical permeability of the semiconfining bed of 0.2 gpd per sq ft and the assumed values of the other coefficients are probably representative of the sandstones of Cambrian age in much of the Madison area.

The leaky aquifer model is useful in predicting water-level changes in the Madison area caused by changes in the rate of ground-water withdrawal. For example, an increase of 50 percent in the pumping rate of the Madison main station group (wells Dn–7/9/13–7, 45, 48, and 49) would probably cause an additional drawdown of about 6 or 7 feet at a distance of 2,000 feet from the center of the cone and about 2 or 3 feet at a distance of 5,000 feet. Pumping lifts might be increased by more than 50 percent because the upper part of the aquifer would be dewatered near the wells. Dewatering part of an aquifer decreases the thickness available to transmit water, and thus increases the resistance to flow and lowers the water levels.

The theoretical specific capacity of a well can be determined from the coefficients of storage and transmissibility, the latter being the

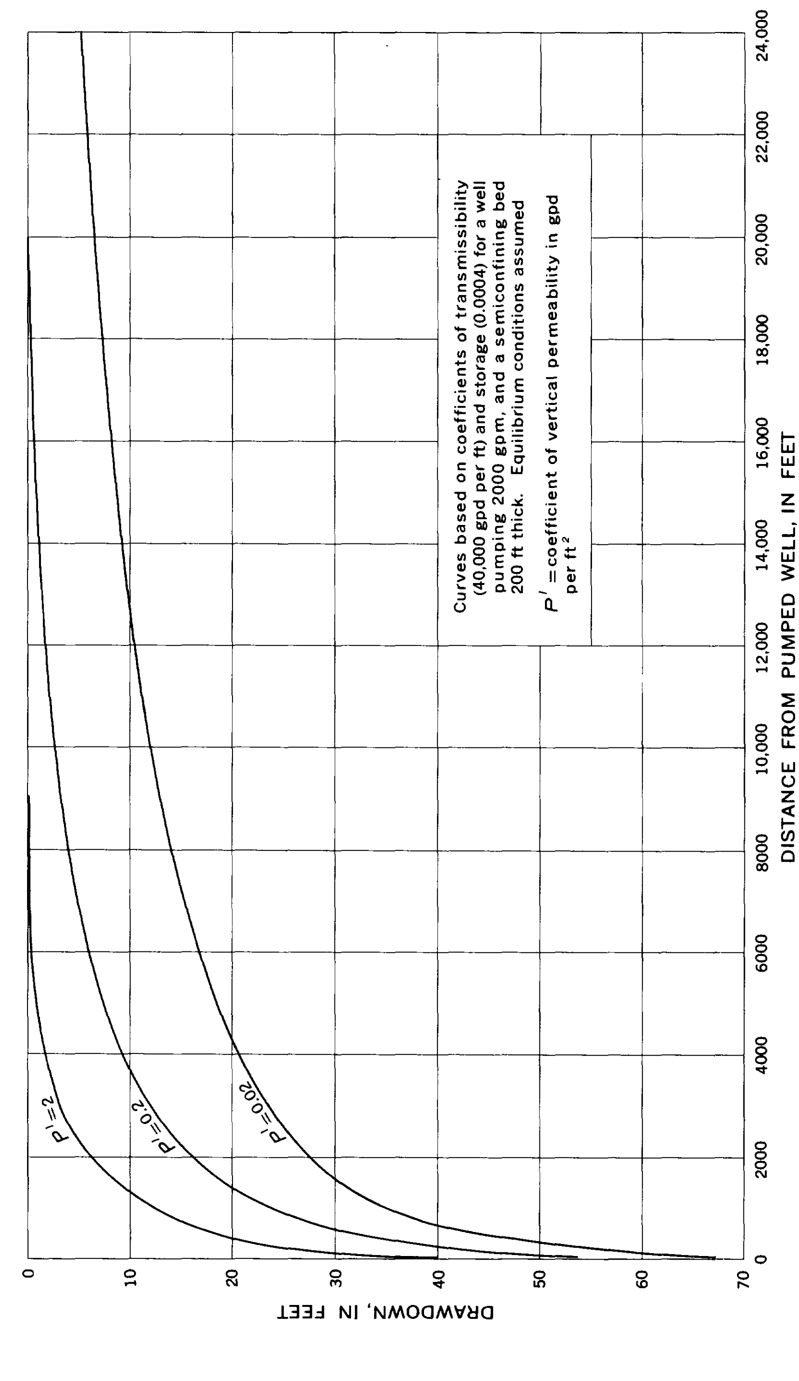

FIGURE 18.—Theoretical distance-drawdown curves determined for pumping from the sandstones of Cambrian age at Madison, Wis. (Vertical leakage is assumed.)

major controlling factor. For a coefficient of storage of 0.0004 and a coefficient of transmissibility between 40,000 and 50,000 gpd per foot, values typical for sandstones of Cambrian age in Madison, the specific capacity of a well should be approximately 20 to 35 gpm per foot of drawdown after pumping 24 hours, if one assumes that no entrance losses occur in the well. Entrance losses, caused mainly by inadequate well development and construction and by encrustation on the walls, lower the specific capacity even though the coefficients of storage and transmissibility remain the same. Specific capacities of most of the newer city of Madison wells are in the expected range of 20 to 25 gpm per foot of drawdown. Some wells in Dane County have abnormally high specific capacities, probably because of large openings in the rock and local recharge.

QUALITY OF GROUND WATER

CHEMICAL CHARACTERISTICS

Ground water in Dane County is a very hard calcium magnesium bicarbonate water that is generally uniform in composition in all water-yielding strata (table 5 and fig. 19). The chemical analyses of water from wells tapping the sandstones of Cambrian age are of water from deep wells except those for wells Dn–7/7/10–226, Dn–7/9/16–303, and Dn–8/7/31–271. Figure 19 shows representative chemical analyses of water from wells in each of the geologic units given in table 5, except the Platteville-Galena unit.

Calcium, magnesium, and bicarbonate are the principal constituents in ground water in Dane County. The dissolved solids average 348 ppm (parts per million), and the calcium magnesium hardness averages 326 ppm (table 6). In table 6, all except one of the 163 analyses for calcium magnesium hardness were more than 200 ppm.

Excessive iron (more than 0.3 ppm) occurs in ground water in the Wisconsin River valley, the Yahara River valley, and in other areas of the county (fig. 20). Iron in ground water appears to be more prevalent in glacial drift than in other geologic units and appears to be more prevalent in poorly drained areas than in well-drained areas. Although iron concentration in ground water may vary with depth, no pattern is discernible from the available data. Reported statements by well owners about objectionable iron concentrations were used as guides to determine boundaries of areas where iron generally exceeds 0.3 ppm (fig. 20).

More than half the samples of water analyzed contained no iron or only a trace (less than 0.05 ppm); however, slightly more than one-

TABLE 5.—*Selected chemical analyses of ground water in Dane County, Wis.*

[Results in parts per million except specific conductance and pH. Source of analysis: G, U.S. Geol. Survey; L, Wisconsin State Laboratory of Hygiene; W, Weidman and Schultz (1915). Geologic source: €u, sandstones of Late Cambrian age; Opc, Prairie du Chien Group; Osp, St. Peter Sandstone; Opg, Platteville, Decorah, and Galena Formations; Q, deposits of Quaternary age]

Well	Date of collection	Geologic source	Source of analysis	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite (NO_2)	Nitrate (NO_3)	Dissolved solids (residue at 105°C or 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Sulfides as H_2S
Dn-5/ 8/34-39	12-29-44	€u	L			0.0	0.0	60	36		381	6.4	3.8	<0.1			292	330			7.2	0.0
5/ 9/12-73	12- 7-44	€u	L			.0	.0	60	32		303	10	7.0	<.1			292	315			7.5	.0
5/11/ 5-79	1- 9-58	€u	L			.5	.0	66	46		391	9.5	1.5	<.1			324	329			7.4	.0
6/ 8/22-316	4- 1-59	€u	L	51		<.05	.0	59	41	4.1	368	13	1.0	<.1			354	310			7.5	
7/ 7/10-226	4-23-58	€u	L	50		<.05	.0	69	40	3	330	28	10	<.1			360	318			7.4	
7/ 9/13-45	10-17-46	€u	L			.2	.0	59	33		335	17	5.5	<.1			290	310			7.8	.0
16-303	6-26-58	€u	L	49		.2		73	40	4	359	22	10	<.1			348	324			7.6	
23-47	1933-35	€u	L			.2	.0				370	10	11		0.0	0.0	343	315				
	8-22-45	€u	L			.0	.0	68	36		378	24	10	.1			344	335			7.3	.0
	4-30-52	€u	G		13	.1	.0	63	42	7.0	374	30	7.5			.8	350	331	23	615	7.2	
	5- 6-57	€u	L			.1	.0	58	32		334	1.2	1.5	.1			298	270			7.6	
	2- 2-61	€u	L			.1	.12	84	44		405	73	16	<.1	.0	1.6	476	434			7.0	
30-144	5-26-58	€u	L			<.05	.0	59	36		332	1.7	1.0	<.1			268	271			7.6	
7/12/21-66	8-24-59	€u	L			.1	.0	58	49		431	8.0	1.5	<.1			360	360			7.4	.0
8/ 6/16-12	2-14-45	€u	L			.4	.0	61	36		350	16	8.0	<.1			294	295			7.3	.0
8/ 7/31-271	4- 9-58	€u	L			.6	.0	59	30	3	283	16	4.5	<.1			272	256			7.8	

8/10/31-53	12- 4-44	Єu	L			.4	.0	70	42		398	11	9.0	<.1			344	350			7.2	.0
	4-30-52	Єu	G					68	38		390	14	2.7					328		592	7.6	
	2- 2-61	Єu	L			.5	.0	70	36		388	14	.0	.0	.0	.0	328	318			7.3	
8/11/ 5-114	8-31-55	Єu	L			.0	.0	66	34		366	3.0	4.0	<.1			314	311			7.3	.0
9/ 8/14-86	12-29-49	Єu	L			.0	.0	94	47		336	112	27	<.1			526	424			7.3	.0
9/10/17-370	1-28-24	Єu	L			.0					378		15		.02	15	332	335				
	11-15-33	Єu	L			.0	.0	72			361	20	13		.0	.2	348	370				
	1-26-45	Єu	L			.0	.0	67	44		369	25	10	<.1			334	375			7.4	.0
	6- 8-60	Єu	L	50		<.05	<.05	67	38	4	361	29	6.0	<.1		.5	342	328			7.1	
6/ 6/12-9	1-24-45	Єu, Opc	L			.0	.0	76	53		383	50	20	<.1			434	430			7.3	.0
-10	11-17-47	Єu, Osp	L			.0	.0	54	31		282	10	9.0	<.1			308	265			7.3	.0
6/12/17-517	9- 3-59	Opc	L			.8	.0	81	41	9	374	43	9.5	<.1			484	377			7.6	
23-509	9- 2-59	Opc	L			<.05	.0	64	35	1	325	28	3.0	<.1			348	307			7.6	
8/12/13-390	8-19-59	Opc	L			<.05	.0	71	37		366	20	4.5	<.1			348	330			7.8	
33-399	8-21-59	Opc	L			.1	.18	80	46	2	391	33	10	<.1			410	378			8.4	
9/11/35-410	8-17-59	Opc	L			<.05	.0	64	34		271	33	9.0	<.1			340	298			8.2	
5/ 9/24-706	5- 5-60	Osp	G			<.05	.0				416	45	24	.1		82		454	113	886	7.8	
8/11/23-430	8-24-59	Osp	L			<.05	.0	75	37		364	32	11	<.1			422	348			7.6	
8/12/35-401	8-21-59	Osp	L			<.05	.0	92	42		400	38	15	<.1			566	428			7.9	
9/12/12-380	8-19-59	Osp	L			<.05	.0	88	42		418	27	36	<.1			468	408			7.6	
25-386	8-19-59	Osp	L			.1	.0	69	34		383	14	2.5	<.1			342	322			7.6	
6/ 6/ 6-615	1-22-09	Opg	W		15			72	40	5.8	364	45	8.9				367					
12-614		Opg	W		5.9			72	37	44	350	16	78				427					
5/10/ 7-655	4-18-60	Q	G	52		<.05	.0				290	18	5.5	.1		9.4		266	28	492	8.0	
5/11/22-588	4-19-60	Q	G	54		.2	.0				344	31	14	.1		30		332	50	642	7.9	
6/10/23-542	1-29-60	Q	G	50		1.4	.05				374	4.2	2.0	.5				305	0	544	7.8	
7/ 7/ 3-32	4- 9-58	Q	L	50		<.05	.0	67	38	3	364	12	2.5	<.1			310	311			7.7	
3-229	4-23-58	Q	L	50		<.05	.0	57	32	2	291	16	3.0	<.1			264	256			7.7	
7/ 8/ 1-214	4-20-60	Q	G	50		2.1	.0				366	36	2.0	.1		.5		330	30	591	7.9	
7-272	4- 9-58	Q	L			<.05	.0	79	46	6	344	58	16	<.1			424	368			7.6	
9/ 6/28-83	4-25-60	Q	G			4.8	.0				353	.8	1.5	.2		.6		290	1	511	7.9	
9/ 7/21-643	4-29-60	Q	G			.3	.0				400	22	6.0	.1		.6		352	24	622	7.9	
9/ 9/26-677	6-29-60	Q	G			5.3	.11				340	35	2.5	.1		.2		309	30	556	7.9	

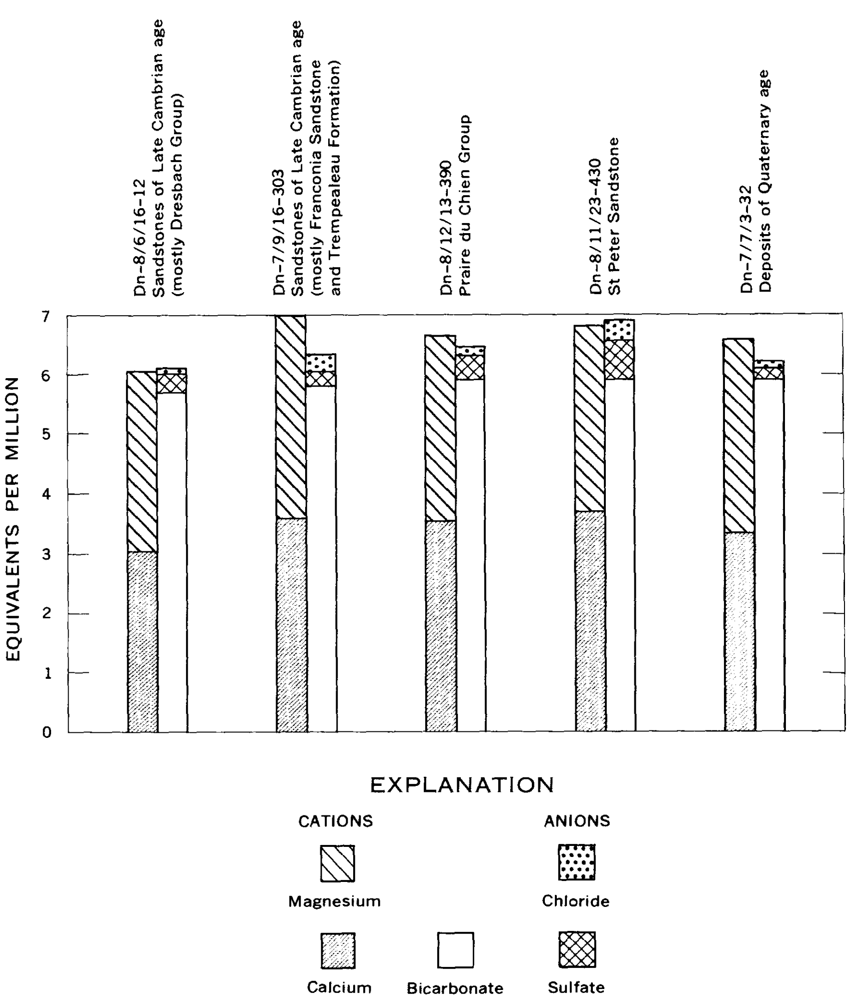

FIGURE 19.—Representative graphical chemical analyses of water from geologic units in Dane County, Wis.

fourth of the analyses showed more than 0.3 ppm iron. The fact that more than 75 percent of the water samples analyzed for iron contained less iron than the arithmetic mean (table 6), indicates that a few high values have unduly influenced the mean values.

Other chemical constituents—silica, manganese, sodium, potassium, sulfate, chloride, nitrite, nitrate, and hydrogen sulfide (tables 5 and 6)—are present in ground water in such minor amounts as to be insignificant. Constituents not listed in the tables are generally present only in trace amounts. Lead deposits south of Blue Mounds (Heyl and others, 1959, p. 288) may locally contribute some lead to ground water.

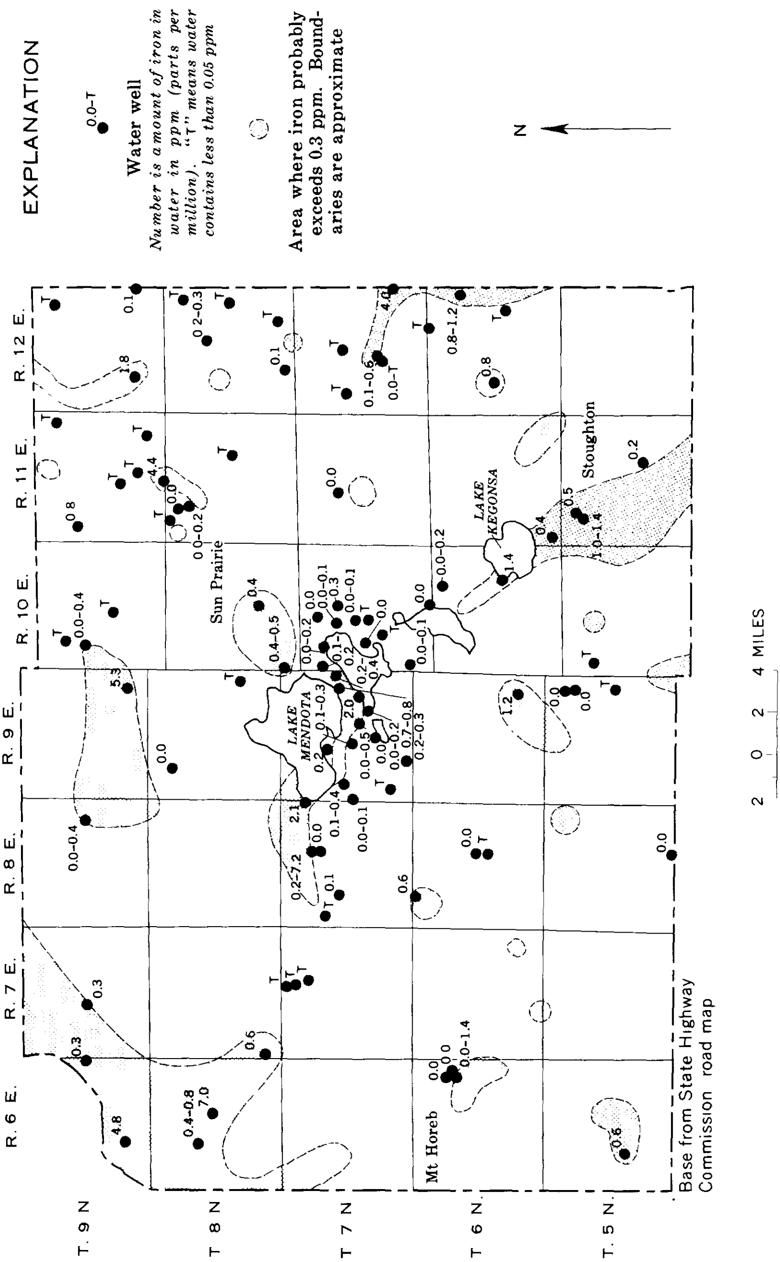

FIGURE 20.—Map of Dane County, Wis., showing distribution of iron in ground water.

TABLE 6.—*Summary of the chemical characteristics of ground water in Dane County, Wis.*

[Results in parts per million, except pH and specific conductance]

	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Sodium plus potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrite (NO_2)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 105°C or 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	pH	Sulfides as H_2S
Number of samples	11.0	159	151	142	131	7	6	39	175	164	166	110	36	55	154	163	14	19	129	[1]43
Minimum value	2.2	.0	.0	22	9	1.5	1.3	1	31	0	0	.0	.0	0	180	88	0	480	6.6	.0
25 percent of samples have less than		.0	.0	58	35				333	6	4	.1		0	303	303			7.4	
50 percent of samples have less than (median)		.05	.0	66	38				362	13	6	.1		1	332	323			7.6	
75 percent of samples have less than		.35	.0	74	43				387	26	10	.1		5	373	362			7.8	
Maximum value	26	6.6	.32	103	65	10	2.6	44	478	177	78	.5	.09	82	584	490	113	886	8.5	.7
Arithmetic mean	15	.40	.01	63	37	4.6	1.7	8	357	22	9	.1	.0	4	348	326	37	507	7.5	.0
U.S. Public Health Service Standard [2] should not exceed		.3	.05							250	250	1.5		45	500					

[1] All zero values except one.
[2] U.S. Public Health Service (1961, p. 941).

The chemical character of ground water does not appear to change with time. Chemical analyses of water collected over a period of years from a few wells indicate that the general quality of water remains constant.

Although the chemical character of ground water in pumping wells does not generally change with time, induced recharge from surface-water bodies may dilute dissolved solids of ground water. The total dissolved solids in water pumped from well Dn–7/9/23–47 (Madison unit 2), a few hundred yards from Lake Monona, was as follows: 477 ppm on February 2, 1961, after pumping 3 million gallons; 350 ppm on April 30, 1952, after pumping 44 million gallons; and 298 ppm on May 6, 1957, after pumping 102 million gallons.

The chemical character of spring water is similar to that of ground water. Stream and lake waters are generally more dilute with respect to dissolved solids than ground water because of dilution by rain and surface runoff and removal of constituents by chemical precipitation.

Although very hard, most of the ground water in Dane County is of good chemical quality for most purposes. Iron and hardness can be reduced by treatment.

TEMPERATURE

The temperature of ground water discharged from wells (table 5) and springs in Dane County averages about 51° F. The temperature of the water discharging from two-thirds of the springs in the county is 50 to 51° F, and the temperature of all the springs ranges from 37 to 66° F (written communication, Wisconsin Conservation Department). The wide range in temperature is probably caused by changes of air temperature. Ground-water temperatures are approximately 5 degrees above the mean annual air temperature of 46° F.

Water discharged from wells deeper than about 50 feet ranged in temperature from 49° F to 54° F. More than one-half of the temperature measurements were between 50° F and 52° F. The temperature of water pumped from a deep well remains nearly constant, varying less than 2° F. The temperature of water in a deep well increases slightly with depth. For example, the temperature of water in well Dn–6/8/22–316 was 50° F at a depth of 80 feet, 51° F at a depth of 1,060 feet, and 53° F at a depth of 1,150 feet. The well tapped crystalline rock at 1,150 feet.

Ground-water temperatures at shallow depths are affected by air temperatures, and this effect diminishes with depth (Summers, 1961). A shallow well, Dn–7/8/7–272 near Cross Plains, that taps water from 23 to 25 feet below land surface had a ground-water temperature range of 13° F. The ground-water temperatures for this well are given in the following table:

Date	*Temperature °F*	*Date*	*Temperature °F*
3-14-58	45	6-18-58	51
3-28-58	43	7- 2-58	52
4- 9-58	44	7-16-58	56
4-23-58	45	9-25-58	56
5- 7-58	45	11-20-58	52
5-21-58	47	1-15-59	47
6- 4-58	49	3-23-59	44

WATER USE

Ground water is used in Dane County for municipal, industrial and commercial, rural domestic and stock, and miscellaneous uses (fig. 21).

In 1959 the municipal use of ground water was 22 mgd, or 60 percent of the total water pumped in Dane County. Municipal pumpage includes all water withdrawn and used in the system for domestic supply, irrigation of lawns, fire protection, and street flushing and by industry and commerce. Leakage is also included because the water is measured at the source. The city of Madison used 17.6 mgd in 1959, or about 80 percent of all water pumped for municipal purposes in Dane County.

In the period 1930–60 the population of the Madison metropolitan area and Dane County nearly doubled and pumpage more than doubled (fig. 13). Total ground-water use has increased more rapidly than population because per capita use of water has also increased. The per capita use of water in the Madison metropolitan area is estimated to have increased from 146 gpd (gallons per day) in 1931 to 165 gpd in 1959. By 1980 the use of ground water is expected to be 222 gpd per person.

In 1959 self-supplied ground water used for industrial and commercial purposes consisted of 5½ mgd, or 15 percent of the total ground water pumped in Dane County. Although the water is used for many purposes, the greatest uses are for meat packing and cooling.

In 1959 about 5½ mgd, or about 15 percent, of ground water was pumped for rural domestic and stock purposes in Dane County. This pumpage includes all self-supplied domestic use (excluding municipal pumpage), water for liverstock and poultry, and general rural use. Frank (1955) estimated that the per capita use of water for people living in the average electrified farm home averaged 60 gpd.

The miscellaneous use of ground water, about 10 percent in 1959, included 1½ mgd of ground water discharged from flowing wells at the Nevin Fish Hatchery and 0.05 mgd of water for irrigation.

The use of surface water in Dane County is large and varied but does not materially affect the hydrologic system. Although very little

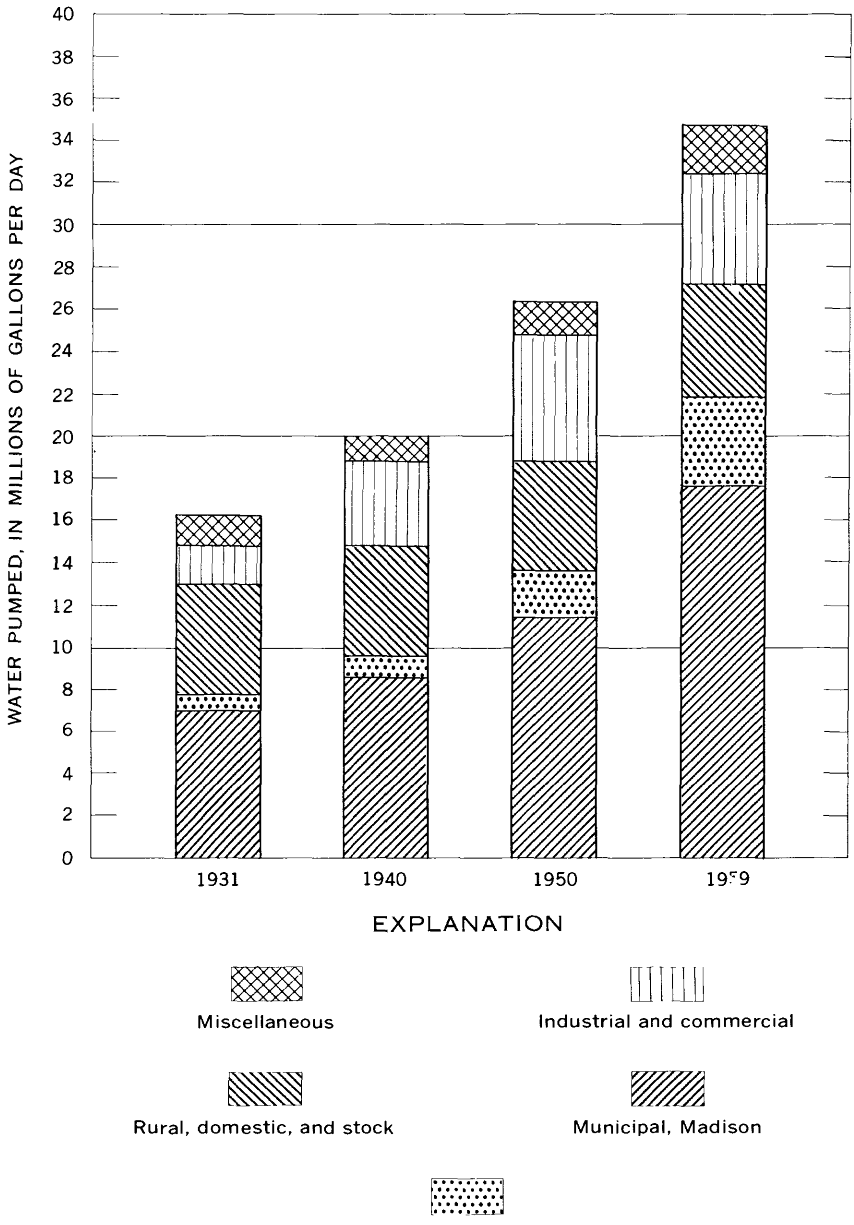

FIGURE 21.—Amount and use of ground water pumped in Dane County, Wis., 1931–59.

surface water is consumed in the county, the temperature and quality of the water may be affected by use.

Industrial cooling is the largest use of surface water in the county. In the Madison metropolitan area, about 55 mgd was pumped in 1960 for industrial cooling from Lake Monona. This amount is about twice the amount of ground water pumped from the area. The surface water is returned directly to the lakes, the only change being an increase in temperature.

Surface water use for irrigation is very small, 2½ million gallons in 1959 and one-quarter million gallons in 1960.

Recreational purposes, although not a withdrawal, are an important use of surface water in the county, particularly in the Madison metropolitan area.

CONCLUSIONS

The principal aquifers in Dane County are the sandstones of Late Cambrian age and outwash and alluvium of Quaternary age. Large producing wells that penetrate only a few hundred feet of these sandstones generally yield several hundred gallons of water per minute, and wells that fully penetrate the sandstones may yield several thousand gallons per minute. Wells that obtain water from the Dresbach Group generally have the highest specific capacities. Locally, large amounts of water may be obtained from unconsolidated deposits of outwash and alluvium, particularly in the Black Earth Creek, Wisconsin River, and Sugar River valleys. The thick unconsolidated deposits in the Yahara River valley contain much clay and silt and are not expected to yield large amounts of water.

Discharge from the ground-water reservoir in Dane County is equal to the ground-water recharge and is estimated to be about 6 inches, or about one-fifth of the average annual precipitation of 31 inches. Of this discharge, 5 inches enters streams, one-half inch leaves the county as underflow, and one-half inch is lost to evapotranspiration. Ground-water discharge contributes 60 to 95 percent of the total streamflow in Dane County. Ground-water pumpage in 1959, 35 mgd, was about 10 percent of the total streamflow leaving the county.

Ground water in Dane County is a very hard calcium magnesium bicarbonate water and, except for its hardness and localized high concentration of iron, is of good quality. High concentrations of iron are common in ground water in wells in the Wisconsin River and Yahara River valleys and appear to be more prevalent in the glacial drift than in other rock units. The temperature of ground water discharged from wells averages about 51° F.

Water levels in wells in Dane County fluctuate mainly because of changes in natural recharge and discharge. An exception is the Madison area where pumpage has locally lowered water levels although not excessively. Ground-water pumpage in the Madison metropolitan area, 73 percent of the total for the county in 1959, has increased rapidly and is expected to double by 1980.

The pumpage from wells in the Madison area has lowered the piezometric surface as much as 60 feet, locally reduced the flow of springs, and induced local recharge from Lakes Mendota and Monona. The most significant area of induced recharge is the isthmus area between the lakes where ground-water levels are about 40 feet below the lake levels.

Interference between wells lowers water levels and, therefore, increases the costs of pumping. For this reason, the city of Madison has spaced new wells at such a distance from other large-capacity wells that interference is small. All ground-water users in the Madison metropolitan area will benefit by a continued coordinated plan of spacing large-capacity wells to reduce interference.

Ground water in the Madison metropolitan area is very closely related to surface water. Changes in the ground-water system are reflected by corresponding changes in streamflow. Because most of the water pumped from wells in the area is discharged as treated effluent into Badfish Creek and not into the Yahara River, the flow of the Yahara River is reduced by about the amount of the pumpage. Ground-water pumpage in 1959 was equal to about 25 percent of the average annual flow of the Yahara River leaving Lake Waubesa and about 35 percent of the flow leaving Lake Monona.

As pumping increases in the Madison metropolitan area, correspondingly larger amounts of water will be diverted from the upper Yahara River system into Badfish Creek. A long-term study of the effects of the diversion on the flow of the Yahara River is needed inasmuch as one year's record is insufficient to make predictions as to the effects of future pumpage. The study would show how much the future diversion will decrease the flow of the Yahara River and thus indicate the effect that pumpage of ground water will have on streamflow.

Additional information is also needed to determine the maximum amount by which the flow of the Yahara River can be decreased without overbalancing the benefits gained from additional pumpage. The distribution of pumpage in the Madison metropolitan area will influence the effect that the withdrawal of ground water will have on the Yahara River system. Increased pumpage around Lake Monona would have little effect on Lake Mendota; however, increased pumpage around Lake Mendota would affect both lakes. Wells placed near the ground-water divides, particularly to the west but also to the east, could shift the ground-water divides away from the city and thus intercept more water without a corresponding decrease in the streamflow of the Yahara River.

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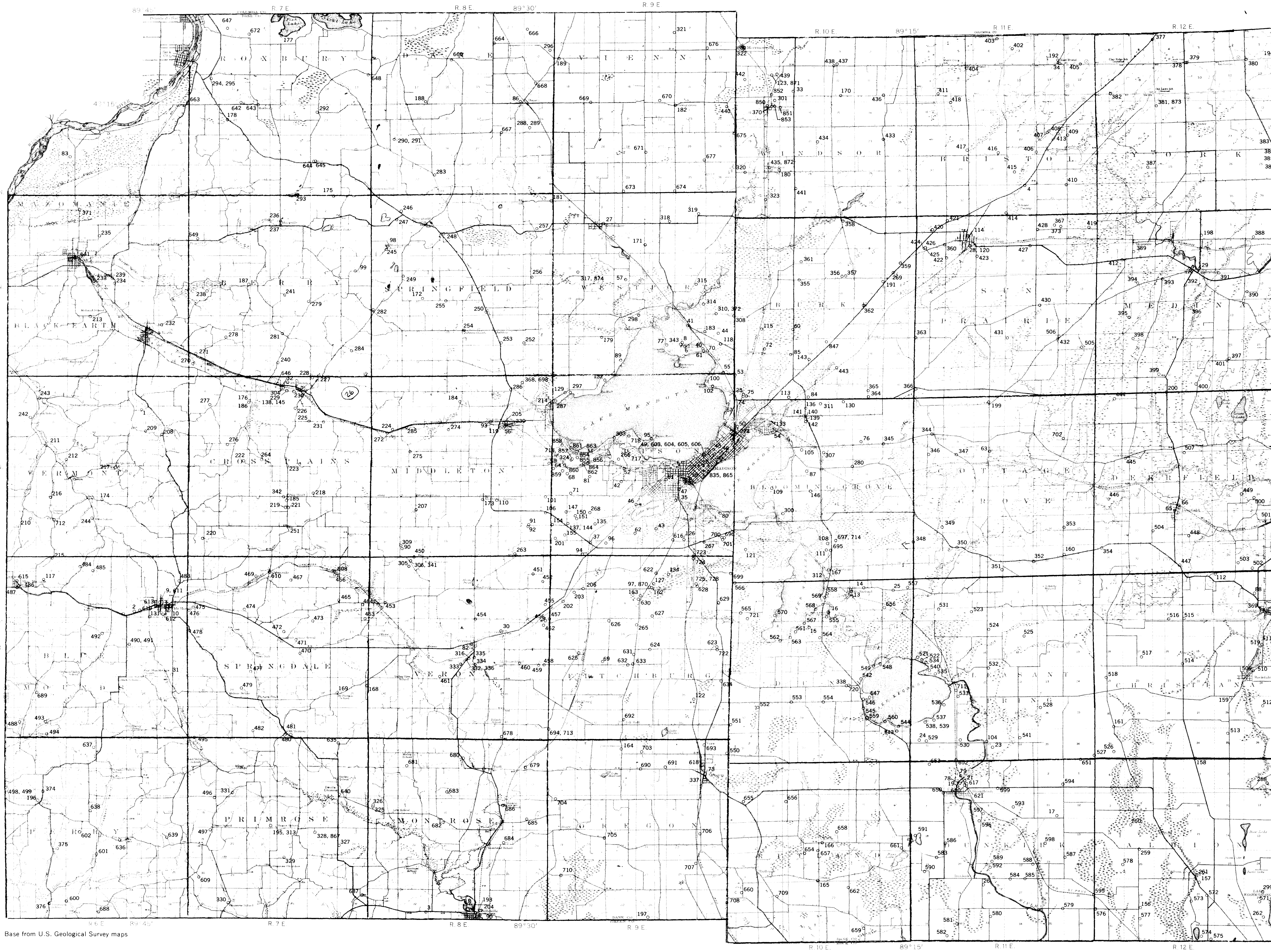
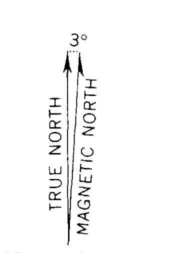
[Italic page numbers indicate major references]



Base from U.S. Geological Survey maps

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1965—W64012



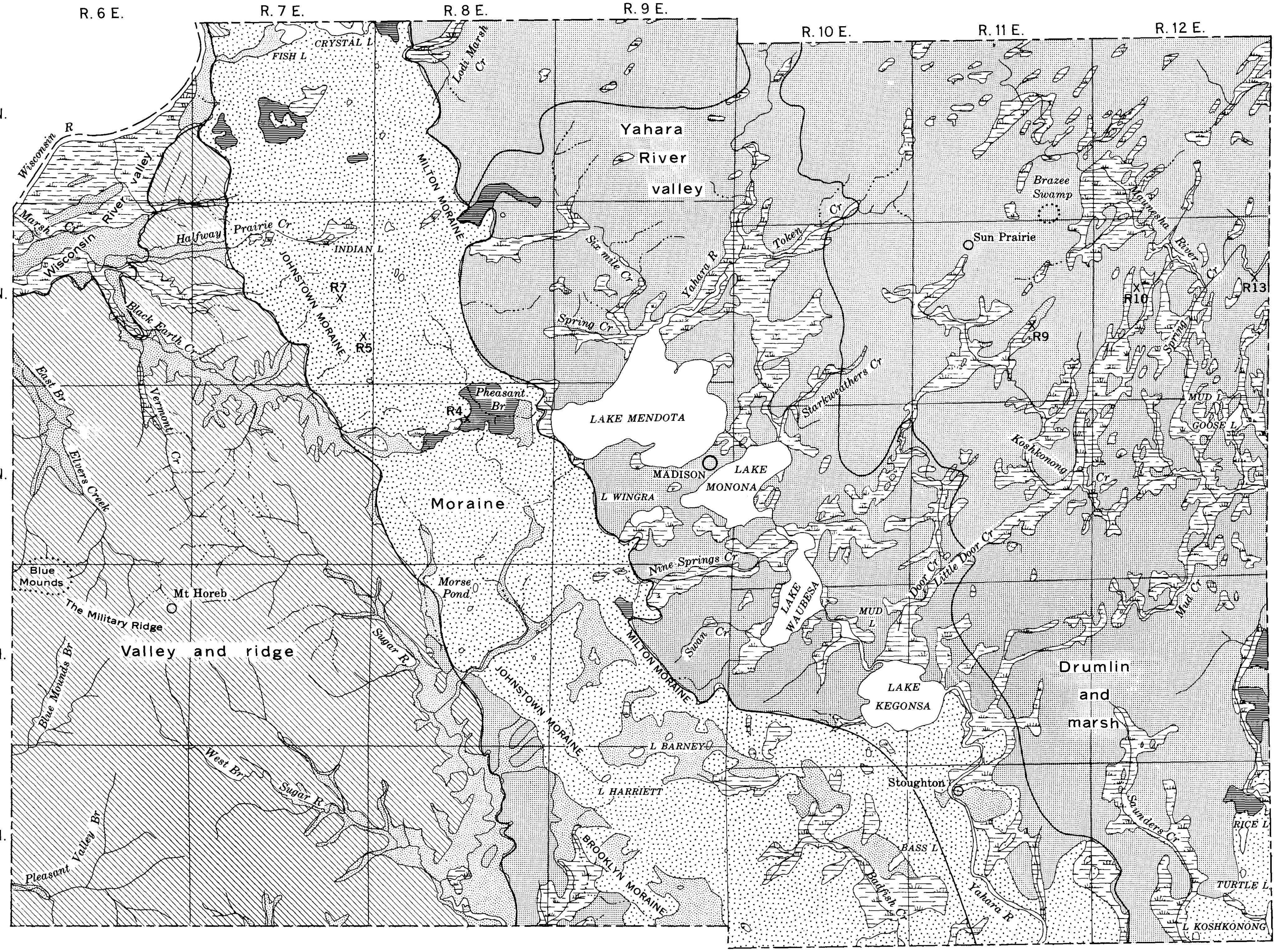
APPROXIMATE MEAN DECLINATION, 1965

MAP OF DANE COUNTY, WISCONSIN, SHOWING LOCATION OF WATER WELLS

SCALE 1:125 000

2 1 0 2 4 6 MILES

2 1 0 2 4 6 KILOMETERS



Base from U.S.G.S. Prof. Paper 106
(Alden, 1918, pl. 1)

Geology modified from Alden (1918)

EXPLANATION

Marsh deposits
Muck and peat

Glacial lake deposits
Stratified clay, silt, sand, and marl

Outwash and alluvium
Mostly sand and gravel, sorted and stratified

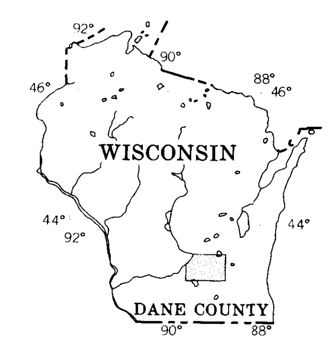
Morainal deposits
Clay, silt, sand, gravel, and boulders, mostly unsorted and unstratified

Undifferentiated glacial deposits mainly ground moraine
Clay, silt, sand, gravel, and boulders, unstratified to stratified, unsorted to sorted

QUATERNARY

Pre-Quaternary rocks
Quaternary deposits thin or absent

R4 ×
Rock-sample site



INDEX MAP SHOWING AREA OF THIS REPORT

MAP OF DANE COUNTY, WISCONSIN, SHOWING PHYSIOGRAPHIC AREAS AND DEPOSITS OF QUATERNARY AGE

3°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1964

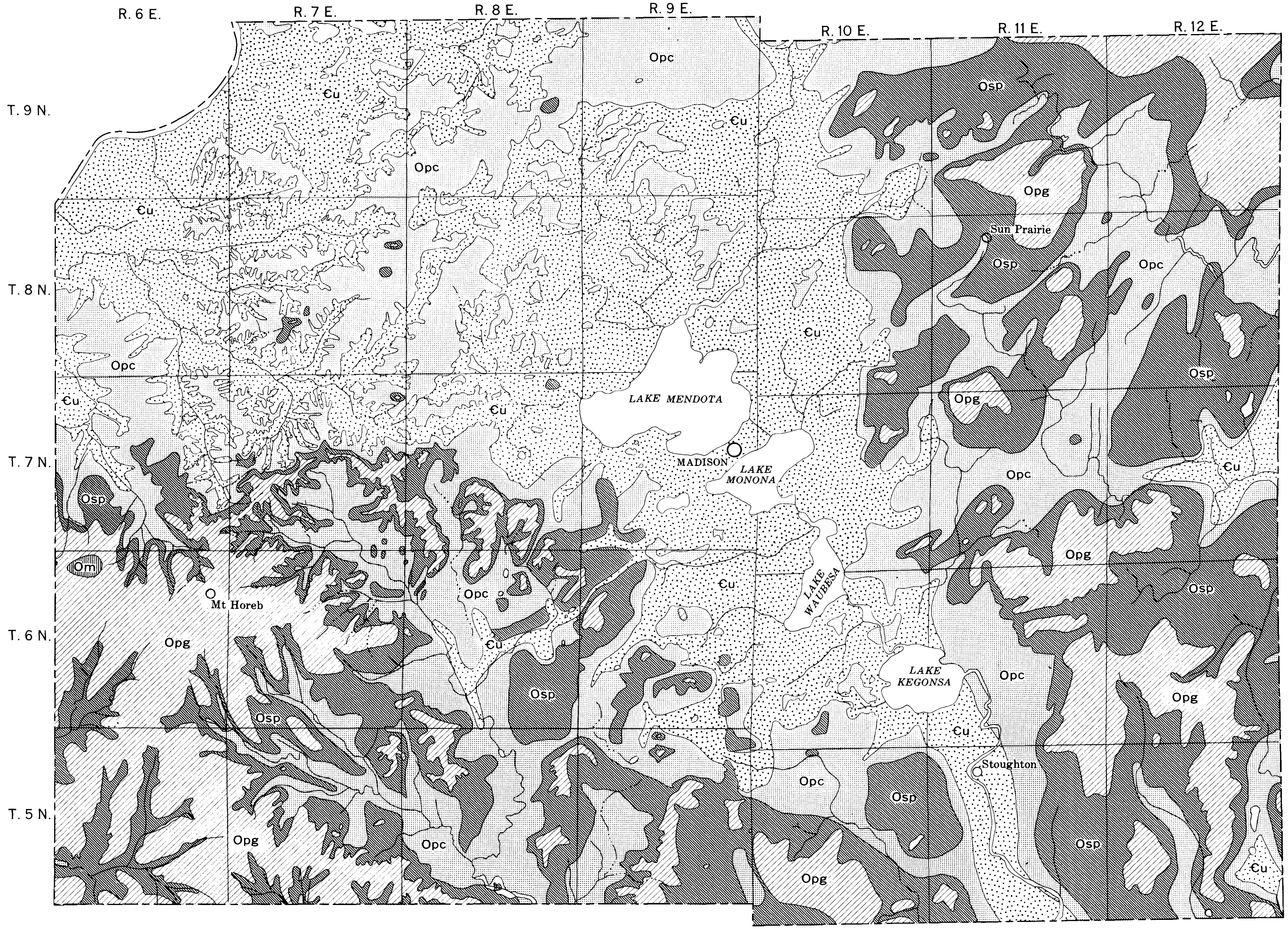
SCALE 1:250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 KILOMETERS

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-SUPPLY PAPER 1779-U
PLATE 3



EXPLANATION

Symbol	Unit	Series	System
Om	Maquoketa Shale		ORDOVICIAN
Opg	Platteville, Decorah, and Galena Formations undifferentiated		ORDOVICIAN
Osp	St. Peter Sandstone		ORDOVICIAN
	UNCONFORMITY		
Opc	Prairie du Chien Group		ORDOVICIAN
Єu	Dresbach Group, Franconia Sandstone, and Trempealeau Formation undifferentiated	*Upper Cambrian*	CAMBRIAN

Base from U.S.G.S. Prof. Paper 106
(Alden, 1918, pl. 1)

Geology modified from Alden (1918)

MAP OF THE BEDROCK GEOLOGY OF DANE COUNTY, WISCONSIN

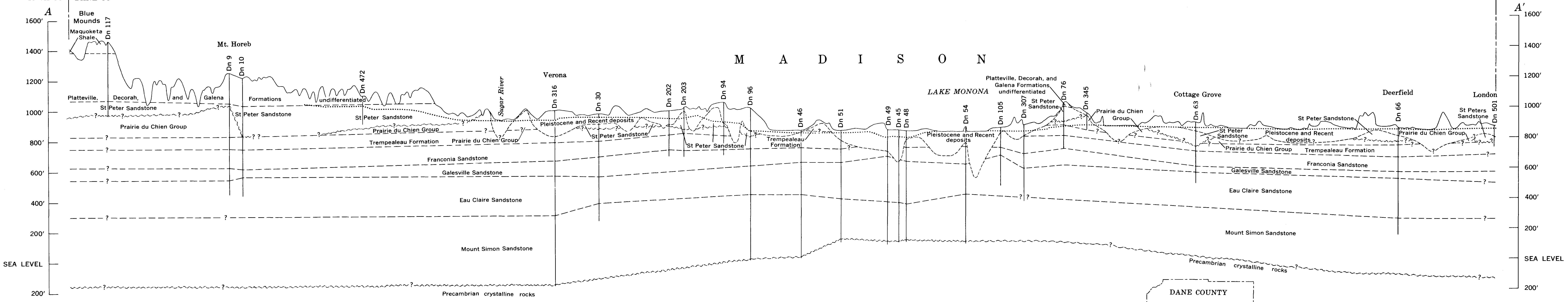
3°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN
DECLINATION, 1964

SCALE 1:250 000

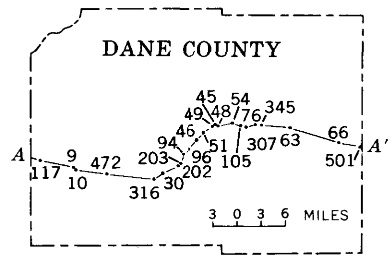
5 0 5 10 15 20 MILES

5 0 5 10 15 20 KILOMETERS

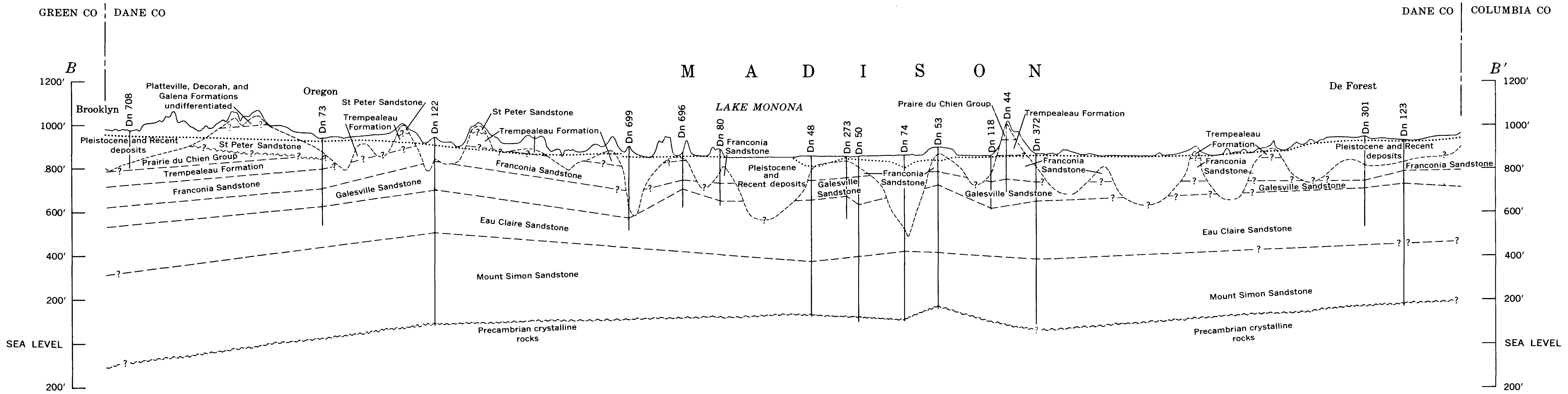
748 - 355 O - 65 (In pocket)



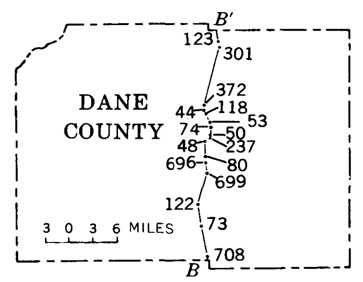
BLUE MOUNDS TO LONDON



INDEX MAP SHOWING LOCATION OF SECTION *A-A′*



BROOKLYN TO NEAR DE FOREST



INDEX MAP SHOWING LOCATION OF SECTION *B-B′*

EXPLANATION

.... Piezometric surface April–May 1960

GEOLOGIC SECTIONS FROM BLUE MOUNDS TO LONDON, AND FROM BROOKLYN TO NEAR DE FOREST, DANE COUNTY, WISCONSIN

SCALE 1:125,000

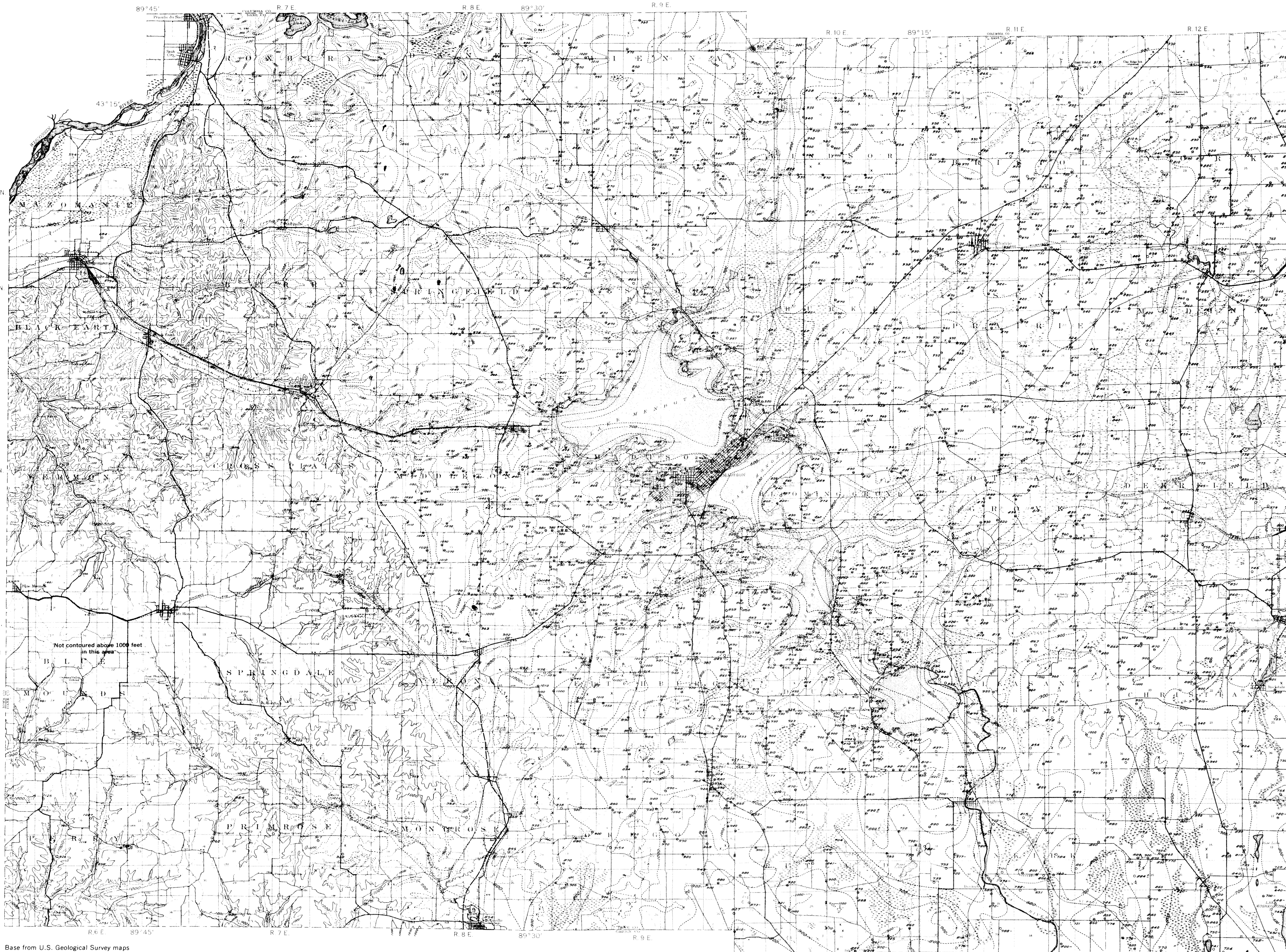
2 1 0 2 4 6 MILES

2 1 0 2 4 6 KILOMETERS

748 - 355 O - 65 (In pocket)

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

WATER-SUPPLY PAPER 1779-U
PLATE 5



EXPLANATION

Contour drawn on bedrock surface
Dashed where control is less accurate; queried where doubtful. Contour interval, 100 feet. Datum is mean sea level

Border of drift (After Alden, 1918, and Bean, 1949)

Water well
Inventoried for this report. Showing altitude of bedrock

Other well showing altitude of bedrock

Outcrop

Base from U.S. Geological Survey maps

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—W64012

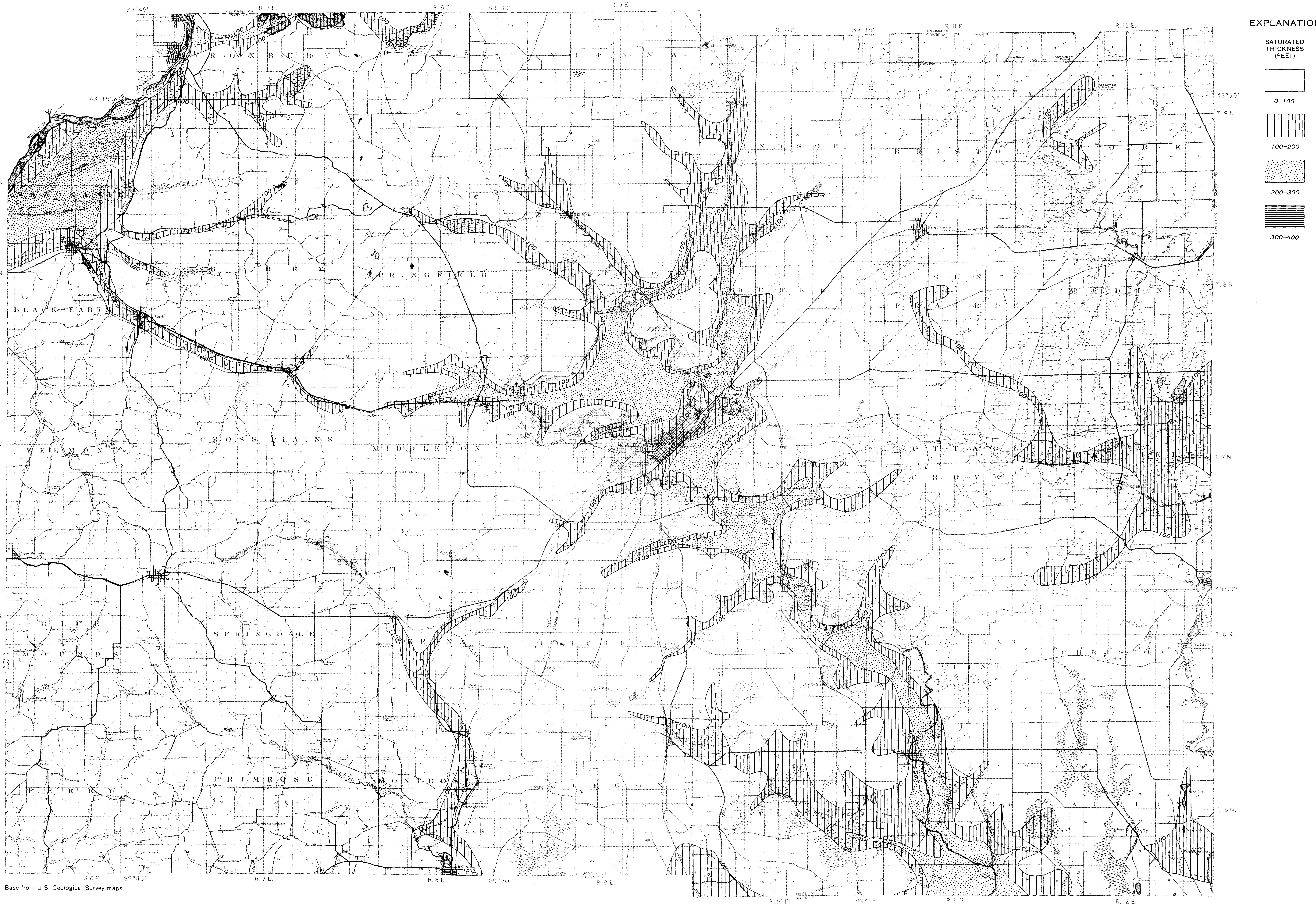
MAP OF DANE COUNTY, WISCONSIN, SHOWING BEDROCK TOPOGRAPHY

SCALE 1:125 000

2 1 0 2 4 6 MILES

2 1 0 2 4 6 KILOMETERS

3°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1965



Base from U.S. Geological Survey maps

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1965—W64012

Hydrology by D.R. Cline

GENERALIZED MAP SHOWING SATURATED THICKNESS OF DEPOSITS OF QUATERNARY AGE IN DANE COUNTY, WISCONSIN

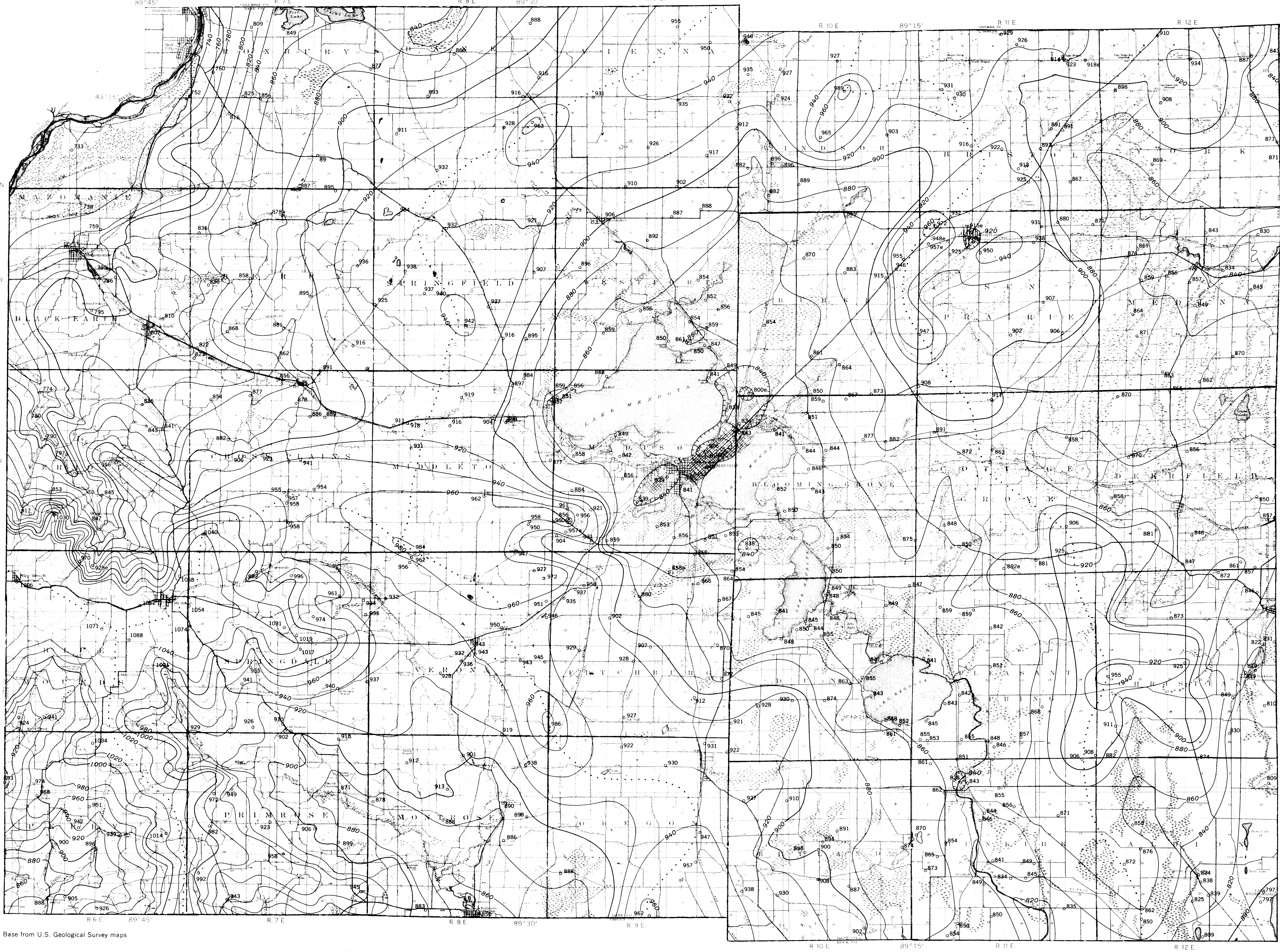
SCALE 1:125 000

2 1 0 2 4 6 MILES

2 1 0 2 4 6 KILOMETERS

TRUE NORTH
MAGNETIC NORTH
3°

APPROXIMATE MEAN DECLINATION, 1965



EXPLANATION

800

820

Piezometric contour

Shows the surface to which water will rise in wells. Contour interval, 20 feet; contours not shown above 1040 feet. Ticks indicate closed depression. Datum is mean sea level

Ground-water divide

800e

Water well

Number indicates altitude of piezometric surface, in feet; "e" is water level estimated for April-May 1960 from measurements in the well and nearby wells

Base from U.S. Geological Survey maps

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C.—1965—W64012

Hydrology by D.R.Cline

MAP OF DANE COUNTY, WISCONSIN, SHOWING CONFIGURATION OF THE PIEZOMETRIC SURFACE IN APRIL-MAY 1960

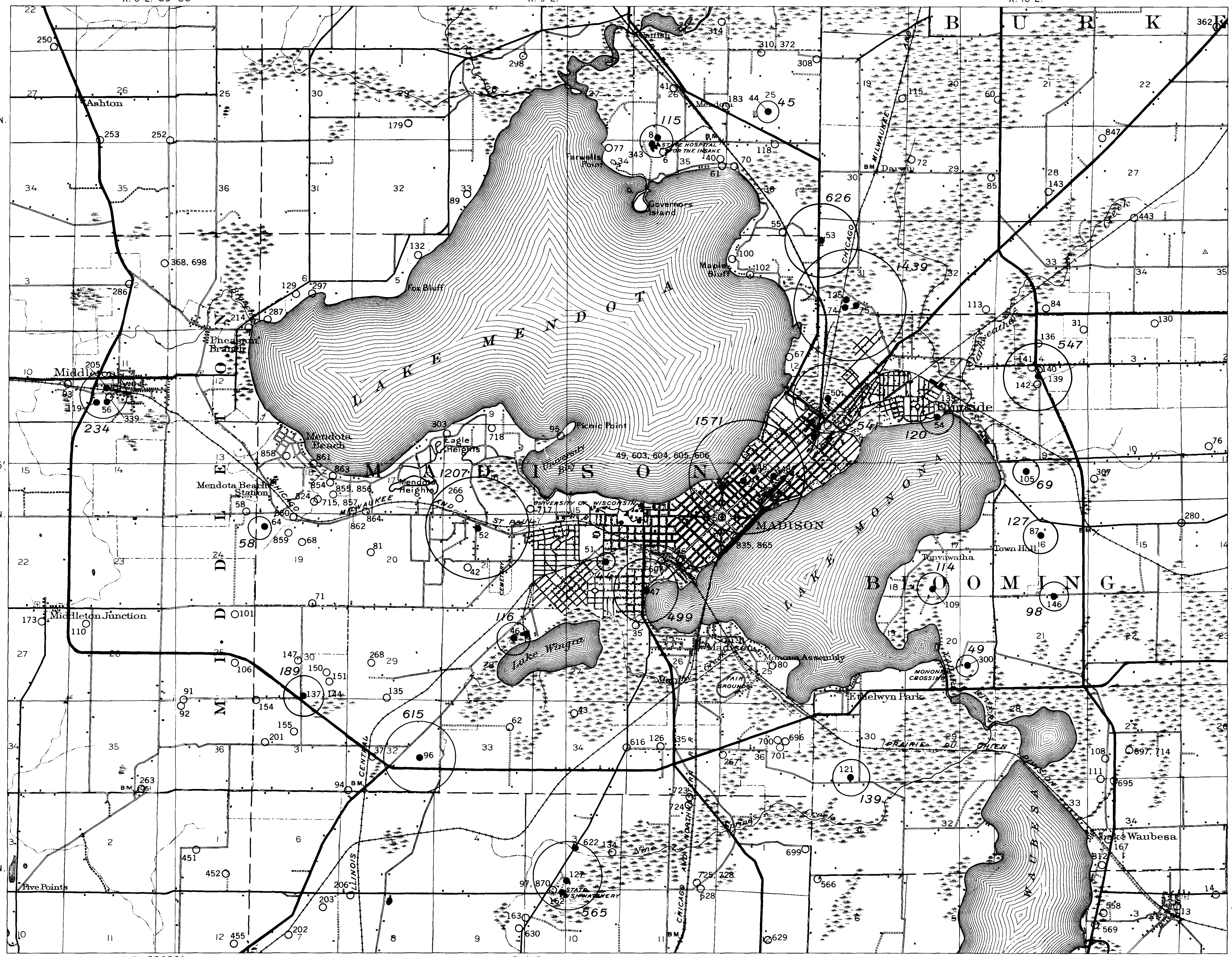
SCALE 1:125 000

2 1 0 2 4 6 MILES

2 1 0 2 4 6 KILOMETERS

TRUE NORTH
MAGNETIC NORTH
3°

APPROXIMATE MEAN DECLINATION, 1965



Base from U.S. Geological Survey map
Madison quadrangle, 1904

Hydrology by D.R.Cline

EXPLANATION

○130 ●44

Water well

Shows well number. Solid circle indicates well pumped more than 20 million gallons

○ 127

Amount of pumpage in millions of gallons, during 1959. Area of circle is proportional to quantity pumped; pumpage of less than 20 million gallons not shown

3°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1964

MAP SHOWING GROUND WATER PUMPED IN 1959 IN THE MADISON AREA, WISCONSIN

SCALE 1:62 500

1 ½ 0 1 2 3 MILES

1 .5 0 1 2 3 KILOMETERS

748 - 355 O - 65 (In pocket)