GROUND-WATER FLOW AND QUALITY IN WISCONSIN'S SHALLOW AQUIFER SYSTEM

By P.A. Kammerer, Jr.

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CONTENTS

CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To Obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Volume	
gallon (gal)	3.785	liter
	3.785	cubic decimeter
	0.003785	cubic meter

Sea Level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)–a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentrations are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value for concentrations in milligrams per liter is the same as for concentrations in parts per million.

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By P.A. Kammerer, Jr.

ABSTRACT

The areal concentration distribution of common mineral constituents and properties of ground water in Wisconsin's shallow aquifer system are described in this report. Maps depicting the water quality and the altitude of the water table are included. The shallow aquifer system in Wisconsin, composed of unconsolidated sand and gravel and shallow bedrock, is the source of most potable ground-water supplies in the State. Most ground water in the shallow aquifer system moves in local flow systems, but it interacts with regional flow systems in some areas.

In terms of chemical quality, the water is suitable for potable supply and most other uses, but objectionable hardness in large areas and concentrations of iron and manganese that exceed State drinking-water standards cause aesthetic problems that may require treatment of the water for some uses. Concentrations of major dissolved constituents (calcium, magnesium, and bicarbonate), hardness, alkalinity, and dissolved solids are highest where the bedrock component of the aquifer is dolomite and lowest where the shallow aquifer is almost entirely sand and gravel. Concentrations of other minor constituents (sodium, potassium, sulfate, chloride, and fluoride) are less closely related to common minerals that compose the aquifer system. Sulfate and fluoride concentrations exceed State drinking-water standards locally. Extreme variability in concentrations of iron and manganese are common locally. Iron and manganese concentrations exceed State drinking-water standards in water from one-third and one-quarter of the wells, respectively. Likely causes of nitrate-nitrogen concentrations that exceed State drinking-water standards include local contamination from plant fertilizers, animal wastes, waste water disposed of on land, and septic systems. Water quality in the shallow aquifer system has been affected by saline water from underlying aquifers, primarily along the eastern and western boundaries of the State where the thickness of Paleozoic rocks is greatest.

1.0 INTRODUCTION

This report describes ground-water flow and quality in Wisconsin's shallow aquifer system. It includes a description of flow and quality of ground water in underlying aquifers to the extent that they affect, or are affected by, flow and quality of ground water in the shallow aquifer system.

In 1978, the U.S. Geological Survey (USGS) and the Wisconsin Department of Natural Resources (WDNR) began a cooperative study to (1) describe ground-water quality and its relation to hydrogeology in Wisconsin's principal aquifers, and (2) identify sites and sources of ground-water quality problems from information in WDNR's files. The first objective was met by a hydrologic investigation by the USGS. The second objective was met by a WDNR administrative report describing the State's water resources, ground-water quality problems, and policy recommendations for ground-water management.

The USGS's investigation consisted of two phases: (1) description of the relation between regional ground-water quality and hydrogeology within and between all aquifers, and (2) use of this information to define a shallow aquifer system for the State and to describe the quality and flow of ground water within this system. A report describing the results of the first phase of the USGS investigation has been prepared (P.A. Kammerer, Jr., L.C. Trotta, D.P. Krabbenhoft, and R.A. Lidwin, U.S. Geological Survey, written commun., 1989). The shallow aquifer system includes geologic units that are most commonly used for water supply (open to the most wells) and that are of most concern to State and local water-resource managers because of their susceptibility to contamination.

The results of the second phase of the investigation are presented in this report. Areal differences in the concentration of major dissolved constituents and the values of properties of water from the shallow aquifer system are shown on maps. Regional hydrogeologic factors such as aquifer composition and interaction with underlying aquifers affect the concentration of major constituents and properties (calcium, magnesium, sodium, potassium, sulfate, chloride, fluoride, dissolved solids, hardness, and alkalinity). Concentrations of iron, manganese, and nitrate nitrogen differ locally to the extent that it is not possible to prepare meaningful small-scale maps showing distribution of the concentrations. Concentrations for these constituents are presented as statistical summaries.

All water-quality data used herein are stored in the USGS's National Water Data Storage and Retrieval System (WATSTORE). The WATSTORE data are from various sources. Included are analyses by the Wisconsin State Laboratory of Hygiene of water samples collected by the WDNR and antecedent agencies, and analyses by USGS laboratories of water samples collected as part of basic data-collection programs and interpretive water-resources investigations by the USGS alone or in cooperation with other Federal, State, and local agencies. WDNR samples are primarily from public water-supply wells, but USGS samples include water from numerous monitoring and private water-supply wells. Most water-quality data used were collected during 1953-83, but dates of sample collection differ areally because of the diversity of data sources. The data were summarized without regard to date of sample collection.

Geologic nomenclature used herein is that of the Wisconsin Geological and Natural History Survey (Ostrom, 1967; Mudrey and others, 1982).

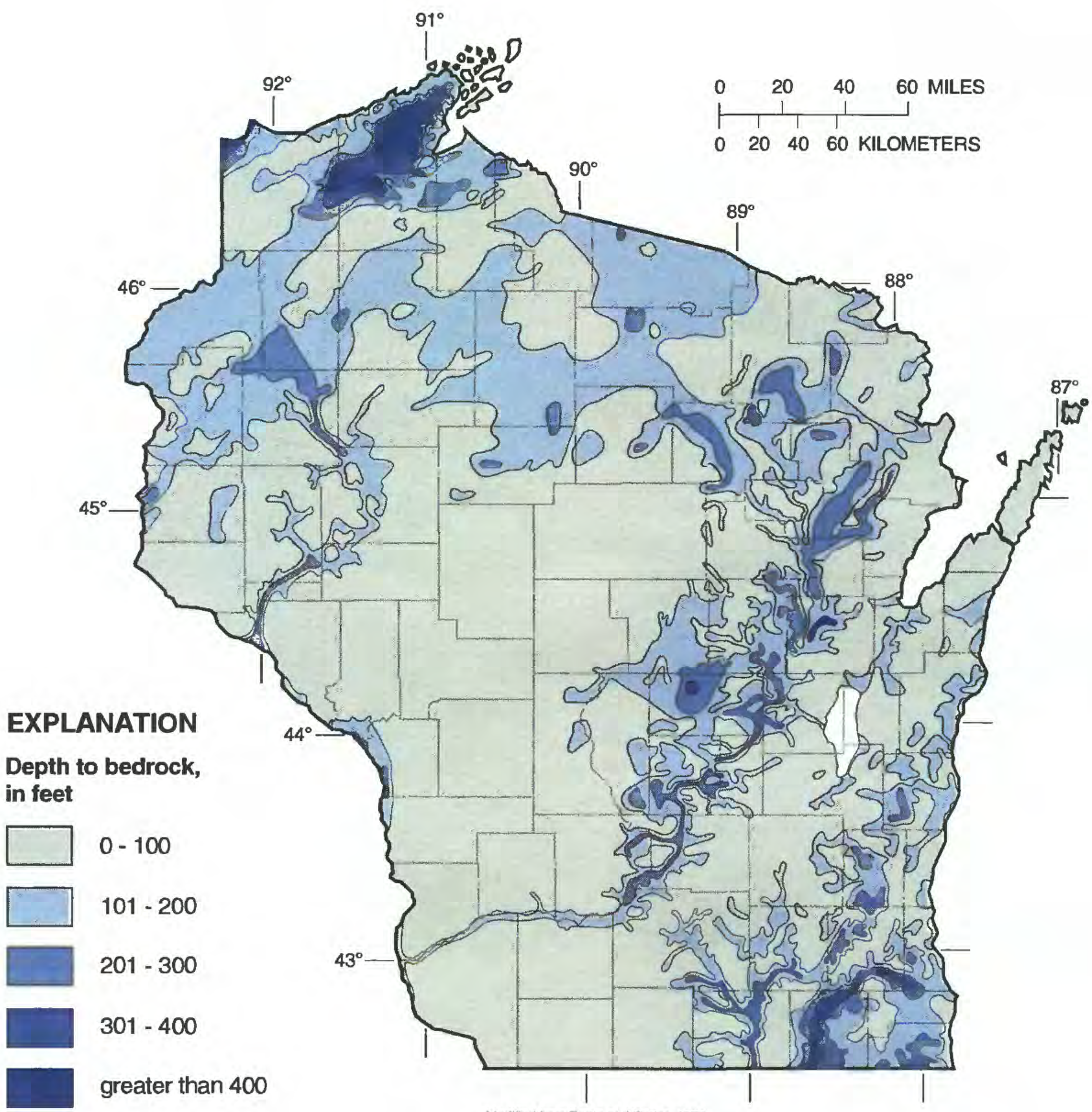
2.0 WISCONSIN'S AQUIFERS

2.1 Major Aquifers

2.1.1 Sand and gravel aquifer

The sand and gravel aquifer is the uppermost of Wisconsin's aquifers in all but the Driftless Area. Use of the aquifer for water supply depends on its thickness and local hydrogeologic characteristics and on the availability of alternative water supplies.

Unconsolidated glacial materials deposited during Pleistocene glaciation cover approximately 70 percent of Wisconsin. These deposits are present in all counties but are sparse in counties within the Driftless Area. In this area, unconsolidated deposits are primarily Holocene (post-Pleistocene) alluvium in river valleys. The characteristics of the deposits at the land surface and their thickness are shown in the maps on this and the facing page. The usefulness of the unconsolidated deposits as an aquifer is determined largely by the thickness and the water-bearing characteristics of buried materials. Lithology and stratigraphy of the unconsolidated deposits have not been mapped extensively.

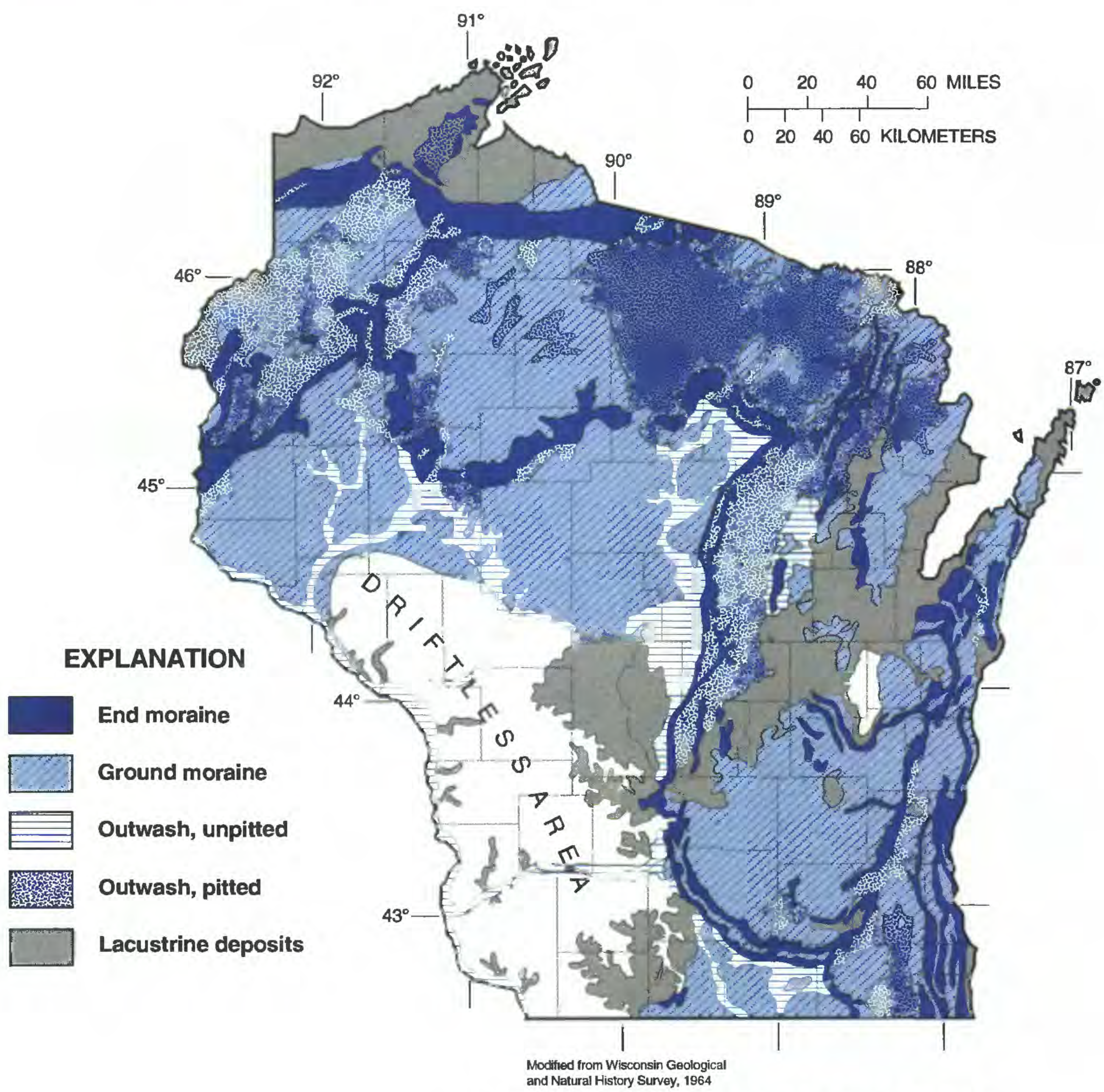


Modified from Trotta and Cotter, 1973

THICKNESS OF GLACIAL DEPOSITS

The sand and gravel aquifer consists primarily of sand and gravel lenses and beds within the glacial deposits; in practice, however, the aquifer includes any material that can provide sufficient water for domestic water supply, including deposits containing large proportions of clay and silt. The sand and gravel aquifer is not a continuous unit as most bedrock aquifers are. It is present as broad, surficial outwash deposits; isolated lenses of sand and gravel within less permeable deposits; valley fill and basal sand and gravel deposits directly overlying bedrock; and other materials deposited by water. The aquifer is present in the Driftless Area only as alluvium within the flood plains of large rivers.

The extent to which the sand and gravel aquifer is used for water supply in a particular area is affected by the quality and the availability of alternative supplies from surface water or underlying aquifers. Because it is the uppermost aquifer, the sand and gravel aquifer is more susceptible to contamination than underlying bedrock aquifers are. Some wells, therefore, are finished in bedrock aquifers even where the overlying sand and gravel aquifer yields sufficient quantities of water for supply.



SURFICIAL GLACIAL DEPOSITS

2.0 WISCONSIN'S AQUIFERS--Continued

2.1 Major Aquifers--Continued

2.1.2 Bedrock aquifers

Wisconsin's principal bedrock aquifers are part of the layered Paleozoic sedimentary rock sequence which dips to the east, south, and west from the Precambrian topographic high in north-central Wisconsin. Many of the bedrock aquifers are hydraulically connected to each other and to overlying unconsolidated deposits; however, confining units, primarily in the southern and the eastern parts of the State, retard vertical water flow between aquifers.

Wisconsin's principal bedrock aquifers are the Silurian dolomite aquifer and the sandstone aquifer. These aquifers are part of the thick sequence of layered marine sedimentary Paleozoic rocks that dips to the east, south, and west from the Precambrian topographic high in north-central Wisconsin. The Paleozoic rocks also include two areally extensive confining units (the Maquoketa Formation and the St. Lawrence Formation) and other less extensive local confining units. Minor bedrock aquifers include Precambrian sandstones (Lake Superior sandstone aquifer) and lava flows underlying glacial deposits in northwestern Wisconsin and Precambrian granitic and metamorphic crystalline rocks that underlie Paleozoic rocks or glacial deposits elsewhere. The weathered upper part of the Maquoketa Formation is a minor aquifer in some areas of eastern Wisconsin, but few wells are open exclusively to it. These minor bedrock aquifers are used locally for domestic supplies.

Although fracturing is known to occur at depth in Precambrian crystalline rocks, the size, the degree of interconnection, and the areal extent of the fractures are not known. Herein, only the near-surface Precambrian crystalline rocks are considered to be productive aquifers.

A map of the bedrock geology of Wisconsin is shown on plate 1. General stratigraphic relations among the Paleozoic rocks that include the aquifers and the confining units discussed herein are shown in the EXPLANATION of the geologic map. The approximate thicknesses of selected geologic units and groups of units that include the major bedrock aquifers are shown on other maps on the plate. The thickness maps are based on small scale (1:1,000,000) unpublished maps (L.C. Trotta, U.S. Geological Survey, written commun., 1983; J.J. Schiller, U.S. Geological Survey, written commun., 1979). The maps are based primarily on geologic logs prepared by the Wisconsin Geological and Natural History Survey and on supplemental information from published reports and geologic maps, well-construction reports from the WDNR, graduate-school theses, and unpublished data on file with the USGS.

The approximate areal extent of each unit or group of units is shown on the thickness maps. The extent of units that are Ordovician age or younger is taken from the geologic map. Cambrian units are difficult to distinguish in the subsurface and are not differentiated on the geologic map, but the approximate areal extent of selected Cambrian units is shown on the thickness maps to show approximate boundaries of hydrogeologic units. Approximate boundaries of areas where units are missing in the subsurface also are shown. These boundaries are from published and unpublished maps (L.C. Trotta, written commun., 1983; Mai and Dott, 1985); reconciliation of differences in detail between the work of these investigators is beyond the scope of this report and was not attempted.

Mai and Dott (1985) also prepared a thickness map for the St. Peter Sandstone (equivalent to the Ancell Group) that differs in detail from the above-mentioned unpublished map by L.C. Trotta used herein. The map by Trotta is used here to preserve internal consistency with thickness maps for other units.

A brief description of the individual hydrogeologic units and groups of units follows.

The Silurian dolomite aquifer, present only in eastern Wisconsin along Lake Michigan, is predominantly Silurian-age dolomite but contains minor amounts of calcite and gypsum crystals, pyrite, and beds of shale and limestone. The aquifer includes a small area of dolomite and shale of Devonian age that extends from Milwaukee to Sheboygan along Lake Michigan.

The Maquoketa confining unit, which includes the Maquoketa Formation and the Neda Formation, underlies the Silurian dolomite aquifer. This unit restricts vertical ground-water flow between the Silurian dolomite aquifer and the underlying sandstone aquifer.

The sandstone aquifer consists of hydraulically connected sandstones and dolomites of Cambrian and Ordovician age. The oldest and the most extensive units are Cambrian sandstones that underlie 60 percent of the State. Differentiation between sandstones of the Elk Mound, Tunnel City, and Trempealeau Groups in the subsurface is difficult in most areas. In the southern part of the State, where Cambrian rocks reach their maximum thickness, the St. Lawrence Formation at the base of the Trempealeau Group is a confining unit that retards water movement between rocks of the underlying Elk Mound and Tunnel City Groups and the overlying Jordan Sandstone and the Ordovician-age rocks. Rocks of the Tunnel City Group are generally less permeable than those of the underlying Elk Mound Group. Thus, the Tunnel City Group and the overlying St. Lawrence Formation commonly function as a confining unit where both are present. The Jordan Sandstone and the rocks of the Elk Mound and the Tunnel City Groups are sandstone cemented with dolomite. The St. Lawrence Formation is predominantly dolomite, shaley sandstone, or siltstone; lithology differs laterally.

The Ordovician-age units of the sandstone aquifer are less extensive and are found in only the western, southern, and eastern parts of the State. The Prairie du Chien Group, a dolomite unit, directly overlies the Cambrian sandstones. Overlying the Prairie du Chien Group, but smaller in areal extent, is the Ancell Group; its principal formation is the St. Peter Formation, a medium- to coarse-grained, well-sorted sandstone, containing minor amounts of limestone, shale, and conglomerate. The Ancell Group (St. Peter and Glenwood Formations) represents a change in nomenclature used on the most recent bedrock geology map of Wisconsin (Mudrey and others, 1982). The Ancell Group corresponds to the St. Peter Sandstone as described by Ostrom (1967) and referred to in previous statewide summaries of ground-water quality (Kammerer, 1981, 1984). The thickness of the Ancell Group is generally 100 to 200 ft, but locally is more than 300 ft. The thickness is greatly variable over short horizontal distances because the group was deposited on an irregular erosional surface (Mai and Dott, 1985). The Sinnipee Group, which overlies the Ancell Group in the southern and eastern parts of the State, consists mainly of dolomite but contains some shale and chert locally. Permeability of the rocks in the Sinnipee Group is due primarily to weathering. This group yields water to domestic wells where it is the upper bedrock.

J.T. Krohelski (U.S. Geological Survey, written commun., 1985) has divided the sandstone aquifer into “upper” and “lower” aquifers. The upper sandstone aquifer consists of units above the St. Lawrence Formation and below the Maquoketa Formation confining unit, and the lower sandstone aquifer consists of the Tunnel City and the Elk Mound Groups. This subdivision is used in the definition of the shallow aquifer system in section 2.2.

2.2 Shallow aquifer system

The shallow aquifer system as defined herein for most areas of the State includes the entire thickness of water-yielding rock units above the uppermost confining unit. In other areas where shallow confining units are poorly defined or are absent, the shallow aquifer system includes only those rocks commonly used for water supplies.

The areal distribution of the rock units that compose the shallow aquifer system is shown on the map on the facing page. The approximate thickness of these units in a particular area can be estimated from the glacial-deposits-thickness map in section 2.1.1 and the bedrock-thickness maps on plate 1 (section 2.1.2).

The shallow aquifer system consists of the entire thickness of water-yielding unconsolidated materials and shallow bedrock over about half of the State where their combined thickness is less than about 300 ft and interbedded confining units are absent. These conditions are present in much of northern and north-central Wisconsin where the shallow aquifer system is composed of unconsolidated glacial deposits and weathered Precambrian crystalline rocks overlying impermeable crystalline rocks (area V) or unconsolidated deposits and Cambrian bedrock overlying impermeable Precambrian crystalline rocks (where area I joins area V). In the northwestern part of the State (areas VI and VII), the combined thickness of the Precambrian lava flows and the Lake Superior sandstone aquifer is unknown, but the depth of wells finished in these units is generally less than 600 ft. This depth is assumed to be the practical depth of the shallow aquifer in the area where these rocks are present. Water-yielding Cambrian sandstones overlying the Precambrian lava flows are also included in the shallow aquifer system.

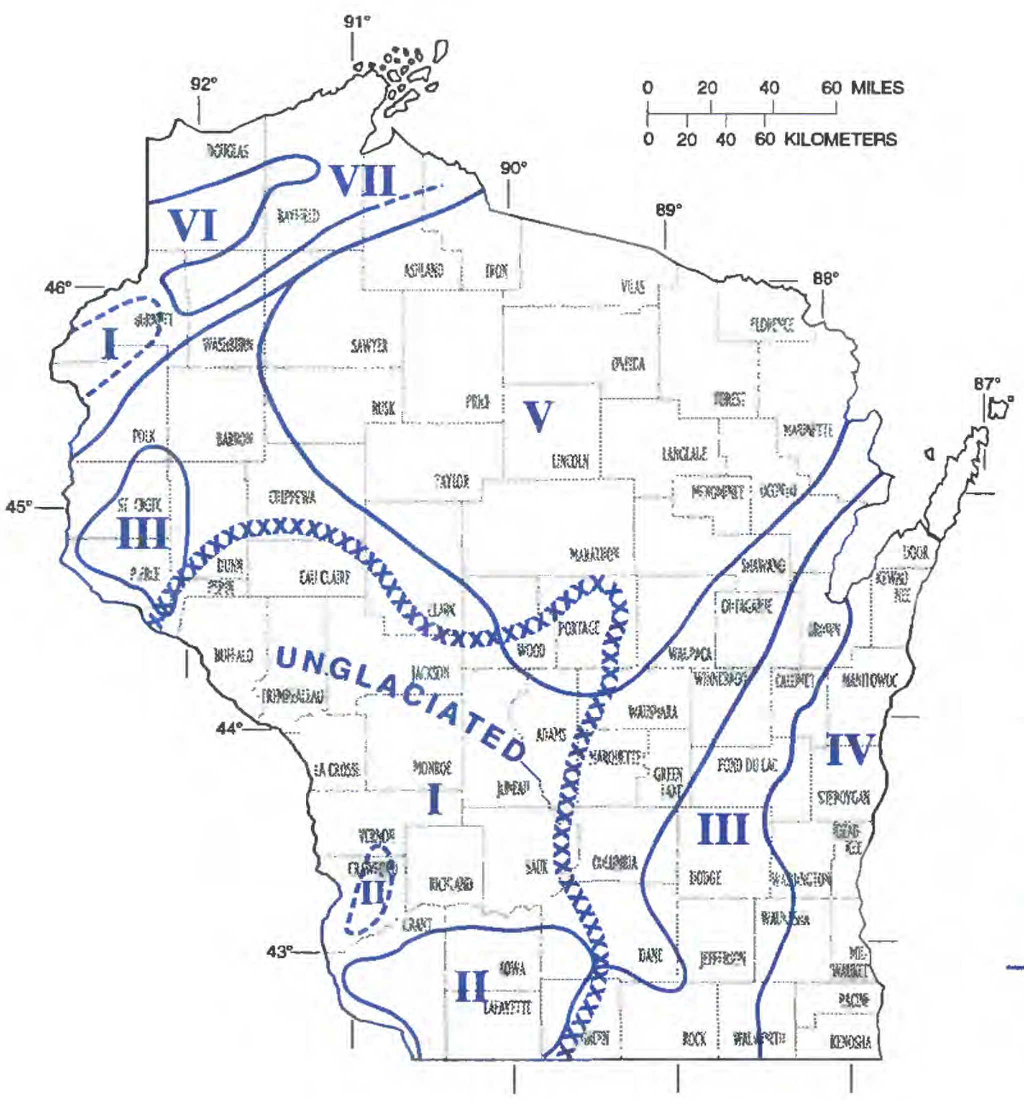
The shallow aquifer system is defined by the relation of water-yielding units to confining units in the west, the south, and the east, where the thickness of sedimentary rocks is greatest, and confining units are present. Where confining units are absent, the rock units included in the shallow aquifer system are identified by age. Whether confining units are present or absent, rock units that are most commonly tapped for water supplies are included in the shallow aquifer system; deeper (older) units that are tapped primarily by a few high-capacity municipal, industrial, or institutional wells are not included, even though they are generally hydraulically connected to overlying units.

The shallow aquifer system in eastern Wisconsin (area IV) consists of the Silurian dolomite aquifer and the overlying sand and gravel aquifer. The underlying Maquoketa Formation confining unit retards water flow between the shallow aquifer system and the deep sandstone aquifer. The Maquoketa Formation, where present, is the lower limit of the shallow aquifer system.

West of the Maquoketa Formation outcrop, in area III, the shallow aquifer system consists of the unconsolidated sand and gravel aquifer, all Ordovician units present, and the Jordan Sandstone. The same combination of bedrock units forms the shallow aquifer system in the southwest (area II), south of the Wisconsin River, and in parts of Pierce and St. Croix Counties in the northwest (area III). Deposits of alluvial sand and gravel in the southwest are important sources of water only in major river valleys.

Where present, the St. Lawrence confining unit defines the base of the shallow aquifer system in areas II and III in the south. Therefore, the shallow aquifer in these areas corresponds to the "upper sandstone aquifer" described by Krohelski (J.T. Krohelski, written commun., 1985). The St. Lawrence confining unit is present locally beneath topographic highs in Vernon and Crawford Counties. Therefore, some wells in these counties obtain water only from rocks above the St. Lawrence Formation, but others are also open to underlying units.

The shallow aquifer system consists of the combined thickness of the sand and gravel aquifer and the Cambrian sandstones in area I, where it borders area V. Between this area and areas to the south where the St. Lawrence Formation is present, the shallow aquifer system consists of the upper 300 to 400 ft of sand and gravel and Cambrian sandstones. The thickness of Cambrian rocks in this area corresponds to the "lower sandstone aquifer" described by Krohelski (J.T. Krohelski, written commun., 1985).



EXPLANATION

- **I** — **Sand-and-gravel deposits end Cambrian bedrock** – Unconsolidated deposits absent in the Driftless Area
- **II** — **Ordovician bedrock and Jordan sandatone In the Driftless Arae** – Includes overlying alluvial deposits in major river valleys
- **III** — **Sand-and-gravel deposits, Ordovician bedrock, end Jordan sandstone**
- **IV** — **Sand-and-gravel deposits end the Silurian dolomite aquifer**
- **V** — **Send-and-gravei deposits, weethered crystalline rocks, and thin Cambrian bedrock**
- **VI** — **Sand-and-gravel deposits and Precembrian lave flows**
- **VII** — **Send-and-gravei deposits and the Lake Superior sandstone aquifer**
- **xxxxxx** — **Extent of glaciation**
- **——— – –** — **Geologic unit boundary** – dashed where approximately located

Geologic units composing Wisconsin's shallow aquifer system

3.0 GROUND-WATER FLOW

3.1 Shallow flow

The configuration of the water table is an indication of the direction of ground-water flow in the shallow aquifer system.

The shallow aquifer system is an unconfined aquifer, so the general horizontal direction of ground-water flow in the system may be inferred from gradients of water-table altitude. The horizontal direction of ground-water flow in the shallow aquifer system is indicated by arrows on the State water-table map shown on plate 2. The direction of flow is perpendicular to the contours of water-table altitude. The flow arrows represent general regional flow; the large contour interval (50 ft) and small map scale (1:1,000,000) preclude representation of local flow. Local flow may differ considerably from that shown on the map, especially in areas where the bedrock component of the shallow aquifer system is fractured dolomite as in the Silurian dolomite aquifer and the rocks in the Sinnipee Group. Detail of the contour lines on the map differs locally because the map is a mosaic of information from many sources.

Ground water in the shallow aquifer system generally moves from beneath topographic highs toward topographic lows. The shallowest ground water discharges to the nearby lakes or streams, but water at greater depths moves greater distances toward major rivers. The flow arrows on the map best represent the direction of movement of the water in the larger, more regional, flow systems.

Water in the shallow aquifer system that neither discharges to surface water bodies nor is lost through evapotranspiration is available to recharge underlying aquifers. Flow from the shallow aquifer system to underlying aquifers is influenced by the extent and the effectiveness of confining units at the base of the shallow system and hydraulic-head gradients. The general decrease in hydraulic-head gradients in the shallow system with depth allows flow of water to deeper aquifers except beneath some major river valleys and some areas in eastern Wisconsin; in these areas where hydraulic heads in deep aquifers are higher than those in the shallow system, water can flow from deep aquifers to the shallow system (Mandle and Kontis, 1992).

Areas where the shallow aquifer system can be recharged from deep aquifers are discussed in section 3.2. The amount of water entering the shallow system from underlying aquifers is generally small compared to the amount entering from surface recharge.

3.0 GROUND-WATER FLOW--Continued

3.2 Regional flow

Ground water flows regionally within the Paleozoic aquifers underlying the shallow aquifer system. Regional flow systems may receive recharge from, or discharge to the shallow system, depending on vertical hydraulic gradients and geologic structure. Regional flow is typically in the direction of the dip of the Paleozoic rocks to the west, south, and east from north-central Wisconsin and locally toward major rivers and lakes.

Deep, regional, ground-water flow in aquifers in Cambrian and Ordovician rocks is typically in the direction of the dip of these rocks to the west, south, and east from north-central Wisconsin and locally toward major rivers and lakes. The regional-flow systems are commonly confined by one of the confining units (St. Lawrence Formation or Maquoketa Formation) at the base of the shallow aquifer system. Water from the shallow system recharges underlying aquifers where confining units are absent or where vertical hydraulic gradients decrease across the confining units, but water from deep aquifers may recharge the shallow system where vertical gradients increase across the confining units.

General horizontal directions of water flow in regional flow systems and hydraulic gradients across confining units may be inferred from flow simulations by Mandle and Kontis (1992) that were done as part of a USGS Regional Aquifer System Analysis (RASA) program study of the Cambrian-Ordovician aquifer system in the northern Midwest. The results of these simulations are used here only to identify areas where the shallow aquifer system is recharged (or may have been in the past) by water from underlying aquifers. More detailed representations of directions of horizontal and vertical flow in Wisconsin's aquifers are given in the unpublished report on the first phase of this project (P.A. Kammerer, Jr., L.C. Trotta, D.P. Krabbenhoft, and R.A. Lidwin, written commun., 1989).

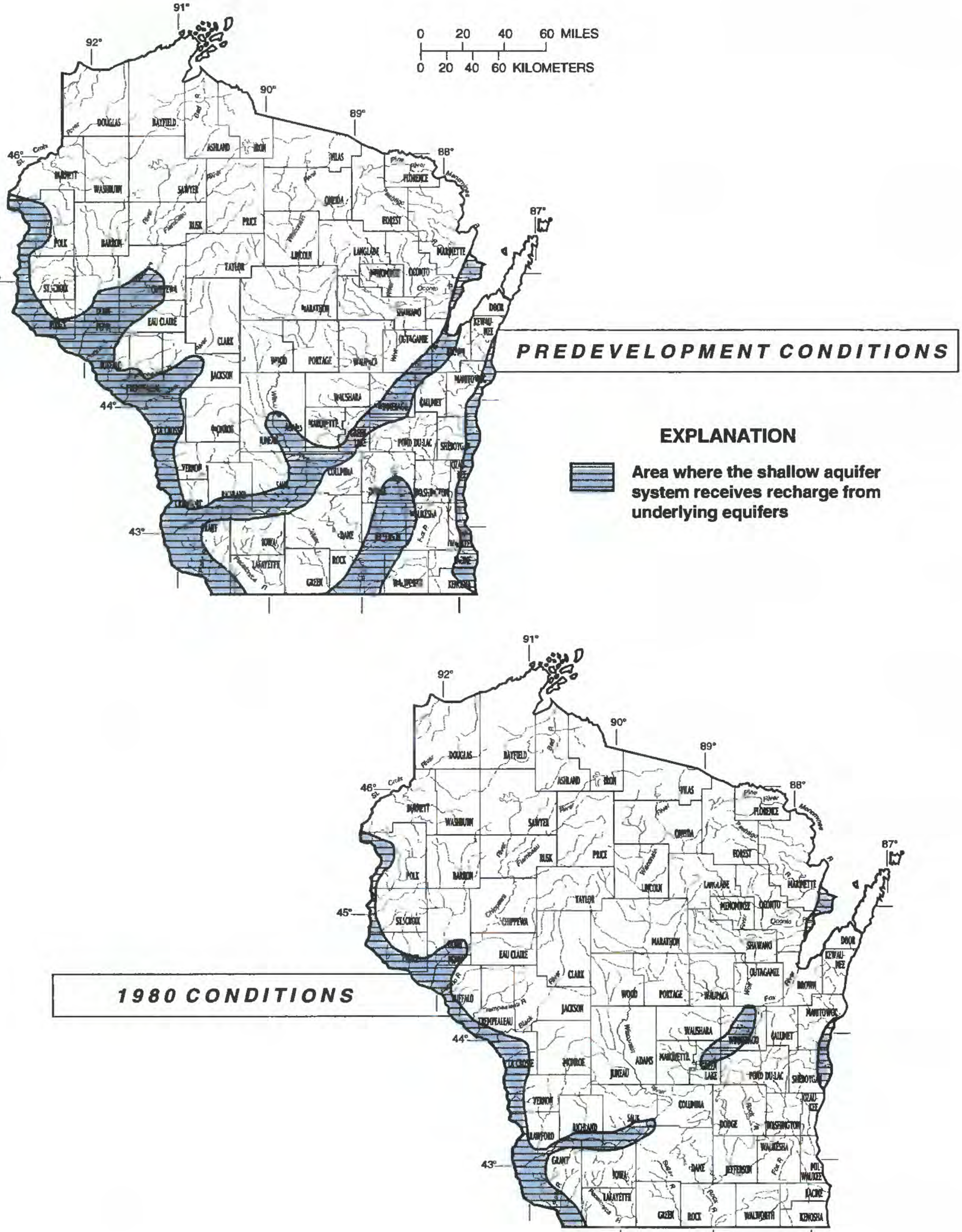
Predevelopment flow (before 1860) and transient flow from 1860 through 1980 were simulated. From a comparison of predevelopment and 1980 flows, one can visualize qualitative changes in the hydrologic relation between the shallow aquifer system and the underlying aquifers.

The maps in this section are based on the results of the flow simulations by Mandle and Kontis (1992) for predevelopment and 1980 flows. Areas where there is potential for upward flow of water into the shallow aquifer system from deep, regional flow systems are depicted on the maps.

Before development, water from deep, regional flow systems discharged to the shallow aquifer system in the Mississippi River Valley and valleys of its major tributaries (St. Croix, Chippewa, Trempealeau, Black, and Wisconsin Rivers), the lower Rock River, the lower Fox River between Green Bay and Lake Winnebago, along the Prairie du Chien Group escarpment west of Lake Winnebago, the west shore of Green Bay, and most of Lake Michigan's shoreline.

The most significant changes in the direction of vertical water flow by 1980 were in eastern Wisconsin. Head declines resulting from heavy pumping of the confined sandstone aquifer caused a reversal of the upward flow through much of the Maquoketa confining unit, particularly in southeastern Wisconsin. Pumping probably caused or contributed to reduction or elimination of upward flow along the lower Fox and the Rock Rivers.

The declines in upward flow along the Mississippi River and its tributaries in western Wisconsin are possibly caused by pumping, but these declines are minor compared to those in eastern Wisconsin.



Areas where the shallow aquifer system receives recharge from underlying aquifers
(modified from Mandle and Kontis, 1992)

4.0 GROUND-WATER QUALITY

4.1 Chemical characteristics

4.1.1 Dissolved solids

Dissolved-solids concentration is a measure of the amount of dissolved minerals in the ground water. Dissolved-solids concentration differs areally because the mineral composition of the aquifer system differs areally. Concentrations are low where the shallow aquifer system is composed entirely of glacial deposits, and high where the system is calcareous sedimentary bedrock.

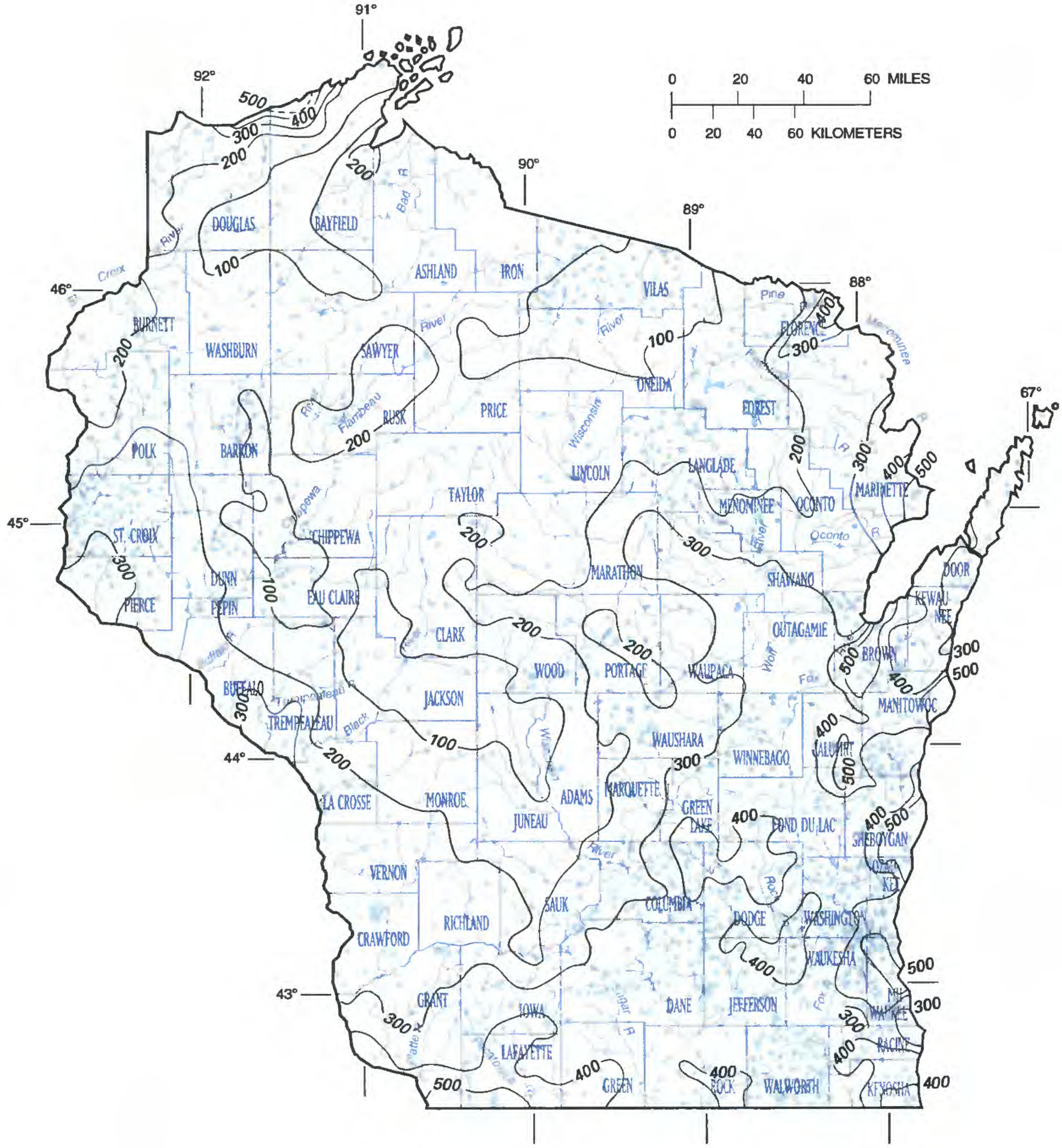
Dissolved-solids concentration is a measure of the amount of material dissolved by water as it passes through soils and rocks in the unsaturated zone and the aquifer. The quantity and the composition of dissolved solids depends on the solubility of the minerals that come in contact with the water and the state of chemical equilibrium between the water and the minerals.

Areal distribution of dissolved-solids concentrations in water from the shallow aquifer system is shown on the map on the facing page. Areal dissolved-solids concentrations in water from unconsolidated components (primarily glacial deposits) of the system are similar to concentrations in water from underlying bedrock components of the system.

Highest dissolved-solids concentrations (greater than about 300 mg/L (milligrams per liter)) for the shallow aquifer system are in areas where the glacial deposits are underlain by the Silurian dolomite aquifer or the Ordovician bedrock, or where the Ordovician bedrock is the uppermost component of the system. Dissolved-solids concentrations exceed 500 mg/L in the Silurian dolomite aquifer in northeastern Manitowoc, east-central Sheboygan, and northeastern Milwaukee Counties. These areas correspond to areas where underlying aquifers contain saline water (Ryling, 1961). Ryling classified water as saline if its dissolved-solids concentration exceeded 1,000 mg/L or if either its chloride or sulfate concentration exceeded 250 mg/L. Dissolved-solids concentrations also exceed 500 mg/L in water from Ordovician units in the Lake Winnebago-Green Bay area, near Marinette, and in the southwestern corner of the State.

Dissolved-solids concentrations exceed 500 mg/L in water from the Lake Superior sandstone aquifer along Lake Superior and locally in other areas of the aquifer.

Lowest dissolved-solids concentrations (less than 100 mg/L) are in water in the north-central and the northwestern parts of the State where the shallow aquifer system is composed of sand and gravel and weathered crystalline bedrock, and in the west-central part of the State where the shallow system is composed of glacial deposits and Cambrian sandstones.



EXPLANATION

100 — **Line of equal dissolved-solids concentration —** Dashed where approximately located. Interval 100 milligrams per liter

• **Sampling site for dissolved solids**

Areal distribution of dissolved-solids concentrations in water from Wisconsin's shallow aquifer system

4.1.2 Hardness

Hardness of water is caused by the presence of calcium and magnesium, two of the major dissolved constituents in Wisconsin's ground water. Hardness is generally highest in areas where the bedrock component of the shallow aquifer system is dolomite. Hardness of water in much of the shallow system is considered objectionably high for domestic use.

Hardness is a property of water that is related to the presence of dissolved calcium and magnesium. Hardness is expressed as an equivalent concentration of calcium carbonate, in milligrams per liter. Classification of water according to its degree of hardness can be somewhat arbitrary and subject to individual preferences. The following ranges of hardness from Durfor and Becker (1964, p. 27) can be used to classify the hardness of water:

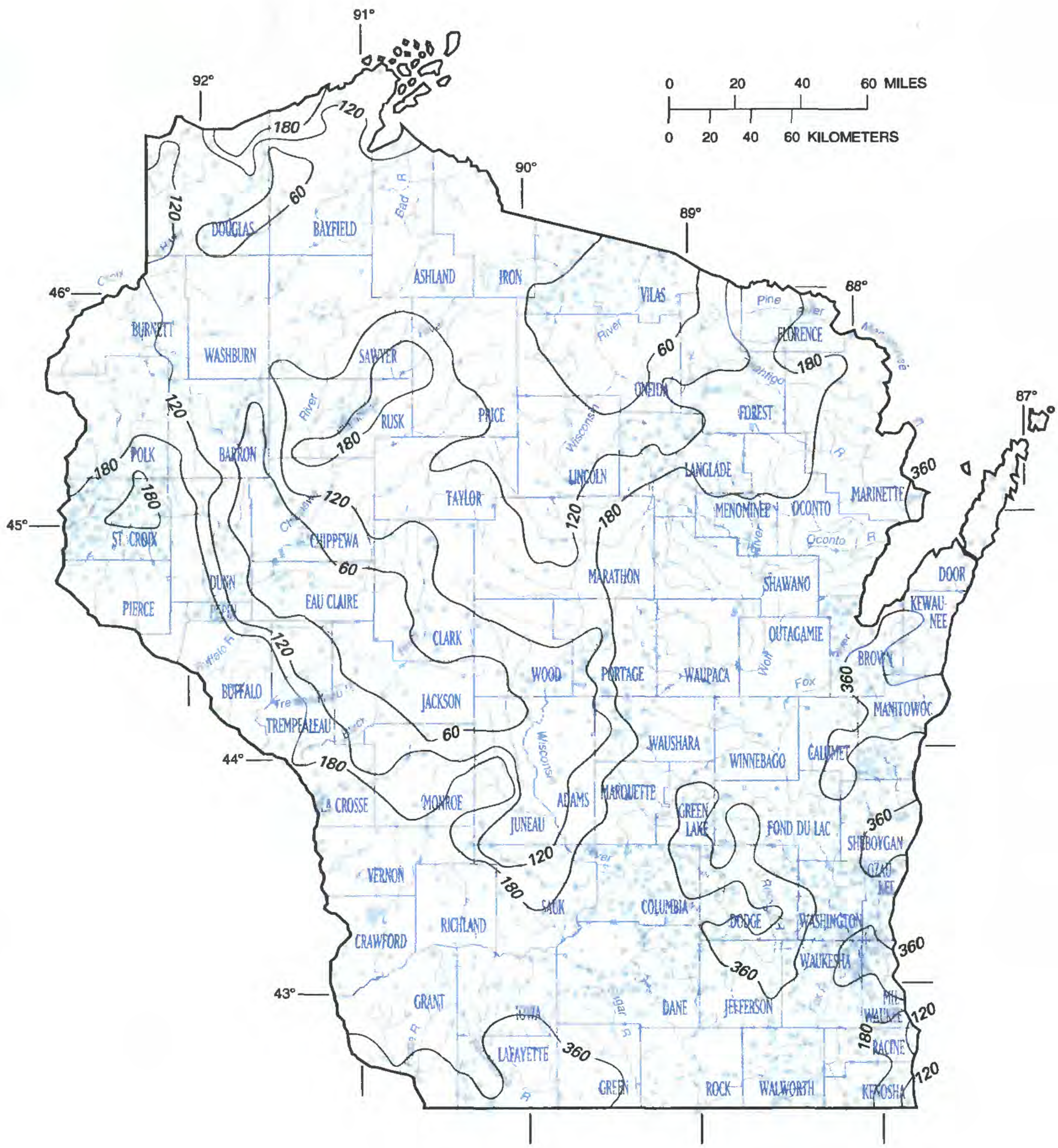
Range of hardness as calcium carbonate (milligrams per liter)	Degree of hardness
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

The areal distribution of hardness in water in the shallow aquifer system is shown on the map on the facing page. Although no standard for hardness is given in the current Wisconsin drinking-water standards (Wisconsin Department of Natural Resources, 1978), water with a hardness of less than 100 mg/L as calcium carbonate is generally considered to be suitable for ordinary domestic use. Water-quality problems caused by excessive hardness include deposition of scale in boilers and heat exchangers and formation of insoluble residues with soap.

Areal trends in hardness tend to parallel trends in dissolved-solids concentrations because calcium and magnesium, the principal components of hardness, are also major constituents of dissolved solids. Hardness of water is highest (greater than about 180 mg/L as calcium carbonate) in areas where the bedrock component of the shallow aquifer system consists of dolomite or dolomitic rocks. Solution of dolomite, a mineral composed of calcium and magnesium carbonate, is a likely cause of high hardness of water. Bedrock composed of or containing some dolomite includes the Silurian dolomite aquifer and the Ordovician rocks in the southern and eastern parts of the State where they are part of the shallow aquifer system. The glacial deposits in these areas contain much calcareous material derived from the underlying bedrock.

Hardness of water differs areally in north-central Wisconsin where the shallow aquifer system consists primarily of glacial deposits that contain little calcareous material. Although available information is not sufficient to relate hardness to stratigraphy, one can assume that hardness is an indication of the amount of calcareous material in the aquifer or in the rock and the soil through which recharge passes.

The trend of decreasing hardness in the southeastern corner of the State (Racine and Kenosha Counties) is related to the chemical composition of the water rather than to a decrease in the dissolved-solids concentration. In this area, sodium instead of calcium and magnesium is the predominant cation in the water.



EXPLANATION

60 **Line of equal hardness of water —** Intervals 60 and 180 milligrams per liter as calcium carbonate

Sampling site for hardness of water

Areal distribution of hardness of water from Wisconsin's shallow aquifer system

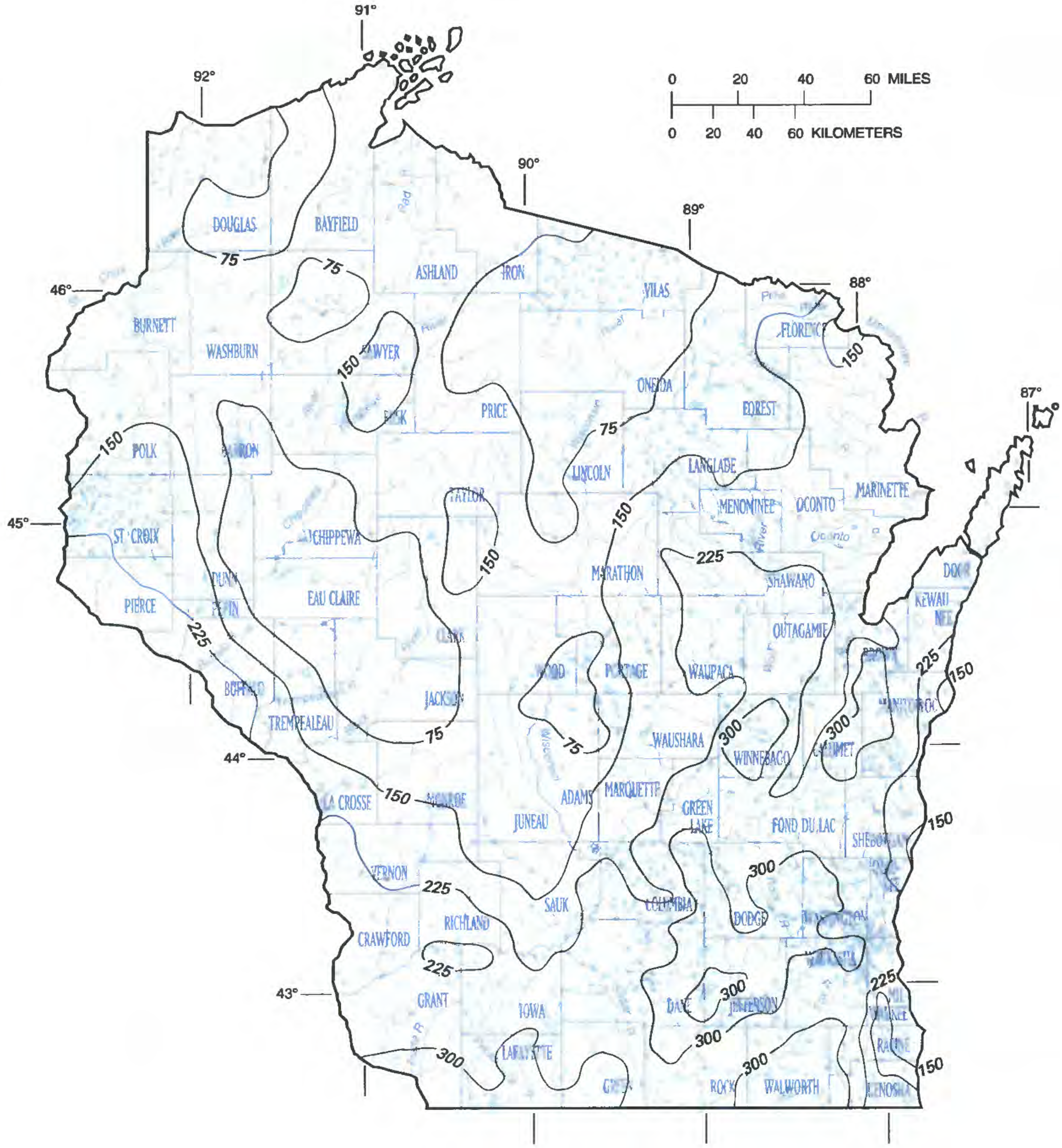
4.1.3 Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acidity. Practically all the alkalinity of natural water is derived from dissolved carbonate and bicarbonate ions. Bicarbonate is a major dissolved constituent in Wisconsin's ground water. Alkalinity is highest in water from areas where carbonate minerals are the primary constituents of the rocks that comprise the shallow aquifer system.

Alkalinity in natural water is produced by the presence of dissolved carbon dioxide gas, bicarbonate, and carbonate; alkalinity is expressed as an equivalent concentration of calcium carbonate, in milligrams per liter. Bicarbonate and carbonate are weathering products of carbonate minerals. Although alkalinity does not adversely affect drinking-water quality, low alkalinity can lead to other problems. For example, water with an alkalinity of less than about 25 mg/L as calcium carbonate may become corrosive if it is chlorinated (National Academy of Sciences, National Academy of Engineering, 1973, p. 54). Alkalinities less than 25 mg/L are uncommon in Wisconsin's ground water.

General ranges of alkalinity for water from the shallow aquifer system are shown on the map on the facing page. Areal trends in alkalinity tend to parallel those of dissolved-solids concentration because bicarbonate (the principal cause of alkalinity) is a principal component of dissolved solids in water.

Alkalinity is generally highest (greater than about 150 mg/L as calcium carbonate) in areas where the bedrock component of the shallow aquifer system consists primarily of carbonate minerals. These rock units include the Silurian dolomite aquifer in the eastern part of Wisconsin and the Ordovician rocks in the eastern and the southern parts. Glacial deposits in these areas contain much carbonate material derived from the bedrock. Alkalinity along the eastern edge of the State, where sulfate instead of bicarbonate is the predominant dissolved anion, is lower than elsewhere in this area. Alkalinity is lowest (less than about 75 mg/L as calcium carbonate) in the northern and central parts of the State, where the principal component of the shallow aquifer system is glacial deposits containing small amounts of carbonate minerals, and in the west-central part of the State, where Cambrian sandstones underlie the glacial deposits.



EXPLANATION

75 **Line of equal alkalinity** — Interval 75 milligrams per liter as calcium carbonate

Sampling site for alkalinity

Areal distribution of alkalinity of water from Wisconsin's shallow aquifer system

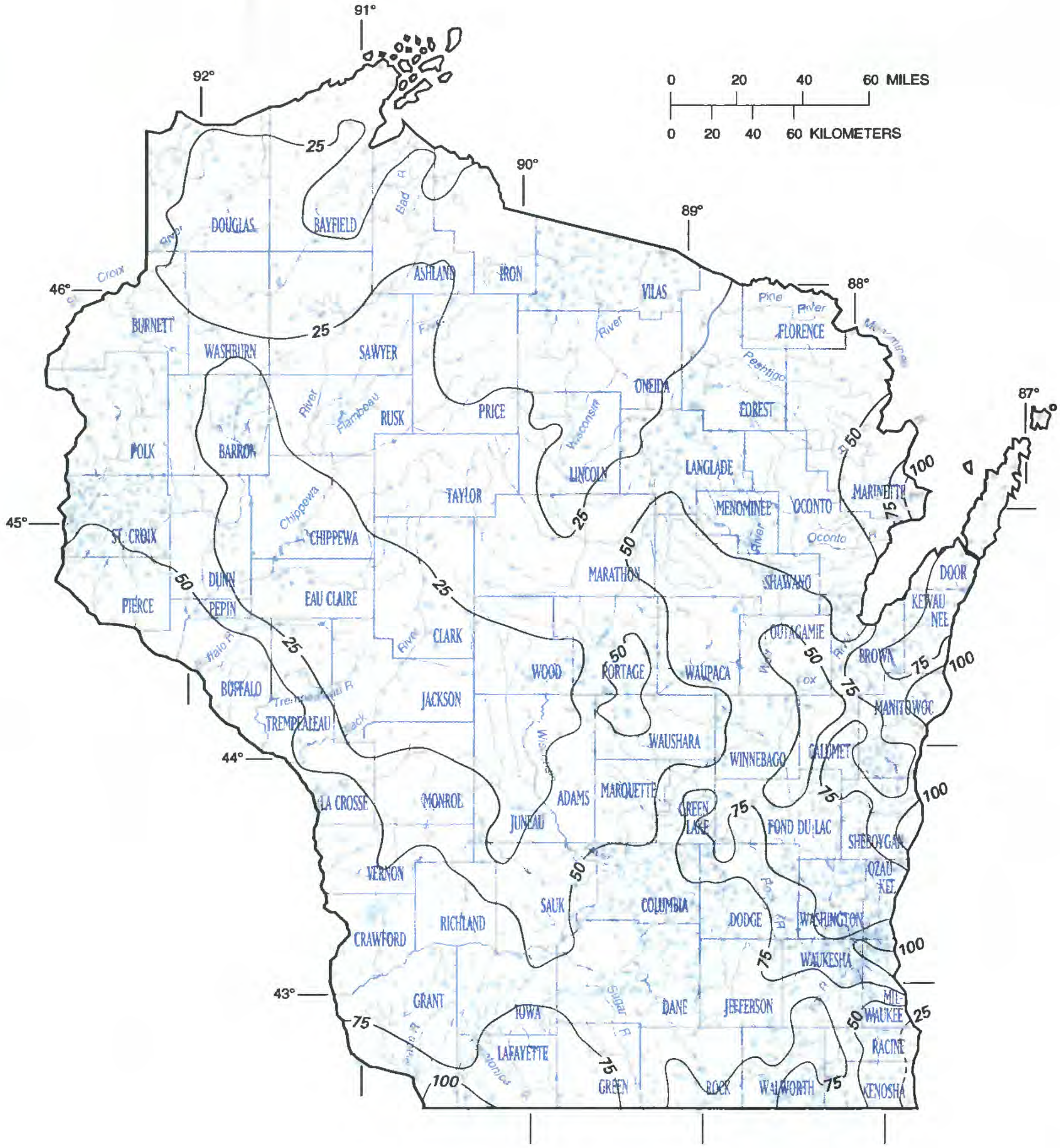
4.1.4 Calcium

Calcium is a major dissolved constituent in Wisconsin's ground water. Calcium concentrations are generally highest where the bedrock component of the shallow aquifer system is primarily dolomite. In general, calcium concentrations in the system are not a problem for most uses of water except where water hardness is a problem.

Calcium in Wisconsin's ground water is derived from weathering of dolomite and other calcareous rocks and sediments and from solution of calcium carbonate cementation in sandstones. Calcium (along with magnesium and bicarbonate ions) is a major dissolved constituent in ground water in most areas. It is also a major component of dissolved solids and hardness.

The general range of calcium concentration in water in the shallow aquifer system is shown on the map on the facing page. Calcium concentrations are highest (greater than about 50 mg/L) in areas where the bedrock component of the shallow aquifer system is predominantly dolomite. These areas include the Silurian dolomite aquifer in eastern Wisconsin and the Ordovician rocks in the eastern and southern parts of the State. The high calcium concentrations (greater than 50 mg/L) in Shawano and northern Waupaca Counties, where underlying bedrock is Precambrian crystalline rocks, are probably due to calcareous glacial deposits carried west and north from the Lake Winnebago-Green Bay area during glaciation. Calcium concentrations are lowest (less than about 25 mg/L) in north-central Wisconsin, where glacial deposits overlie Precambrian crystalline rocks, and in west-central Wisconsin, where glacial deposits overlie thin Cambrian sandstones.

Calcium concentrations of ground water decrease to the east in extreme southeastern Wisconsin where sodium, rather than calcium and magnesium, is the predominant cation in the ground water.



EXPLANATION

25 **Line of equal calcium concentration —** Dashed where approximately located. Interval 25 milligrams per liter

• **Sampling site for calcium**

Areal distribution of calcium concentrations in water from Wisconsin's shallow aquifer system

4.0 GROUND-WATER QUALITY--Continued

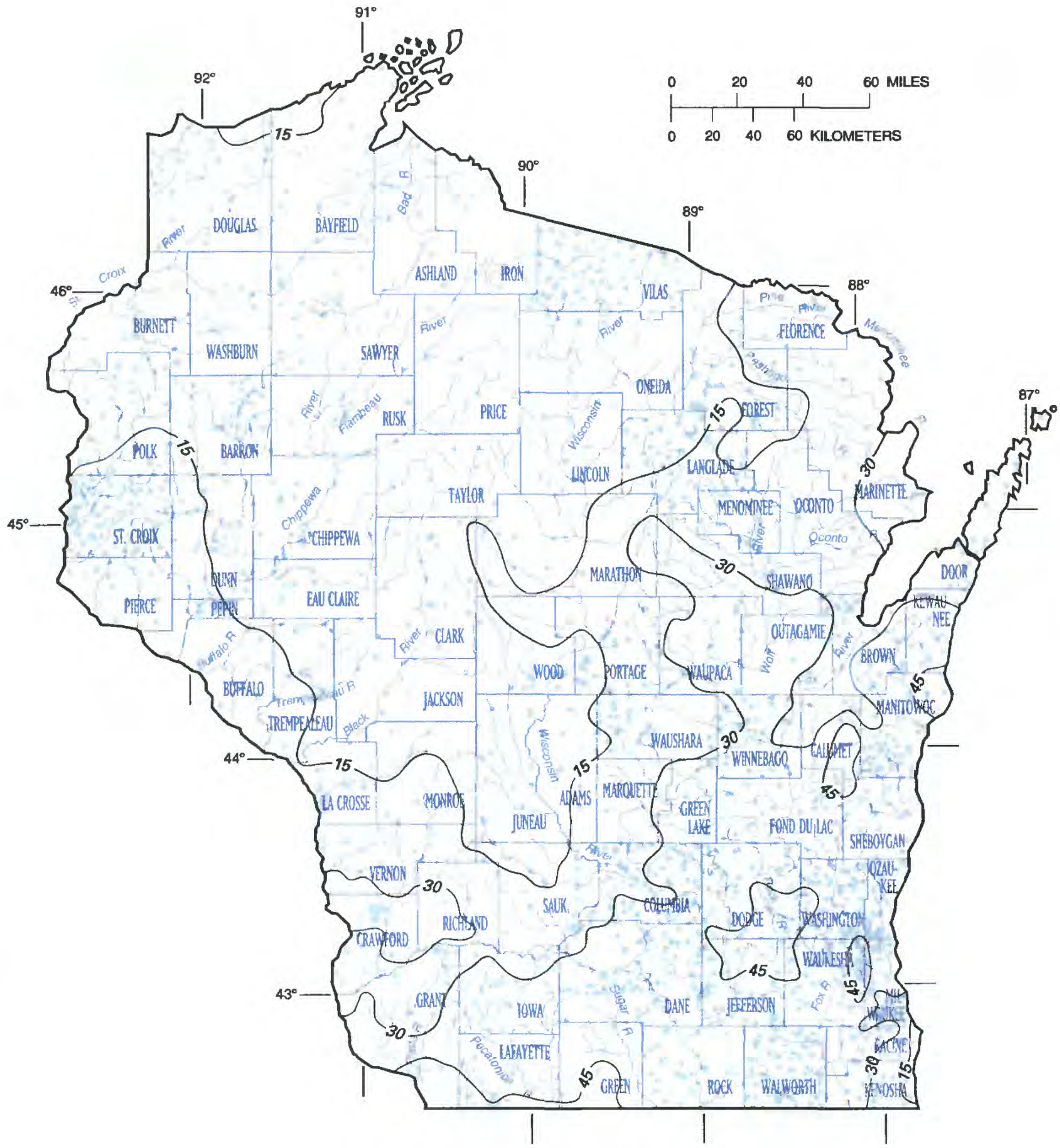
4.1 Chemical characteristics--Continued

4.1.5 Magnesium

Magnesium is a major dissolved constituent in Wisconsin's ground water. Magnesium concentrations are generally highest in water from areas where the bedrock component of the shallow aquifer system is dolomite. In general, magnesium concentrations for water in the system are not a problem for most uses of water except where water hardness is a problem.

Magnesium in Wisconsin's ground water is derived primarily from weathering of dolomite, magnesian limestone, and other magnesium-containing minerals in glacial deposits. Magnesium (along with calcium and bicarbonate ions) is a major dissolved constituent in ground water in most areas. It is also a major component of dissolved solids and hardness.

The general range of magnesium concentrations found in water from the shallow aquifer system is shown in the map on the facing page. Magnesium concentrations are generally highest (greater than about 30 mg/L) in water from areas where the bedrock component of the shallow aquifer system is predominantly dolomite. Dolomitic bedrock in the shallow aquifer system includes the Silurian dolomite aquifer in eastern Wisconsin and the Ordovician rocks in the eastern and southern parts of the State. Magnesium concentrations are lowest (less than about 15 mg/L) in west-central Wisconsin, where glacial deposits overlie thin Cambrian sandstones, and in north-central Wisconsin, where glacial deposits overlie Precambrian crystalline rocks. Higher magnesium concentrations (nearly 30 mg/L) in Shawano and northern Waupaca Counties are probably due to glacial deposits derived from the dolomitic rocks to the east that were transported into these counties during glaciation.



EXPLANATION

15 **Line of equal magnesium concentration —** Interval 15 milligrams per liter

Sampling site for magnesium

Areal distribution of magnesium concentrations in water from Wisconsin's shallow aquifer system

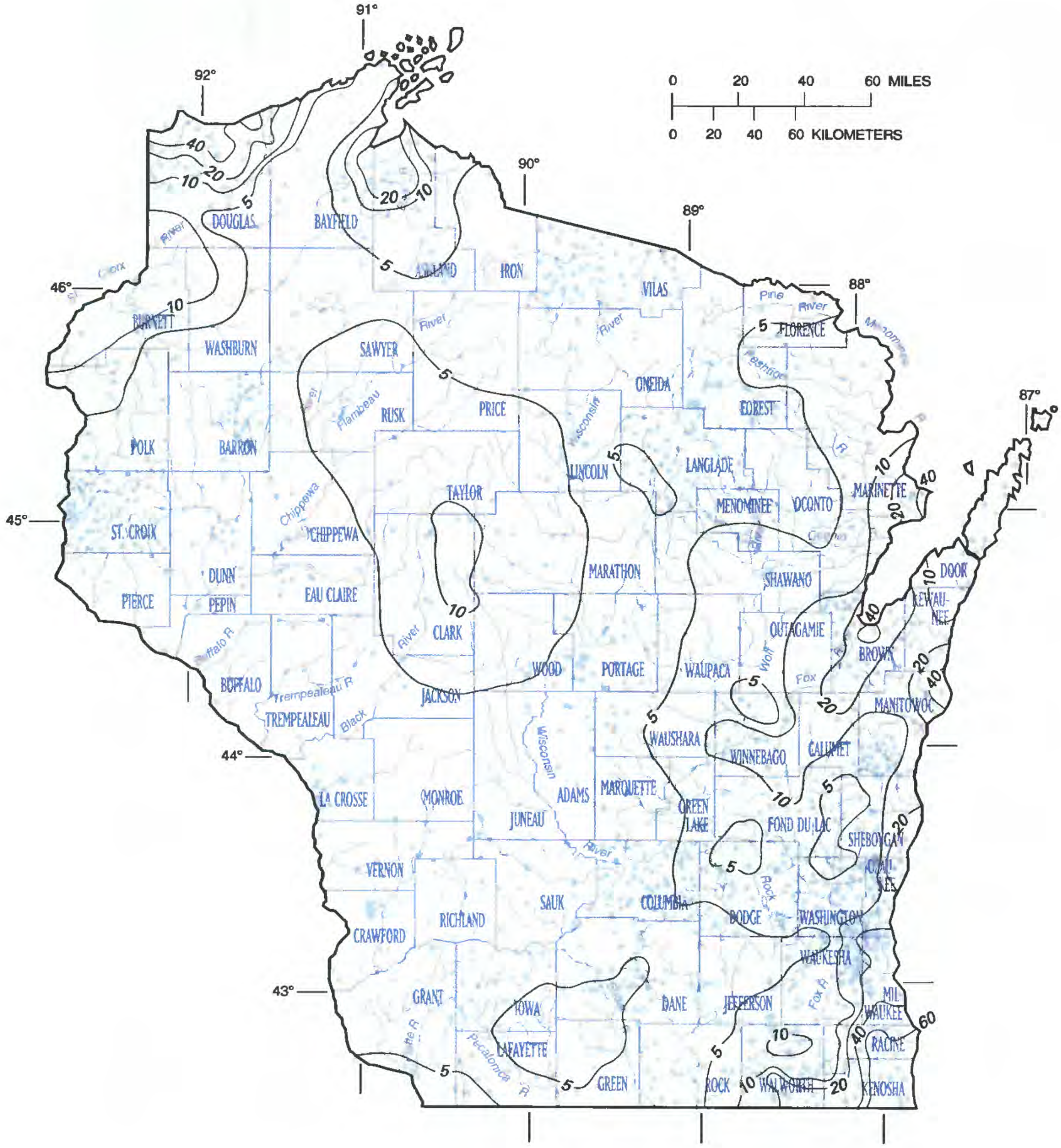
4.0 GROUND-WATER QUALITY--Continued
4.1 Chemical characteristics--Continued
4.1.6 Sodium

Sodium is a minor dissolved constituent in water from the shallow aquifer system. In general, sodium concentrations in water from the shallow aquifer system are not a problem for most uses of water.

Sodium is not abundant in the types of rocks that compose the shallow aquifer system; thus, sodium is a minor dissolved constituent in ground water from these rocks. Wisconsin's drinking-water standards do not specify a concentration limit for sodium (Wisconsin Department of Natural Resources, 1978), but drinking water with less than 20 mg/L of sodium has been recommended for individuals on severely sodium-restricted diets (National Academy of Sciences, National Academy of Engineering, 1973, p. 88).

General distribution of sodium concentrations in water from the shallow aquifer system are shown on the map on the facing page. Sodium concentrations are less than 10 mg/L in most of the State, but higher concentrations are found in the northwestern part along Lake Superior, in southern Marinette County, from Green Bay to Lake Winnebago, in northeastern Manitowoc County, in east-central Sheboygan County, and in northeastern Milwaukee County. Areas where sodium concentrations are greater than 20 mg/L roughly coincide with the areas where dissolved-solids concentrations are highest (greater than about 400 mg/L). Sodium, rather than calcium and magnesium, is the predominant cation in the water in the southeastern corner of the State, where sodium concentrations exceed 60 mg/L.

Sodium concentrations for scattered wells greatly exceeded ambient concentrations; these values were assumed to be anomalous and were not used in preparation of the map.



EXPLANATION

5 — **Line of equal sodium concentration —** Intervals 5, 10, and 20 milligrams per liter

* **Sampling site for sodium**

Areal distribution of sodium concentrations in water from Wisconsin's shallow aquifer system

4.0 GROUND-WATER QUALITY--Continued

4.1 Chemical characteristics--Continued

4.1.7 Potassium

Potassium is a minor dissolved constituent in Wisconsin's ground water. In general, potassium concentrations in water from the shallow aquifer system are not a problem for most uses of water.

Potassium content of the types of rocks in the bedrock component of the shallow aquifer system exceeds that of sodium (Hem, 1985, p. 104), but sodium concentration for ground water in the bedrock component of the system exceeds that of potassium, because these elements react differently in water than in rocks despite their chemical similarities. Minerals containing potassium are more resistant to weathering than minerals containing sodium, and potassium is more likely than sodium to be removed from solution and incorporated into solid products of weathering. No limits for potassium concentrations are specified in Wisconsin's drinking-water standards (Wisconsin Department of Natural Resources, 1978), and potassium is not known to cause water-quality problems.

The general distribution of potassium concentration in water from the shallow aquifer system is shown on the map on the facing page. Concentrations are less than 4 mg/L in most of the State and are apparently not related to aquifer mineralogy. Potassium concentration exceeds 4 mg/L only near Green Bay and Marinette in northeastern Wisconsin and in water from the Lake Superior sandstone aquifer in the northwestern part of the State.

EXPLANATION

1 **Line of equal potassium concentration —** Intervals 1 and 2 milligrams per liter

Sampling site for potassium

Areal distribution of potassium concentrations in water from Wisconsin's shallow aquifer system

4.1.8 Sulfate and sulfide

Sulfate concentrations are generally low in much of the shallow aquifer system, but concentrations exceed Wisconsin's drinking-water standards in some areas. These high sulfate concentrations are not a major water-quality problem because alternative drinking-water supplies are commonly available. Hydrogen sulfide in water from the shallow aquifer system is a problem in some areas.

Probable sources of sulfate in the shallow aquifer system include oxidation of metallic sulfides (most commonly pyrite), dissolution of gypsum, and atmospheric deposition. Metallic sulfides and gypsum are widely distributed in the rocks that comprise the shallow aquifer system. The sulfate concentration in precipitation is 1 to 3 mg/L over most of the United States (Hem, 1985, p. 116).

Sulfate is the dominant form of sulfur in most natural waters, but sulfide (HS^- ion or hydrogen sulfide gas) can be present under certain reducing conditions. Chemical transformation between oxidized (sulfate) and reduced (sulfide) sulfur is slow unless mediated by biological processes.

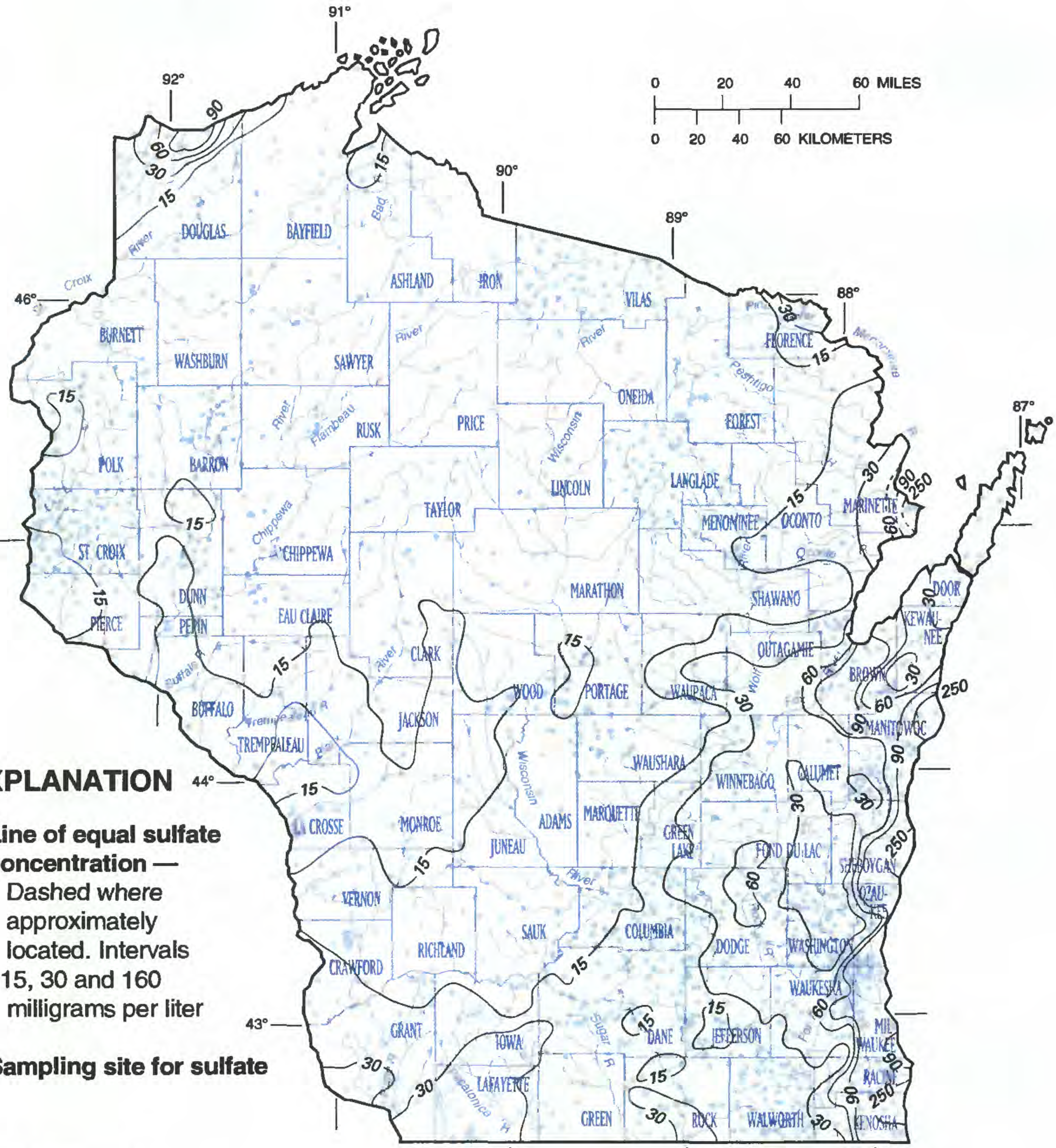
Wisconsin's secondary drinking-water standards specify a maximum sulfate concentration of 250 mg/L (Wisconsin Department of Natural Resources, 1978). Excessive sulfate in water can have a temporary laxative effect in some people unaccustomed to consuming high-sulfate water. The threshold concentration for this effect depends somewhat on the sensitivity of the individual and the concentrations of other ions (primarily magnesium and sodium) in the water. High sulfate concentrations can also impart an unpleasant taste.

The general range of sulfate concentration in water from the shallow aquifer system is shown on the map on the facing page. Sulfate concentrations are less than 30 mg/L in much of the State. Concentrations are highest (greater than about 60 mg/L) in southeastern Marinette County, in eastern Wisconsin where the shallow aquifer system consists of the Silurian dolomite aquifer and glacial deposits, and in the northwestern part of the State along Lake Superior. Areas where sulfate concentrations generally exceed the State drinking-water standard of 250 mg/L are delineated on the map. Water from Lake Michigan is used for drinking water in most of the areas where sulfate concentrations in ground water exceed the drinking-water standards, so the effect of the high sulfate concentrations on water users is diminished.

The areas in Sheboygan and Manitowoc Counties where sulfate concentrations in the shallow aquifer system exceed 250 mg/L correspond to areas where Ryling (1961) reported sulfate concentrations greater than 250 mg/L in water from the Silurian dolomite aquifer.

Oxidation of sulfide minerals exposed by lead and zinc mining in the southern part of Lafayette County in southwestern Wisconsin has produced locally high sulfate concentrations in water from some strata of the shallow aquifer system. Sulfate concentrations ranging from about 200 to 600 mg/L in this area were not used in preparing the map because they are the result of local activities and, therefore, do not represent the natural regional water quality.

Hydrogen sulfide in water from the shallow aquifer system has been reported in some parts of the State. Areas where problems with hydrogen sulfide in ground water were reported in a survey of well drillers by T.A. Calabresa of the WDNR (Kammerer, 1984, p. 46) and are shown on the map on the facing page. The wells in southeastern Wisconsin draw water from the Silurian dolomite aquifer, and the wells in the other areas draw water from rocks of the Sinnipee Group. A likely source of the hydrogen sulfide is biochemical reduction of sulfate. Data on hydrogen sulfide concentrations are generally not available, but it is likely that both sulfate and sulfide are present in water in some areas. Sulfate was detected in water from all wells, but anomalously low sulfate concentrations were detected in water from scattered wells in eastern Wisconsin, where sulfate concentrations are generally high–an indication that sulfate is reduced locally.

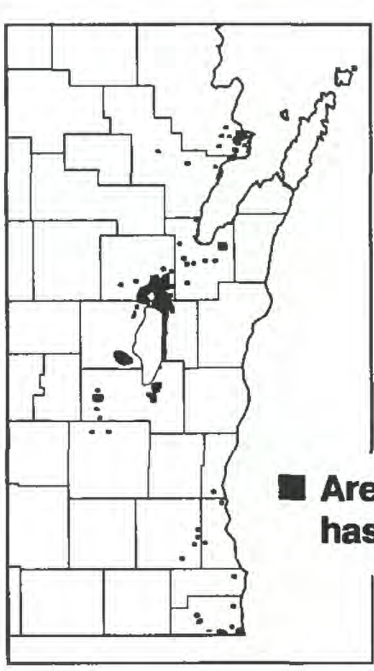


EXPLANATION

15 Line of equal sulfate concentration — Dashed where approximately located. Intervals 15, 30 and 160 milligrams per liter

• Sampling site for sulfate

Areal distribution of sulfate concentrations in water from Wisconsin's shallow aquifer system



■ **Areas where hydrogen sulfide in ground water has been reported** (from Kammerer, 1984)

4.1.9 Chloride

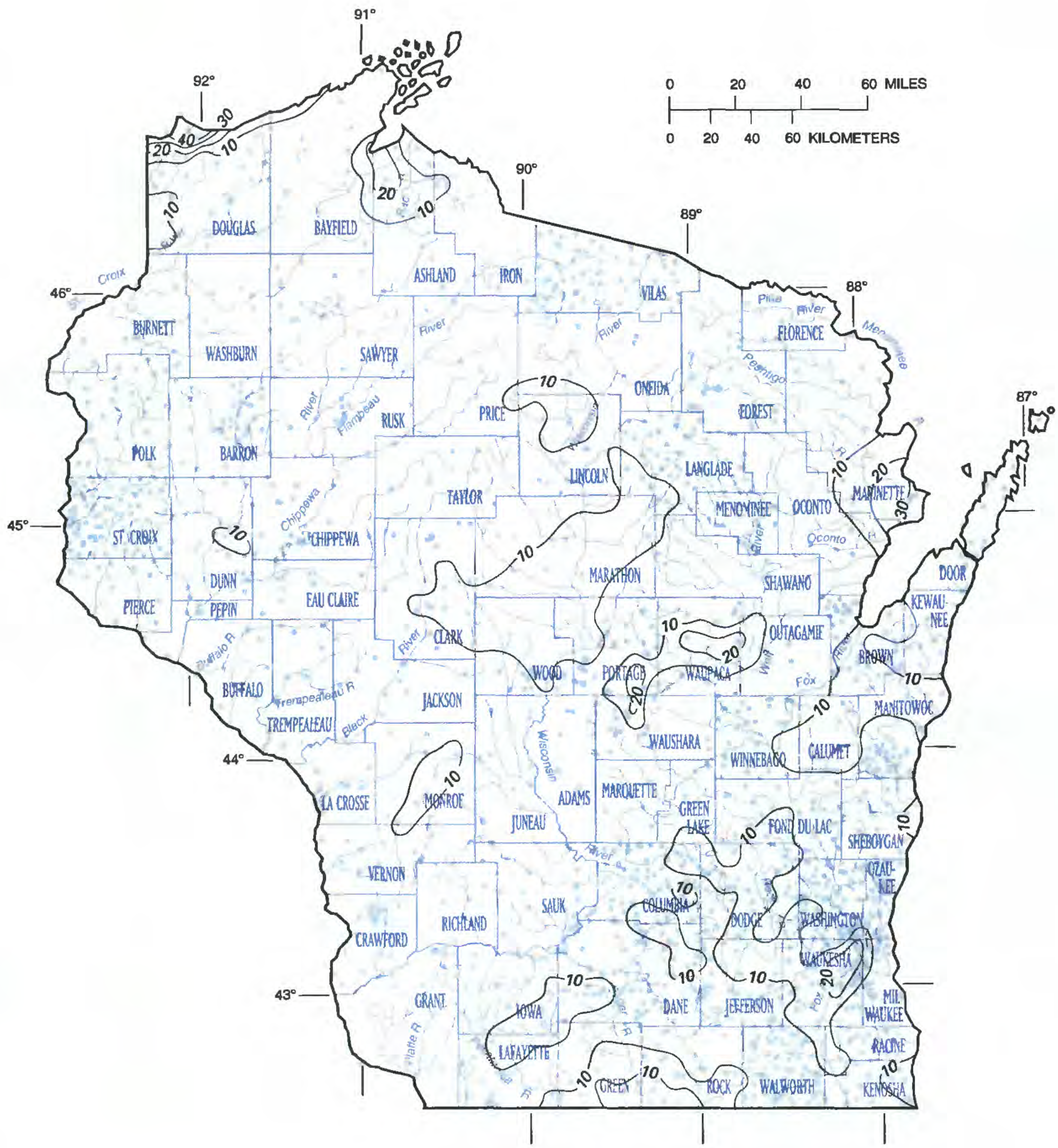
Chloride concentrations in water from the shallow aquifer system are commonly low. Concentrations are highest in the northwestern part of Wisconsin, near Lake Superior, and in southeastern Marinette County. Chloride concentrations in water from the shallow aquifer system do not cause problems for most uses of water.

Chloride is less abundant in most common rock types than its concentration in most natural waters would indicate (Hem, 1985, p. 118). Other sources of chloride, in addition to products of weathering and dissolution of minerals, and peculiarities of chloride's chemical behavior compared to that of other common dissolved constituents, help to explain this apparent discrepancy. The chemical behavior of chloride differs from that of other dissolved constituents, because it does not form low-solubility precipitates, sorb on mineral surfaces, nor participate in oxidation-reduction reactions or biochemical cycles to the extent that its concentration in ground water is affected. Chloride tends to remain in solution once it is mobilized.

Natural sources of chloride in potable water, other than weathering of minerals, include atmospheric deposition and connate water. A complete review of the occurrence and the behavior of chloride in natural continental water is given by Feth (1981). Human and animal wastes and salt used for snow and ice removal are important sources of chloride in some areas. Because chloride is itself a possible contaminant, and is also found in contaminants such as waste water and animal waste, it is potentially useful as a general indicator of ground-water contamination when it is present in greater-than-ambient concentrations.

Wisconsin's secondary drinking water standards specify a maximum concentration of 250 mg/L for chloride in drinking water (Wisconsin Department of Natural Resources, 1978). The standard is based on aesthetic (taste) considerations. Only 12 wells in the shallow aquifer system produced water with a chloride concentration exceeding 250 mg/L.

The general areal distribution of chloride concentrations in water from the shallow aquifer system is shown in the map on the facing page. Concentrations are less than 10 mg/L in much of the State. Concentrations that exceed 20 mg/L are common only in southeastern Marinette County and in water from the Lake Superior sandstone aquifer along Lake Superior. Chloride concentrations higher than ambient concentrations are present in water from individual wells scattered throughout the State. These higher concentrations probably result from local ground-water contamination and do not seem to represent areal ground-water quality. Because of this, these locally high concentration values were not used in preparing the map.



EXPLANATION

10 — **Line of equal chloride concentration —** Interval 10 milligrams per liter

• **Sampling site for chloride**

Areal distribution of chloride concentrations in water from Wisconsin's shallow aquifer system

4.1.10 Fluoride

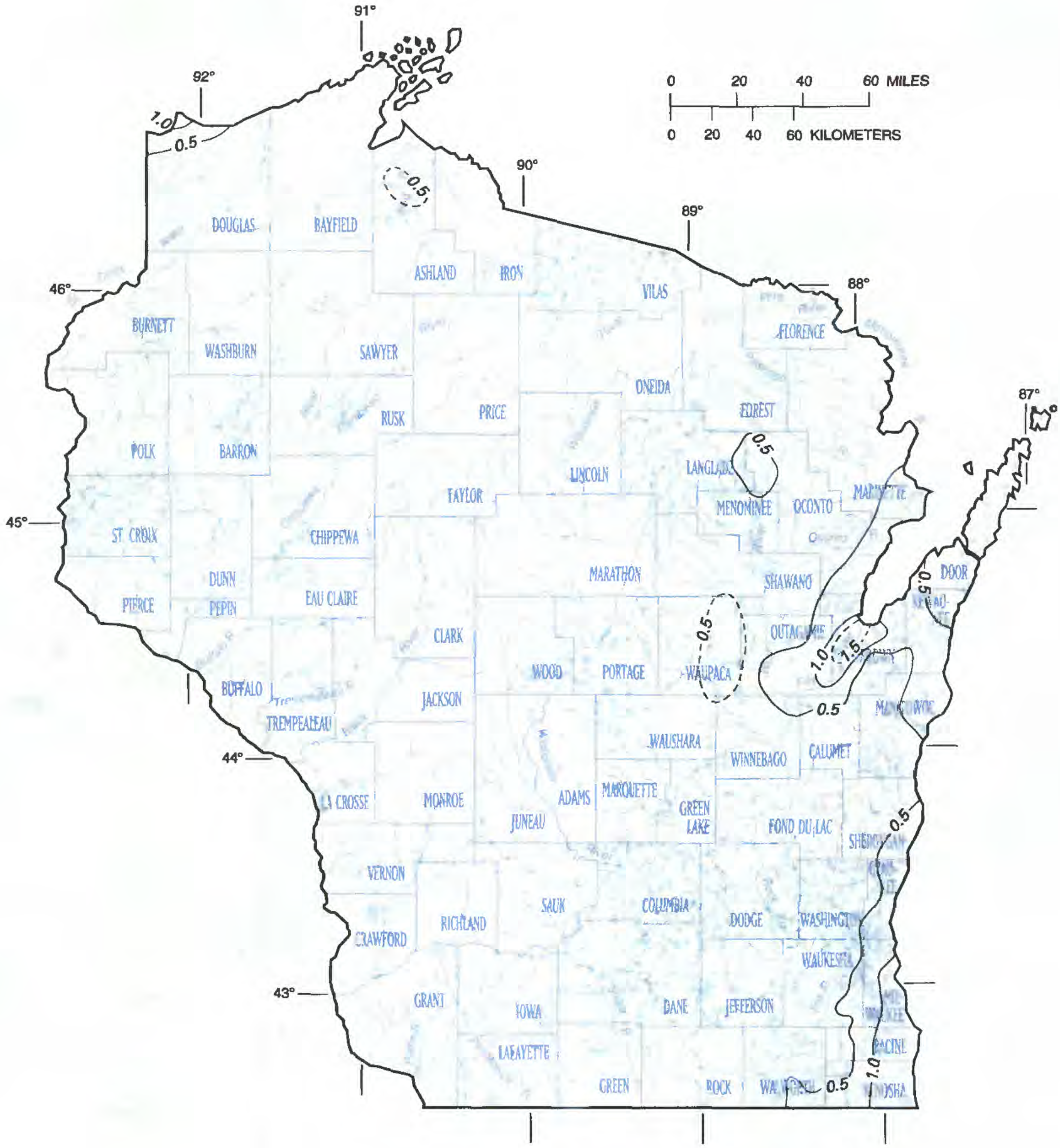
Fluoride concentrations in water from the shallow aquifer system are low in most of the State. Concentrations approach the State drinking-water standard in only a small area in Brown County.

Fluoride-containing minerals are a minor component but are widely distributed in sedimentary and igneous rocks, which are common in the shallow aquifer system. Products of the weathering and the dissolution of these minerals are the most likely sources of fluoride in the ground water. Fluoride concentrations are generally less than 1.0 mg/L in most natural fresh waters (Hem, 1985, p. 120).

Wisconsin's drinking-water standards (Wisconsin Department of Natural Resources, 1978) specify a maximum allowable fluoride concentration of 2.2 mg/L for drinking water. Concentrations exceeding the standard may discolor tooth enamel.

Fluoride in drinking water, however, can be beneficial in reducing the incidence of tooth decay. Supplemental fluoridation is therefore used in many public-water supplies. Optimum fluoride concentration recommended to realize these benefits in Wisconsin is 1.0 to 1.2 mg/L (U.S. Environmental Protection Agency, 1975, p. 67). The optimum concentration is based on annual average maximum daily air temperature and on the assumption that the amount of fluoride consumed by children (who are most susceptible to the effects of fluoride) is determined by their water consumption. Water consumption, in turn, can be related to annual average maximum daily air temperature.

The general range of fluoride concentrations in water from the shallow aquifer system can be seen in the map on the facing page. Concentrations are less than 0.5 mg/L in much of the State. Highest concentrations are in eastern Wisconsin and in a small area in northwestern Wisconsin near Lake Superior. Fluoride concentrations exceed 2.0 mg/L in only a small area of Brown County; the highest concentration observed in this area is 2.8 mg/L. Several municipalities in this heavily populated area depend on this high-fluoride water for public drinking-water supplies.



EXPLANATION

0.5 **Line of equal fluoride concentration** — Dashed where approximately located. Interval 0.5 milligrams per liter

Sampling site for fluoride

Areal distribution of fluoride concentrations in water from Wisconsin's shallow aquifer system

4.0 GROUND-WATER QUALITY--Continued
4.1 Chemical characteristics--Continued
4.1.11 Iron and manganese

Iron and manganese concentrations exceed State drinking-water standards in water from many wells in the shallow aquifer system. Extreme local differences in concentration of these elements are common.

Iron and manganese are widely distributed in rocks and soils. Their solubility and mobility in ground water are affected by combinations of complex chemical and biological processes. Solubilities of these elements depend on their oxidation state, which is strongly affected by the intensity of oxidation or reduction conditions in the aquifer. Solubility also depends on pH. Rapid changes in oxidation state, commonly mediated by biological processes, can affect solubility and cause extreme local concentration differences.

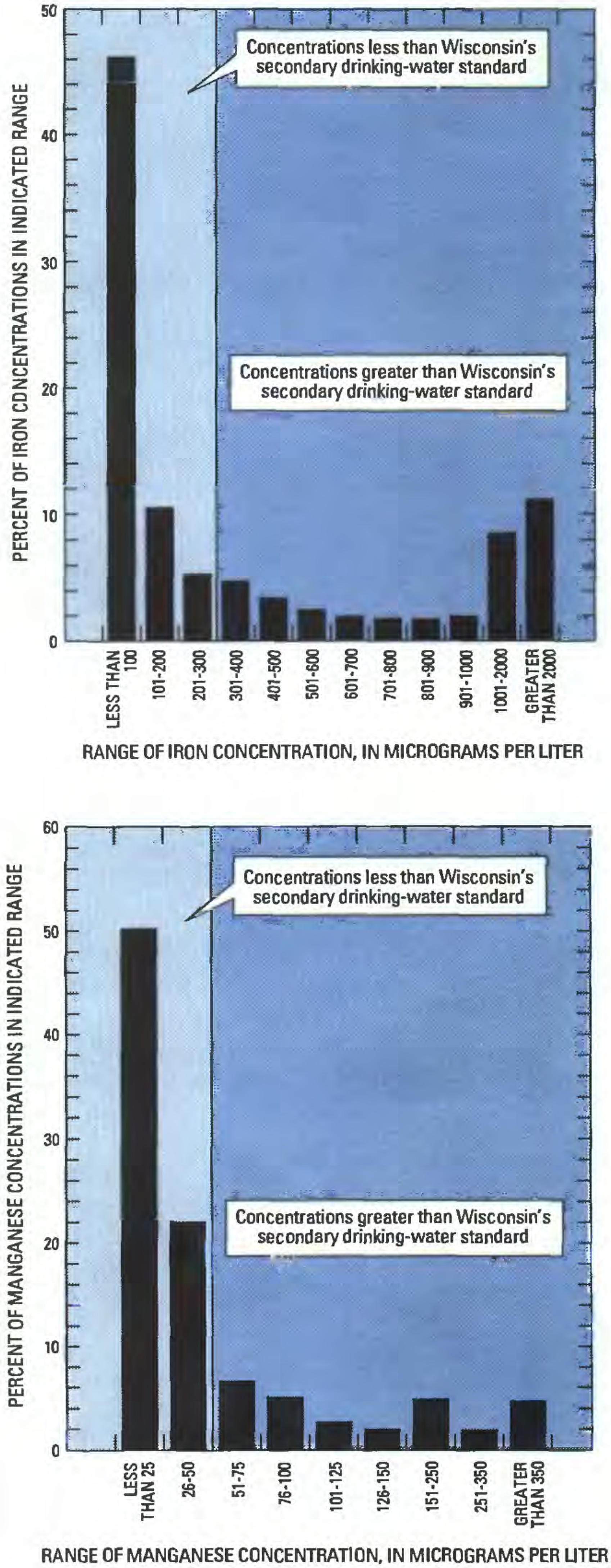
Maximum concentrations of iron and manganese specified in Wisconsin's secondary drinking-water standards are 300 and 50 µg/L (micrograms per liter) (Wisconsin Department of Natural Resources, 1978). Neither constituent poses a health hazard at the concentrations normal for natural water, but both can cause a variety of aesthetic problems, such as objectionable taste, staining of laundry and plumbing fixtures, and encrustation and clogging of well screens and distribution systems. An iron or manganese concentration greater than 200 µg/L is objectionable for many industrial uses of water (Durfor and Becker, 1962, p. 16).

Rapid changes in oxidation state and, hence, solubility of iron and manganese complicate both the collection and interpretation of concentration data for these constituents. Extreme local differences in concentration of these elements make the preparation of areal distribution maps for iron and manganese impractical. Solubility can change between the times of sample collection and of analysis. Improper processing of samples can lead to discrepancies between concentrations determined in the laboratory and the concentrations of the constituents in the aquifer.

The distribution of iron and manganese concentrations in water from the shallow aquifer system is shown in the bar graphs on the facing page. The data used in these bar graphs are from analyses in which concentrations are reported as dissolved iron and manganese, as iron and manganese "in solution when analyzed," and as total iron and manganese. The "in solution when analyzed" classification applies particularly to historical data where sample collection and analytical procedures are unknown or poorly documented.

Iron concentrations in water from about one-third of the wells exceed Wisconsin's drinking-water standard, and manganese concentrations in water from about one-fourth of the wells exceed the State's drinking-water standard. This generalization is fairly consistent Statewide for manganese. Iron concentrations that exceed drinking-water standards are more common in eastern Wisconsin, where the shallow aquifer system consists of Ordovician or Silurian rocks overlain by glacial deposits, than in the rest of the State. In the east, the drinking-water standard for iron was exceeded in water from about half of the wells sampled.

More detailed summaries of iron and manganese concentrations for water in individual geologic units, including those that comprise the shallow aquifer system, are given by Kammerer (1984, p. 16, 24, 32, and 40). These summaries are further subdivided by ground-water province to reduce the effects of areal differences of hydrogeology.



Distribution of iron and manganese concentrations in water from Wisconsin's shallow aquifer system

4.0 GROUND-WATER QUALITY--Continued

4.1 Chemical characteristics--Continued

4.1.12 Nitrate

Nitrate-nitrogen concentrations in water from the shallow aquifer system differ locally. Concentrations that exceed State standards commonly result from local ground-water contamination. The incidence of high nitrate-nitrogen concentrations is greatest in private water supplies in rural areas.

Likely sources of nitrate nitrogen in ground water include other forms of nitrogen (nitrogen gas, organic nitrogen, ammonia, nitrite nitrogen) that can be converted to nitrate nitrogen by chemical and biological processes, plant fertilizers, waste water disposed of on land, animal wastes, and septic systems.

Wisconsin's drinking-water standards (Wisconsin Department of Natural Resources, 1978) specify a maximum permissible nitrate-nitrogen concentration of 10 mg/L in public-water supplies. Human-health standards for nitrate nitrogen are based primarily on the role of nitrate nitrogen in causing a temporary, but potentially serious, blood disorder called "methemoglobinemia" in infants. High nitrate-nitrogen concentrations can also affect the health of livestock, but livestock can generally tolerate higher nitrate-nitrogen concentrations in water than the 10 mg/L State limit for human consumption.

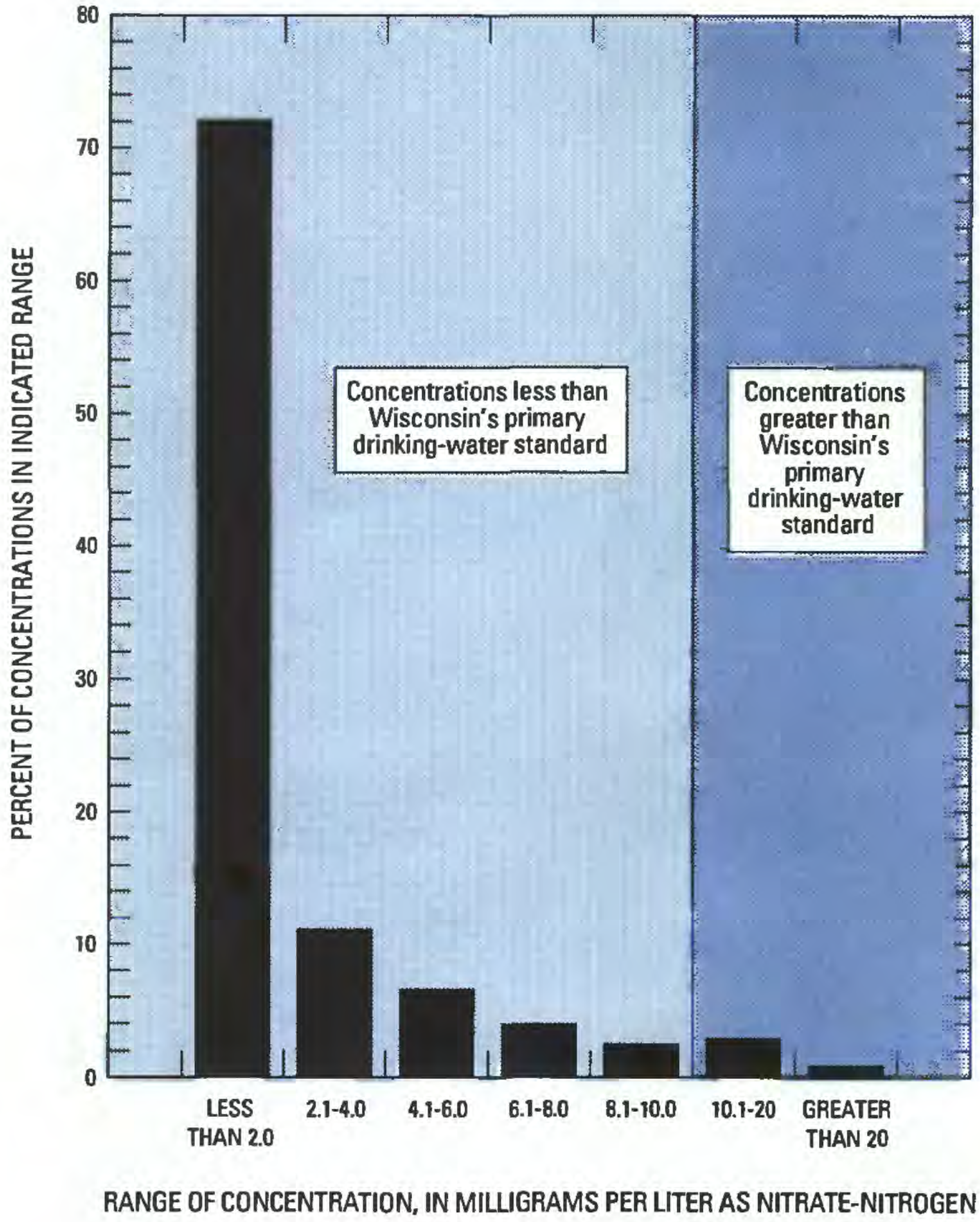
The incidence of high nitrate-nitrogen concentrations (concentrations that approach or exceed State drinking-water standards) is greatest in water from private water-supply wells in rural areas. Therefore, the apparent extent of contamination by nitrate in the shallow aquifer depends on the degree to which these wells are represented in the data.

Nitrate-nitrogen concentrations from the USGS water-quality data base (WATSTORE) are summarized in the bar chart on the facing page. The apparent incidence of high nitrate-nitrogen concentrations in water from the wells represented by these data is low; less than 3 percent of the concentrations exceed the 10 mg/L State drinking-water standard. These data include analyses of water from a variety of public and private water supplies and commercial and industrial wells in urban and rural areas. Private water-supply wells in rural areas, especially older wells that are deteriorating or are not in compliance with current codes, are underrepresented in this data base.

Few public water-supply wells yield water with high nitrate-nitrogen concentrations. A 1970 compilation of water-quality data for Wisconsin's public water supplies, most of which are ground-water supplies, reported no nitrate-nitrogen concentrations that exceeded 10 mg/L in more than 1,200 analyses (Wisconsin Department of Natural Resources, 1970). In results of a 1979 and 1980 sampling of 11,396 noncommunity ground-water supplies (systems serving at least 25 people at least 60 days per year) reported by Strous (1986, p. 5), nitrate-nitrogen concentrations in water from 2.6 percent of the wells exceeded 10 mg/L.

Other investigations document a greater incidence of high nitrate-nitrogen concentrations in water from private rural wells than from public supply wells. In a survey of 1,468 private, rural-water supplies in Dane and Columbia Counties, Schuknecht and others (1975) concluded that nitrate-nitrogen concentrations in water from 39 and 38 percent of the wells sampled in these counties exceeded 10 mg/L, respectively. Delfino (1977) summarized data from surveys of private rural-water supplies done in 1968-72. Statewide, nitrate-nitrogen concentrations in water from 550 of 5,950 wells (9.2 percent) exceeded 10 mg/L.

Detailed statistical summaries of nitrate-nitrogen concentrations for individual geologic units, including those in the shallow aquifer system, are given by Kammerer (1984, p. 18, 24, 34, and 42). These summaries are further subdivided by ground-water province within the State.



Distribution of nitrate-nitrogen concentrations in water from Wisconsin's shallow aquifer system

4.2 Effect of water from underlying aquifers

Saline water from underlying aquifers has entered the shallow aquifer system and affected water quality in some areas of the State.

Deep aquifers in some areas of the State contain saline water (water with dissolved-solids concentration greater than 1,000 mg/L or chloride or sulfate concentration greater than 250 mg/L). These areas are generally along the western, southern, and eastern borders where sedimentary rocks are thickest, and in Precambrian sandstones in northwestern Wisconsin. Detailed discussion of water quality in deep aquifers is beyond the scope of this report, but a brief discussion of the occurrence and the extent of saline water is pertinent because of its actual and potential effects on water quality in the shallow aquifer system.

Hydraulic heads in some deep units of the sandstone aquifer are, or have been, higher than hydraulic heads in the shallow aquifer system. This head differential causes upward flow of ground water and creates the potential for saline water from the sandstone aquifer to move upward into the shallow system.

Areas where there is or was potential for regional upward ground-water flow are described in detail in section 3.2 of this report. Before the beginning of deep-well drilling in the late 1800's, areas of upward flow were near major rivers, Lake Michigan, and the western shore of Green Bay. Their extent has been reduced in some areas since then because of decreasing hydraulic heads caused by ground-water pumping. Areas of current upward flow of water coincide with areas of saline water directly beneath the shallow aquifer at two locations–in eastern Sheboygan County, and in southwestern Wisconsin near the confluence of the Mississippi and Wisconsin Rivers. Upward flow of saline water to the shallow aquifer through improperly sealed or abandoned wells and wells with corroded casings was reported in the early 1900's in both of these areas (Weidman and Schultz, 1915, p. 287, 571).

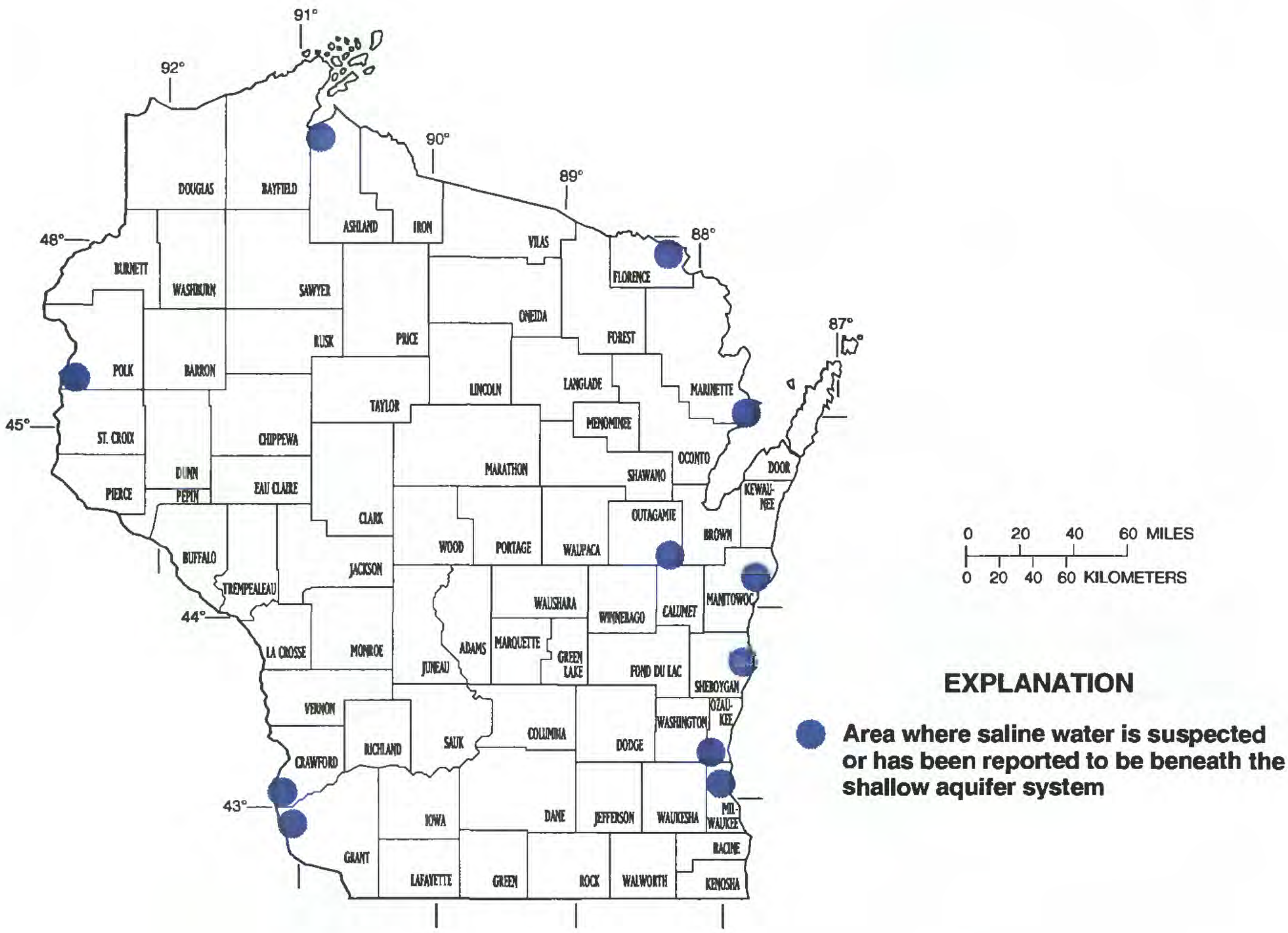
Geologic units immediately beneath the shallow aquifer system contain saline water in other areas where upward hydraulic gradients are absent but were probably present in the past. Some of these units correspond to areas where dissolved-solids concentrations are high (greater than 500 mg/L) in water from the shallow system (see section 4.1.1); this could mean that saline water flowed upward in the past.

Several places in Ordovician and Cambrian units underlying the shallow aquifer system that contain saline water were reported by Weidman and Schultz (1915, p. 170). Wells finished in Ordovician rocks (Sinnipee Group, Ancell Group) or Cambrian sandstones underlying the Silurian dolomite aquifer have produced saline water in southern Brown County, eastern Manitowoc County, Milwaukee County, and Ozaukee County. Wells in southeastern Marinette and southern Outagamie Counties produce saline water from the same units where the Silurian dolomite is absent. Wells in the shallow system produce water with dissolved-solids concentrations greater than 500 mg/L in all of these areas. Two wells in Jefferson County produce saline water from Cambrian sandstone, but dissolved-solids concentrations in water from the shallow aquifer system in these areas do not exceed ambient concentrations.

Saline water has also been reported to be in Precambrian rocks (Weidman and Schultz, 1915, p. 170). These areas of saline water are poorly defined, because geology is not well known and interest in use of the Precambrian rocks for ground-water supplies is slight. Saline water is produced by deep wells in northeastern Florence County, and along Lake Superior near Ashland and east of Superior. Dissolved-solids concentrations in water from the shallow aquifer system in these three areas are higher than concentrations in adjoining areas.

Saline water was reported at shallow depth at a well near the contact of Precambrian basalt and Cambrian sandstone in southwestern Polk County (Weidman and Schultz, 1915, p. 515-516). The source of the saline water is unknown.

Areas where saline water has been reported to be in geologic units underlying the shallow aquifer system are identified on the map. Available data are insufficient to define the extents of these areas, so their extents are not shown on the map.



Areas where saline water underlies Wisconsin's shallow aquifer system

5.0 SUMMARY

Wisconsin's shallow aquifer system, composed of unconsolidated sand and gravel and shallow bedrock, is the source of most potable ground-water supplies in the State. In terms of chemical quality, the water is suitable for most uses, but hard water and locally high concentrations of iron and manganese cause aesthetic problems that may require treatment.

Wisconsin has three major and two minor aquifers. Major aquifers are the sand and gravel, Silurian dolomite, and sandstone aquifers; minor aquifers include Precambrian sandstone and lava flows in the northwestern part of the State and, in some areas, the Precambrian crystalline rocks that underlie the entire State. Most wells used for potable water supply draw water from the sand and gravel aquifer or from shallow bedrock aquifers. The shallow aquifer system, as here defined, includes the unconsolidated sand and gravel aquifer and the uppermost bedrock aquifer; where both are present, they are hydraulically connected. Confining units, where they are present, form the base of the shallow aquifer system.

The shallow aquifer system is unconfined except locally by layers of low-permeability material. Flow of ground water is generally from beneath topographic highs to the nearest lake or stream. Most of the water is from local recharge.

Regional ground-water flow in the Paleozoic rocks underlying the shallow aquifer system is generally to the east, south, and west in the direction of the regional dip away from a Precambrian topographic high in north-central Wisconsin. Water from the shallow system recharges the regional system except in discharge areas along the Mississippi and the lower Wisconsin Rivers and locally along Lake Michigan and Green Bay. In the discharge areas, hydraulic heads are higher in deep aquifers than in the shallow aquifers, and water flows upward from deep aquifers to the shallow system.

Hardness of water, alkalinity, and dissolved-solids concentrations are determined wholly or in large part by concentrations of major dissolved constituents (calcium, magnesium, and bicarbonate) and are generally related to the mineral composition of the aquifer and other rock materials through which the water flows. Concentrations of these constituents are highest where the bedrock component of the shallow aquifer system is dolomite or limestone (primarily in the eastern, southern, and western parts of the State) and lowest in north-central Wisconsin, where the shallow system consists almost entirely of glacial deposits that contain little calcareous material. Water is moderately hard to very hard in much of the State.

Concentrations of other common chemical constituents (sodium, potassium, sulfate, chloride, and fluoride) in water from the shallow aquifer system are less closely related to mineral composition of the rocks. Most sodium concentrations are less than 10 mg/L. Higher sodium concentrations in water along Lake Superior, and in the Green Bay-Lake Winnebago area, southern Marinette County, northeastern Manitowoc County, east-central Sheboygan County, and northeastern Milwaukee County, coincide with areas where dissolved-solids concentrations exceed 400 mg/L. Potassium concentrations exceed 4 mg/L only in water from the Lake Superior sandstone aquifer. Sulfate concentrations are less than 30 mg/L in much of the State. Sulfate concentrations in some areas exceed the State drinking-water standard of 250 mg/L in southeastern Wisconsin, where the shallow aquifer system is composed of the Silurian dolomite and the sand and gravel aquifers, in southeastern Marinette County, and in the northwestern part of the State along Lake Superior. Chloride concentrations are generally less than 10 mg/L, and concentrations exceeding 20 mg/L are common only in southeastern Marinette County and in water from the Lake Superior sandstone aquifer along Lake Superior. Anomalously high chloride concentrations in water from isolated wells throughout the State are probably the result of local contamination and do not seem to represent areal ground-water quality. Fluoride concentrations are less than 0.5 mg/L in much of the State, but they are close to Wisconsin's drinking-water standard of 2.2 mg/L in a small area of Brown County.

Iron concentrations exceed the State's secondary drinking-water standard of 300 µg/L in water from about one-third of the wells, and manganese concentrations exceed the secondary drinking-water standard of 50 µg/L in water from about one-fourth of the wells. This generalization is fairly consistent Statewide for manganese. Iron concentrations tend to exceed the drinking-water standard for more wells (about half of the wells) in eastern Wisconsin, where the shallow aquifer system consists of glacial deposits over Silurian dolomite rocks, than in the rest of the State.

Nitrate-nitrogen concentrations in water from the shallow aquifer system differ locally; concentrations that approach or exceed the State drinking-water standard of 10 mg/L probably result from local ground-water contamination. The incidence of nitrate contamination is greatest for private water supplies in rural areas.

Saline water from deep aquifers has apparently contaminated the shallow aquifer system in some areas. This water could eventually affect water quality in other areas as well. Saline water is in the sandstone aquifer beneath the shallow aquifer system in two areas (eastern Manitowoc and Sheboygan Counties, and near the mouth of the Wisconsin River) where water flow is upward to the shallow system. Hydraulic heads in these two areas are higher in the deep aquifer than in the shallow system. Saline water is also in deep aquifers in other areas where the present hydraulic gradient has been reversed, and ground-water movement is no longer upward. In some of these areas, dissolved-solids concentrations in water from the shallow aquifer system are higher than ambient concentrations, which could indicate that saline water migrated upward to the shallow aquifer system in the past.

6.0 REFERENCES CITED

Delfino, J.J., 1977, Contamination of potable water supplies in rural areas, *in* Pojasek, R.B., ed., Drinking water quality enhancement through source protection: Ann Arbor, Mich., Ann Arbor Science Publishers, chap. 17, p. 276-295.

Durfor, C.N., and Becker, Edith, 1964, Public water supplies in the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Feth, J.H., 1981, Chloride in natural continental water--a review: U.S. Geological Survey Water-Supply Paper 2176, 30 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water (3d ed.): U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Kammerer, P.A., Jr., 1981, Ground-water quality atlas of Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 39, 39 p.

___1984, An overview of ground-water quality data in Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 83-4239, 58 p.

Mai, Huazhao, and Dott, R.H., Jr., 1985, A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 47, 26 p., 14 figs., 2 pls.

Mandle, R.J., and Kontis, A.L., 1992, Simulation of regional ground-water flow in the Cambrian-Ordovician aquifer system in the Northern Midwest, United States: U.S. Geological Survey Professional Paper 1405-C, p. C1-C97.

Mudrey, M.G., Jr., Brown, B.A., and Greenburg, J.K., 1982, Bedrock geologic map of Wisconsin: Wisconsin Geological and Natural History Survey map, scale 1:1,000,000.

National Academy of Sciences, National Academy of Engineering, 1973 [1974], Water quality criteria, 1972: U.S. Government Printing Office, 594 p.

Ostrom, M.E., 1967, Paleozoic stratigraphic nomenclature for Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 8, 1 sheet.

Ryling, R.W., 1961, A preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin: Wisconsin Geological and Natural History Survey Information Circular No. 5, 23 p., 6 figs.

Schuknecht, Bob, and others, 1975, Nitrates in Wisconsin ground water: Environmental Letters, v. 9, no. 1, p. 91-98.

Strous, R.E., Jr., 1986, Ground-water monitoring report--noncommunity well nitrate resampling: Wisconsin Department of Natural Resources, PUBL-WR-136 86, 19 p.

Trotta, L.C., and Cotter, R.D., 1973, Depth to bedrock in Wisconsin: Wisconsin Geological and Natural History Survey map, 1 sheet, scale 1:1,000,000.

U.S. Environmental Protection Agency, 1975, National interim primary drinking water regulations: U.S. Environmental Protection Agency, EPA-570/9-76-003, 159 p.

Weidman, Samuel, and Schultz, A.R., 1915, The underground and surface water supplies of Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 35, 664 p.

Wisconsin Department of Natural Resources, 1978, Wisconsin administrative code, Chapter 109, Safe drinking water: Register, February 1978, no. 266, Environmental Protection.

Wisconsin Department of Natural Resources, Division of Environmental Protection, 1970, State of Wisconsin public water supply data 1970: 101 p.

Wisconsin Geological and Natural History Survey, 1964 (modified 1985), Ice age deposits of Wisconsin: page-size map.

___1981, Bedrock geology of Wisconsin: page-size map.