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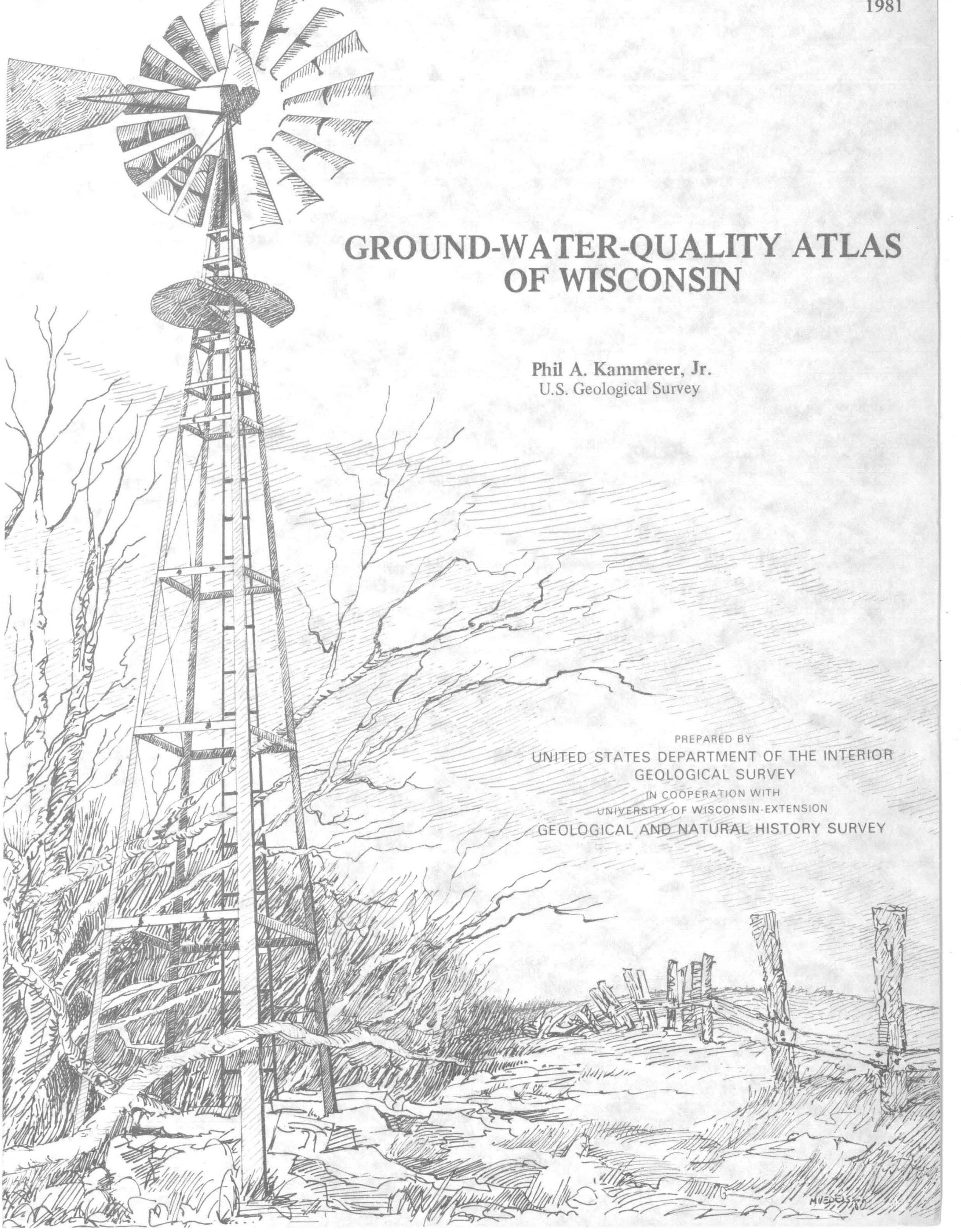

GROUND-WATER-QUALITY ATLAS OF WISCONSIN

Phil A. Kammerer, Jr.
U.S. Geological Survey

PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
IN COOPERATION WITH
UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

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

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
and
UNIVERSITY OF WISCONSIN–EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
M. E. Ostrom, Director and State Geologist
Madison, Wisconsin
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Abstract

This report summarizes data on ground-water quality stored in the U.S. Geological Survey's computer system (WATSTORE). The summary includes water-quality data for 2,443 single-aquifer wells, which tap one of the State's three major aquifers (sand and gravel, Silurian dolomite, and sandstone). Data for dissolved solids, hardness, alkalinity, calcium, magnesium, sodium, potassium, iron, manganese, sulfate, chloride, fluoride, and nitrate are summarized by aquifer and by county, and locations of wells for which data are available are shown for each aquifer. Calcium, magnesium, and bicarbonate (the principal component of alkalinity) are the major dissolved constituents in Wisconsin's ground water. High iron concentrations and hardness cause ground-water quality problems in much of the State. Statewide summaries of trace constituent (selected trace metals, arsenic, boron, and organic carbon) concentrations show that these constituents impair water quality in only a few isolated wells.

1.0 INTRODUCTION

This Report Summarizes Ground Water Quality Data for Wisconsin

Considerable chemical-quality data for ground water in Wisconsin have been collected for a variety of purposes and uses by State, Federal, and local government agencies. A comprehensive summary of these data provides a source of general information on ground-water quality.

This report, prepared in cooperation with the Wisconsin Geological and Natural History Survey, summarizes data on ground-water quality stored in the U.S. Geological Survey's (USGS) computer system (WATSTORE). These data include USGS analyses and analyses compiled from other sources during the course of investigations pertaining to the ground-water resources of river basins, counties, and other special study areas in Wisconsin.

The selected bibliography on the facing page lists published reports that describe or summarize various aspects of ground-water quality in Wisconsin, but none provide a comprehensive statewide summary of ground-water quality. References containing only very general or sparse information were generally not included if the same information also was found in other more comprehensive reports.

Most of the reports are limited as to areal coverage (such as counties or river basins), the number of chemical constituents considered, or sources of data (public water supplies, for example). An earlier statewide tabulation of ground-water-quality analyses (Holt and Skinner, 1973) included analyses of water from 1,890 wells, but did not summarize the data by aquifer or by area.

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1.0 INTRODUCTION

Wisconsin has Three Major and Several Minor Aquifers

Water-quality data are summarized separately for the sand-and-gravel, Silurian dolomite, and sandstone aquifers. The summary is limited to wells that are open only to one of these aquifers. Water-quality data are available for approximately 2,800 wells--2,443 of them draw water from a single major aquifer.

Definition of the three aquifers is based on geology and the amount of hydrogeologic data available for most wells in each aquifer. The geologic section on the facing page shows the stratigraphic relationship of these aquifers to each other and to other geologic units.

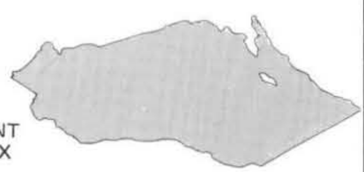
The sand-and-gravel aquifer consists of unconsolidated deposits of sand and gravel within the glacial drift that covers approximately 70 percent of the State. It is present in every county in Wisconsin, although its occurrence in 12 counties in the "Driftless Area" of southwestern Wisconsin is limited. The sand-and-gravel aquifer is not a continuous rock unit, as are the bedrock aquifers, but occurs as broad surficial outwash deposits, narrow valley fills within till, basal sand and gravel directly overlying bedrock, isolated lenses of sand and gravel within less permeable glacial deposits, and other water-lain deposits. In the "Driftless Area", the sand-and-gravel aquifer occurs only as valley alluvium within the flood plains of larger rivers.

The Silurian dolomite aquifer underlies all or part of 15 counties along the eastern boundary of the State. The aquifer is mostly dolomite of Silurian age, but a small area of dolomite and shale of Devonian age, extending from Milwaukee to Sheboygan along Lake Michigan, is also included.

The sandstone aquifer is comprised of Cambrian and Ordovician sandstones and dolomites undifferentiated in this report. The oldest and most extensive unit in the sandstone aquifer consists of Cambrian sandstones, which occur under 60 percent of the State (all or part of 59 counties). A dolomite unit, the Prairie du Chien Group, overlies the Cambrian sandstones in the south, east, and west parts of the State. Overlying the Prairie du Chien Group is the St. Peter Sandstone.

The Galena-Platteville dolomite unit overlies the St. Peter Sandstone in southern and eastern Wisconsin. Where it is the uppermost bedrock formation (not overlain by the Maquoketa Shale), it may be considered a separate aquifer, but, for the purpose of this report, it is included in the sandstone aquifer.

Minor aquifers not considered in this report include the Precambrian aquifers and the Maquoketa Shale. Most of the wells in Precambrian aquifers are in Precambrian sandstone and lava flows in the northwest part of the State, although there are also some wells in the igneous and metamorphic rocks of the basement complex in north-central and south-central Wisconsin. These aquifers were not considered because of the limited amount of water-quality data available (96 wells) and the wide areal variation in water quality seen in these data. The wide areal differences in water quality indicates that it is controlled by local hydrogeologic conditions and that areal summaries of concentration values are poor indicators of local conditions. The Maquoketa Shale is a useable aquifer in some areas, but it was not included here due to lack of data for wells drawing water exclusively from it.

SYSTEM	GEOLOGIC UNIT	DOMINANT LITHOLOGY	AQUIFER
QUATERNARY	HOLOCENE ALLUVIAL AND PLEISTOCENE GLACIAL DEPOSITS	UNCONSOLIDATED SAND AND GRAVEL; VARIABLE AMOUNTS OF SILT, CLAY AND ORGANIC MATERIAL	SAND AND GRAVEL 
DEVONIAN	UNDIFFERENTIATED	DOLOMITE AND SHALE	SILURIAN DOLOMITE 
SILURIAN	UNDIFFERENTIATED	DOLOMITE	
ORDOVICIAN	MAQUOKETA SHALE	SHALE	MAQUOKETA SHALE 
	GALENA DOLOMITE, AND DECORAH AND PLATTEVILLE FORMATIONS; UNDIFFERENTIATED	DOLOMITE	GALENA-PLATTEVILLE
	ST. PETER SANDSTONE	SANDSTONE	SANDSTONE 
	PRAIRIE du CHIEN GROUP	DOLOMITE	
CAMBRIAN	CAMBRIAN SANDSTONES, UNDIFFERENTIATED	SANDSTONE	
PRECAMBRIAN	LAKE SUPERIOR SANDSTONE AND LAVA FLOWS	SANDSTONE AND SHALE, BASALT	PRECAMBRIAN AQUIFER: LAKE SUPERIOR SANDSTONE AND LAVA FLOWS 
	IGNEOUS AND METAMORPHIC ROCKS	GRANITIC AND METAMORPHIC ROCKS	PRECAMBRIAN AQUIFER: BASEMENT COMPLEX 

GENERALIZED GEOLOGIC SECTION OF WISCONSIN AQUIFERS

2.0 APPROACH

2.1 Designation of aquifer systems

Water Quality Data were Summarized, by Constituent, for each of the State's Major Aquifers

Water-quality data were divided into two general groups: common properties and inorganic constituents, and trace constituents. Computer techniques were used in the preparation of the summaries because of the large amount of data.

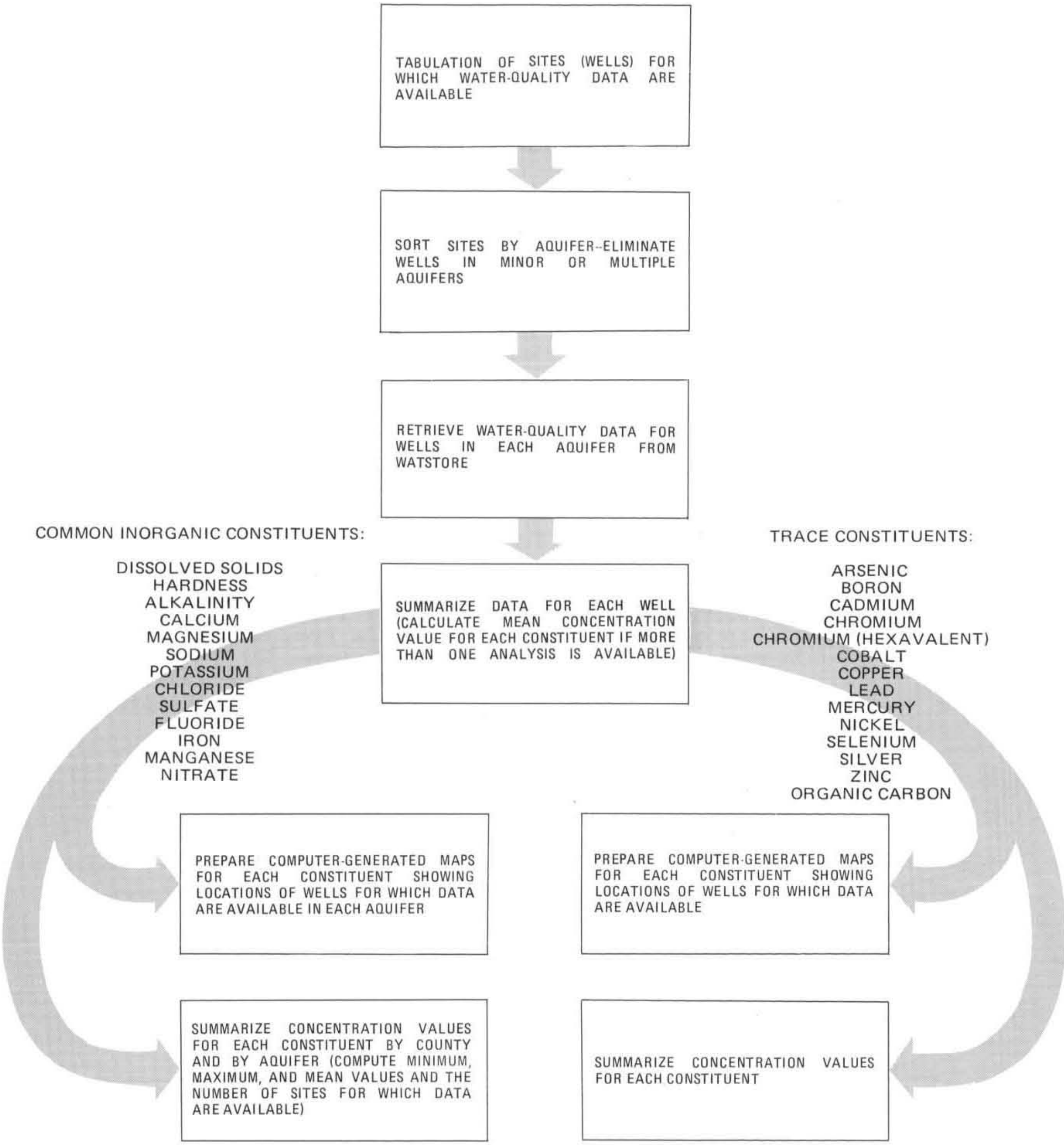
The flow chart on the facing page shows the procedure used to summarize the data. Common properties and inorganic constituents were summarized by county for each of the aquifers; summaries include the number of wells for which data are available and maximum, minimum, and mean concentrations values of these constituents for each county and aquifer. Less comprehensive summaries were prepared for trace constituents because of the limited amount of data available. Trace constituent data for the three aquifers were combined, and each constituent was summarized on a statewide basis.

Pesticides in ground water were not considered in this report because the available data are limited to two small areas of the State. The data from these areas, the sand plain of central Wisconsin and the Rice Lake-Eau Claire area, were summarized in two recently published reports (Hindall, 1978, and Bell and Hindall, 1975).

For each constituent, only a single concentration for each well was considered in the summaries; for wells where multiple analyses were available, the mean value was used.

Locations of wells where data are available for each constituent are shown on the maps along with the data summaries. Where wells are less than about 100 yards apart, their locations are represented by a single symbol on the maps.

Discussions of individual constituents in the following sections of this report include applicable national primary drinking water standards (Environmental Protection Agency, 1975); primary drinking water standards established by the State of Wisconsin (Wisconsin Department of Natural Resources, 1978) are the same as the national standards except where otherwise noted.



PREPARATION OF DATA SUMMARIES

Maps Showing Ranges of Dissolved Solids Concentrations Provide a General Overview of Ground Water Quality

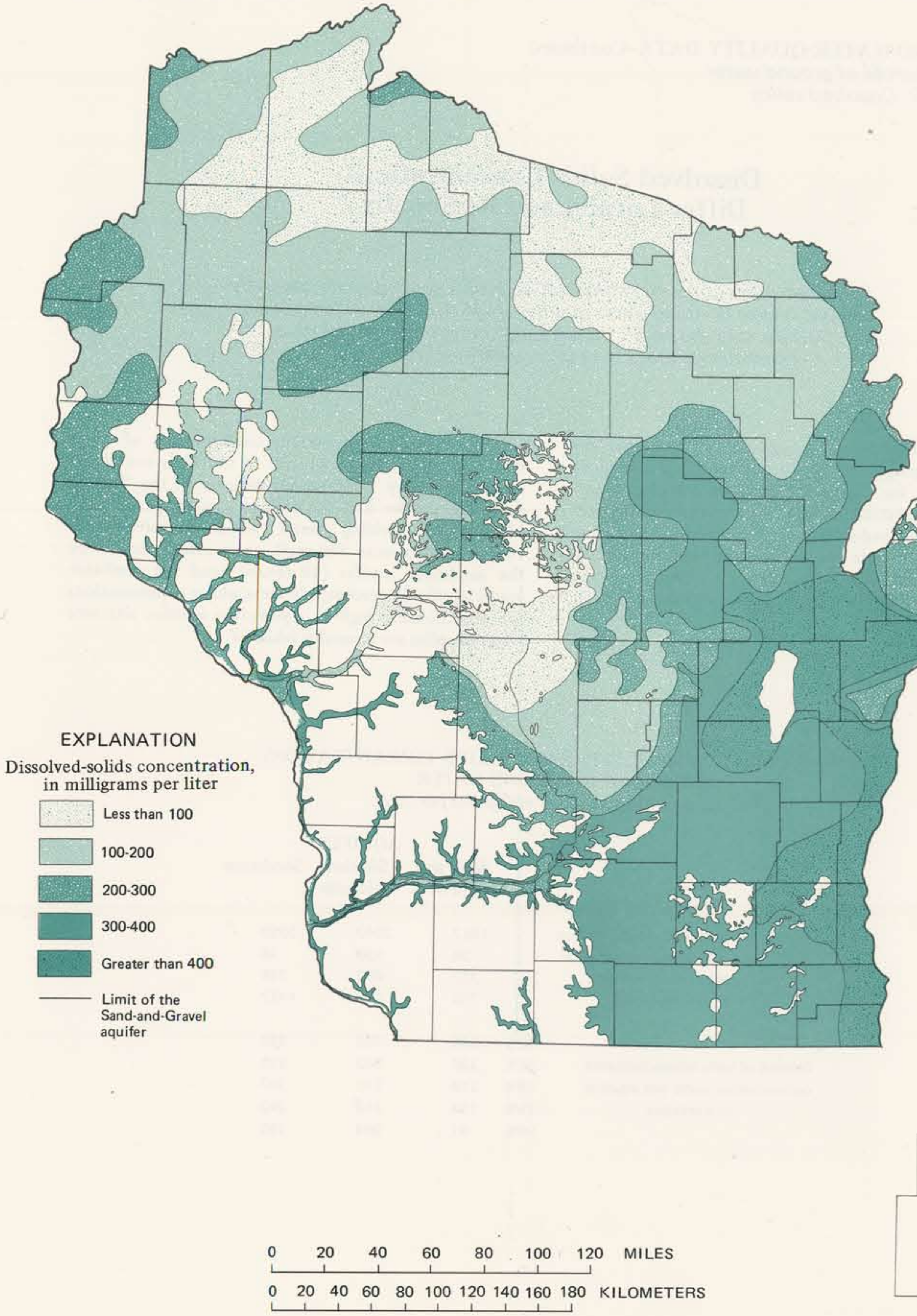
Dissolved-solids concentration is a measure of the total amount of material dissolved in the water. Major constituents of dissolved solids in Wisconsin's ground water are calcium, magnesium, and bicarbonate. Dissolved-solids concentrations indicate differences in the concentrations of major dissolved constituents.

The maps on the facing page show the areal distribution of dissolved-solids concentrations in the State's three major aquifers. The maps are from those compiled by Devaul (1975a, 1975b, and 1975c).

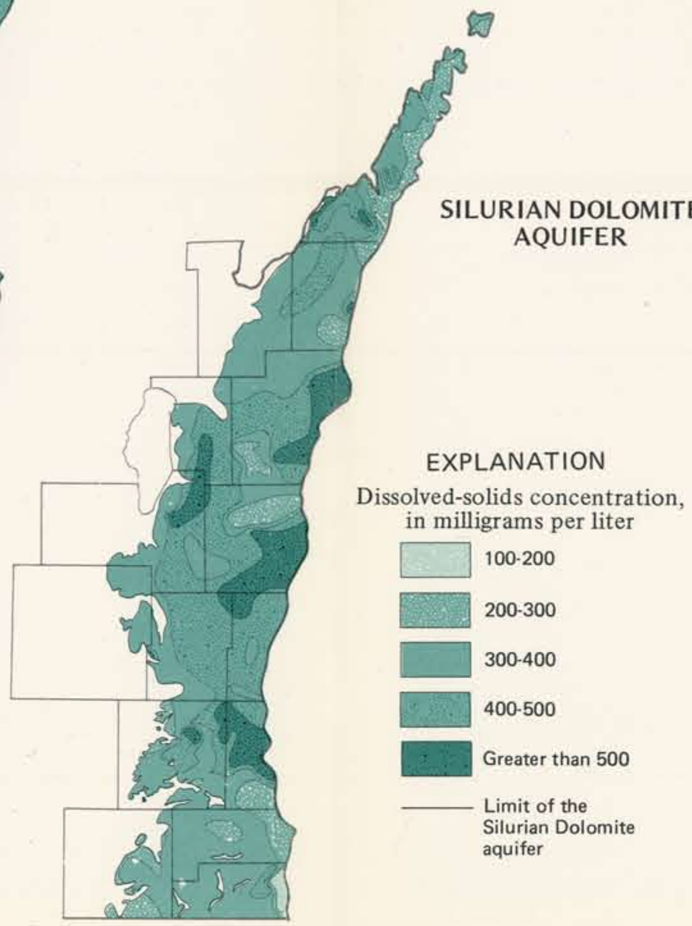
In the sand-and-gravel aquifer the highest dissolved-solids concentrations are generally found east and south of a line from Marinette to Columbia to Crawford Counties, and the lowest values occur in the north where Precambrian rocks underlie the aquifer.

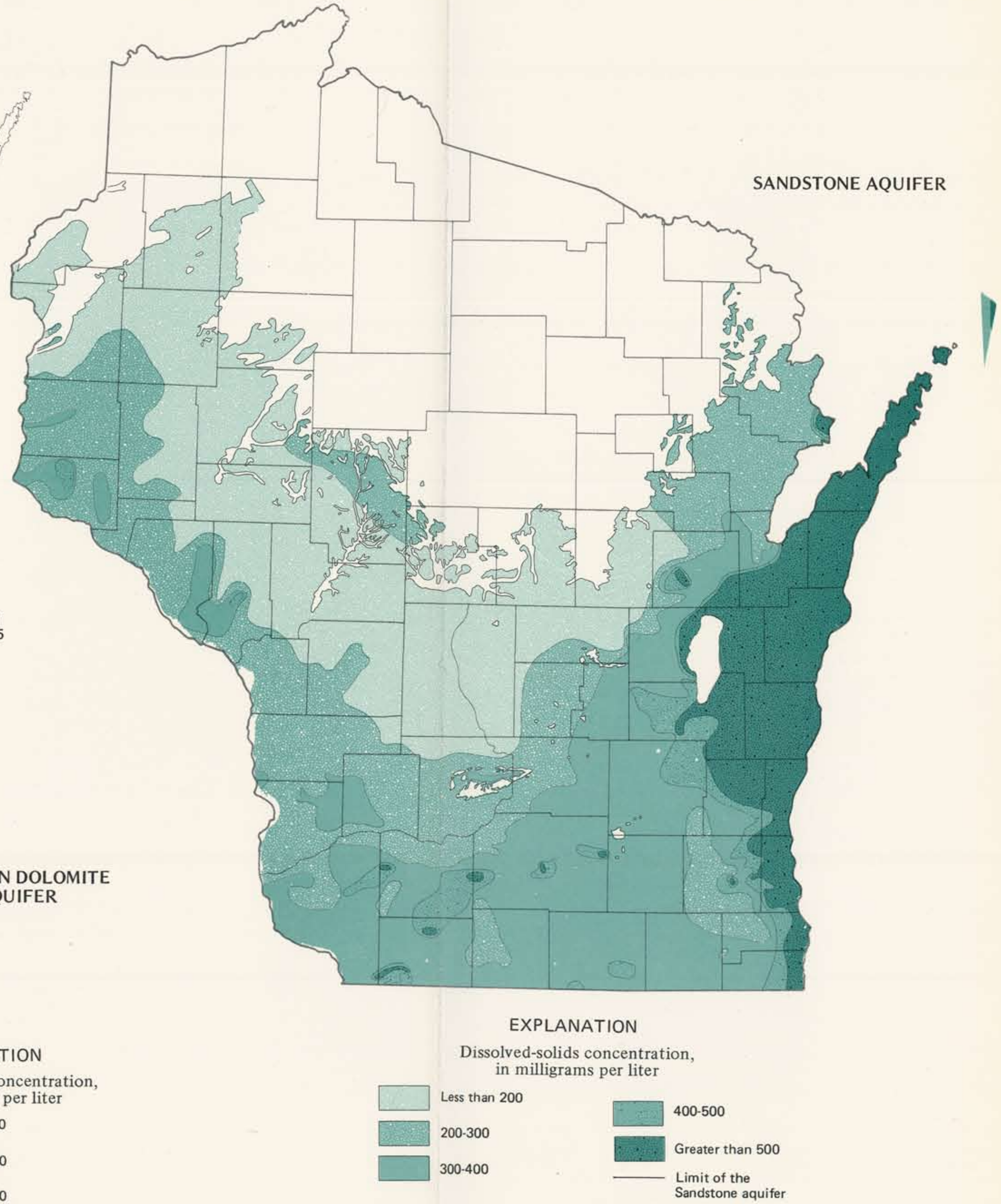
Highest dissolved-solids concentrations in the Silurian dolomite aquifer (referred to as the "Niagara aquifer" in the work by Devaul, 1975b) are found in eastern Manitowoc County, southern Sheboygan and northern Ozaukee Counties, and in Milwaukee County. Scattered high values also occur along the west edge of the aquifer.

Highest dissolved-solids concentrations in the sandstone aquifer occur in the eastern part of the system (all or parts of Door, Kewaunee, Brown, Calumet, Manitowoc, Sheboygan, Ozaukee, Milwaukee, Racine, and Kenosha Counties); small areas with high concentrations are also found in southeast Marinette and southwest Lafayette Counties.



DISSOLVED SOLIDS FROM DEVAUL, 1975





GENERALIZED DISSOLVED-SOLIDS DISTRIBUTION BY AQUIFER

Dissolved Solids Concentrations Differ Locally and Regionally

Dissolved-solids concentrations in Wisconsin's ground water generally do not impair drinking-water quality. High dissolved-solids concentrations may, however, indicate high concentrations of other constituents that could pose water-quality problems.

Current drinking-water regulations (Environmental Protection Agengy, 1975) do not specify a maximum concentration for dissolved solids in drinking water, but some earlier standards have recommended that water with a dissolved-solids concentration exceeding 500 mg/L (milligrams per liter) not be used for drinking if an alternate supply with a lower concentration was available. This limit was based mainly on taste considerations.

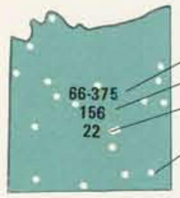
The mean dissolved-solids concentration of water from approximately 10 percent of the wells considered in this summary is 500 mg/L or greater; the Silurian dolomite aquifer had the highest percentage of wells (25 percent) yielding water whose dissolved-solids concentrations were 500 mg/L or greater, followed by the sandstone aquifer (10 percent) and the sand-and-gravel aquifer (3 percent). In areas where concentrations are objectionably high in a particular aquifer, alternate water supplies are generally available.

SUMMARY BY AQUIFER OF DISSOLVED SOLIDS CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		1567	2340	3320
Minimum concentration		28	130	18
Mean concentration		237	459	338
Number of wells		758	348	1137
Percent of wells where indicated concentration value was equaled or exceeded	10%	388	750	497
	25%	320	502	370
	50%	219	377	307
	75%	134	310	242
	90%	91	264	150

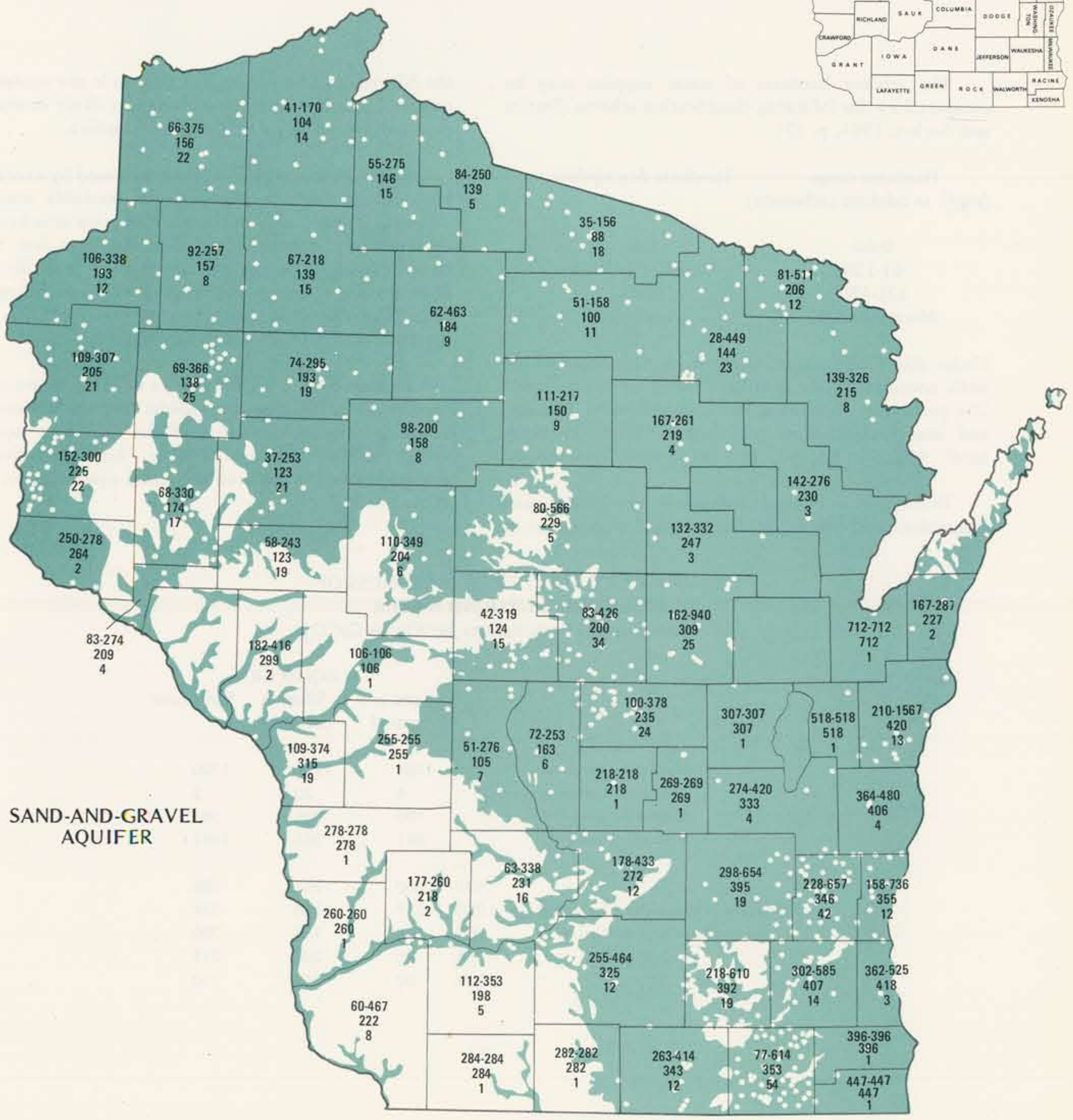
EXPLANATION

Dissolved solids concentration, in milligrams per liter

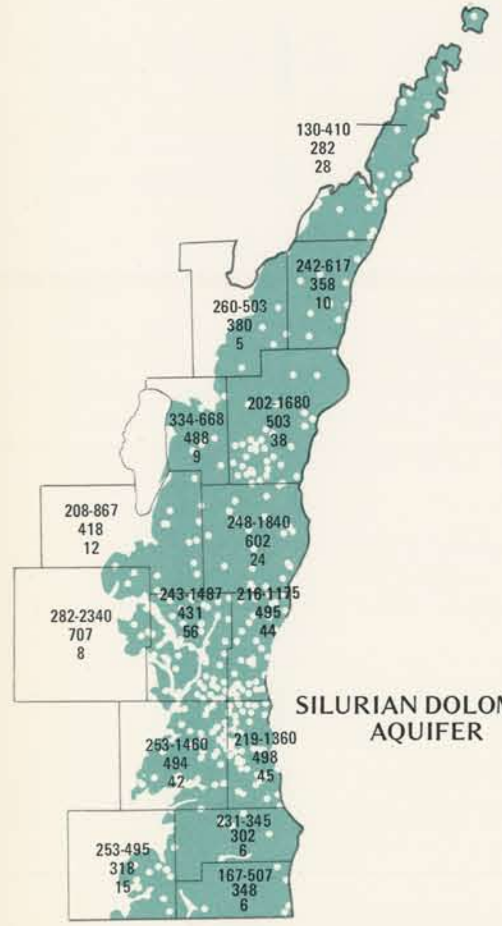


Minimum-Maximum concentration
Mean concentration
Number of wells
Location of sampled well
Color indicates area where aquifer is present

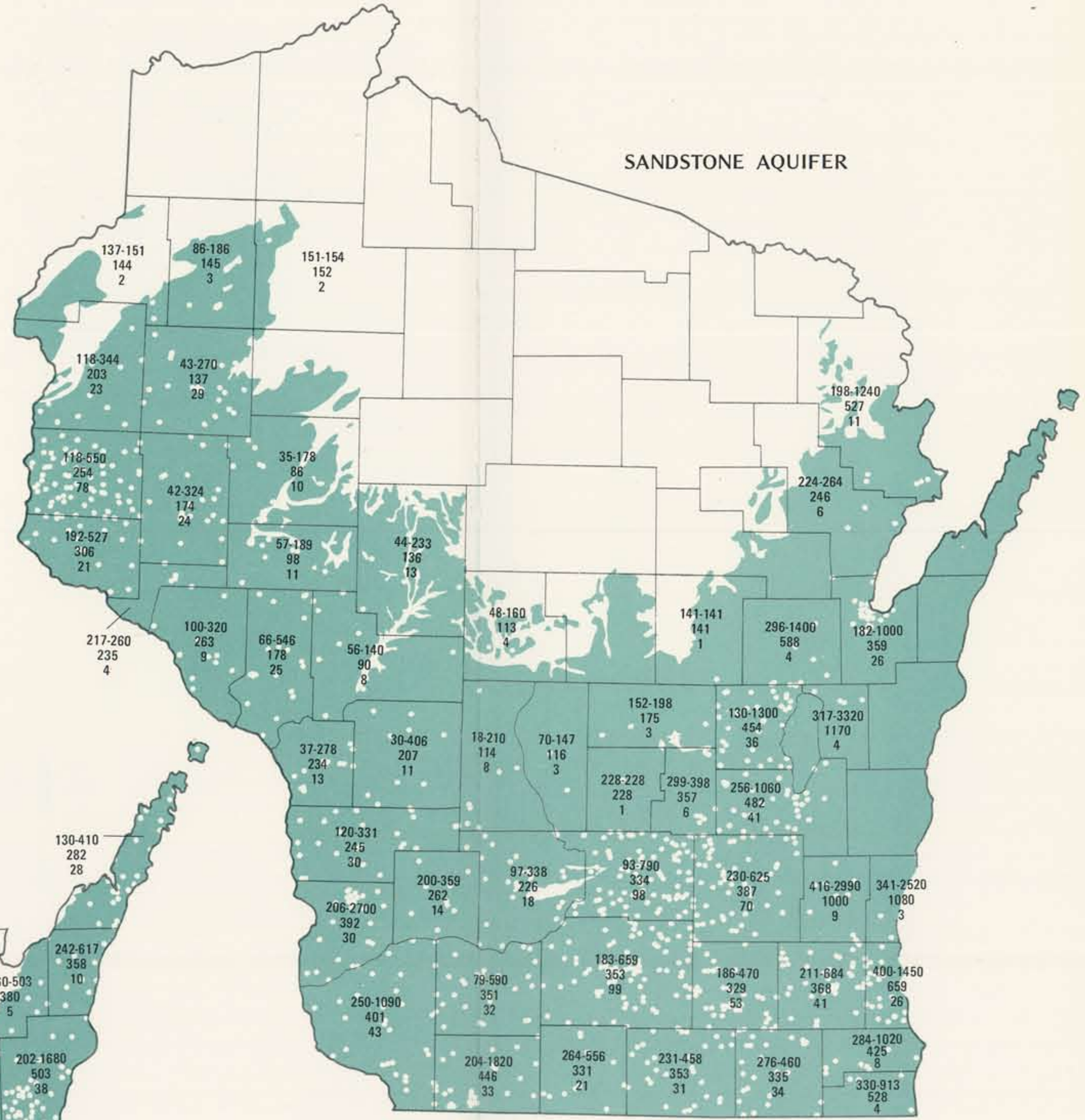
0 20 40 60 80 100 120 MILES
0 20 40 60 80 100 120 140 160 180 KILOMETERS



SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER



SANDSTONE AQUIFER

SUMMARY OF DISSOLVED-SOLIDS CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA–Continued
3.1 Properties of ground water
3.1.2 Dissolved solids

Ground Water is Hard in Much of Wisconsin

Hardness of water is caused by calcium and magnesium, two of the major dissolved constituents found in Wisconsin's ground water. Hardness is objectionably high for domestic use in large areas of the State's most heavily used aquifers.

The relative hardness of water supplies may be compared by the following classification scheme (Durfor and Becker, 1964, p. 27).

Hardness range (mg/L as calcium carbonate)	Hardness description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

Under this classification, water from 81 percent of the wells considered here is either "hard" or "very hard". The percentage of wells in the sand-and-gravel, Silurian, and sandstone aquifers with either "hard" or "very hard" water is 63, 97, and 88 percent, respectively.

Dolomite, a mineral composed of calcium and magnesium carbonates, is the principal component of the Silurian aquifer and is also common in the sandstone aquifer. Solution of the dolomite is a likely source of the hardness in the water from these aquifers.

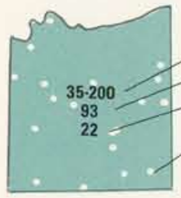
The main water-quality problem caused by excessive hardness of water is formation of insoluble residues when the water comes in contact with soap or is heated. For ordinary domestic purposes, hardness less than about 100 mg/L as calcium carbonate is generally not objectionable. Current national drinking-water regulations (Environmental Protection Agency, 1975) do not specify a maximum allowable hardness.

In Wisconsin, areal differences in hardness generally parallel those of dissolved solids; highest hardness is found in the southern part of the sandstone aquifer and in the Silurian dolomite aquifer. Lowest hardness is generally found in the sand-and-gravel aquifer, especially in the north.

SUMMARY BY AQUIFER OF HARDNESS OF WISCONSIN'S GROUND WATER
(All hardness values in milligrams per liter as $CaCO_3$)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum hardness		1180	1700	1700
Minimum hardness		4	30	2
Mean hardness		190	356	281
Number of wells		841	363	1197
Percent of wells where indicated hardness value was equaled or exceeded	10%	350	502	395
	25%	287	390	334
	50%	168	333	290
	75%	86	280	211
	90%	50	213	110

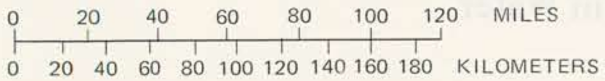
EXPLANATION

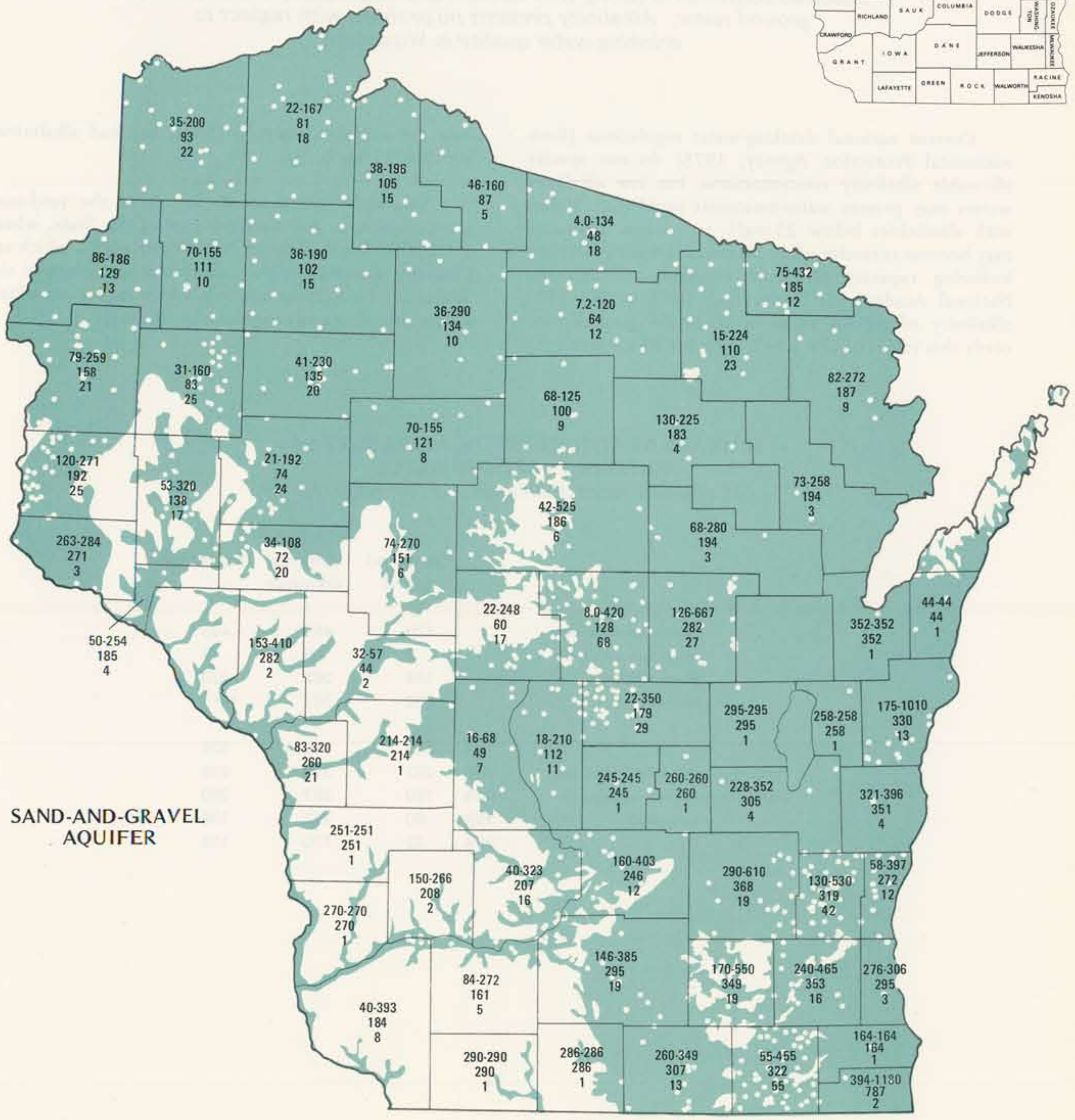


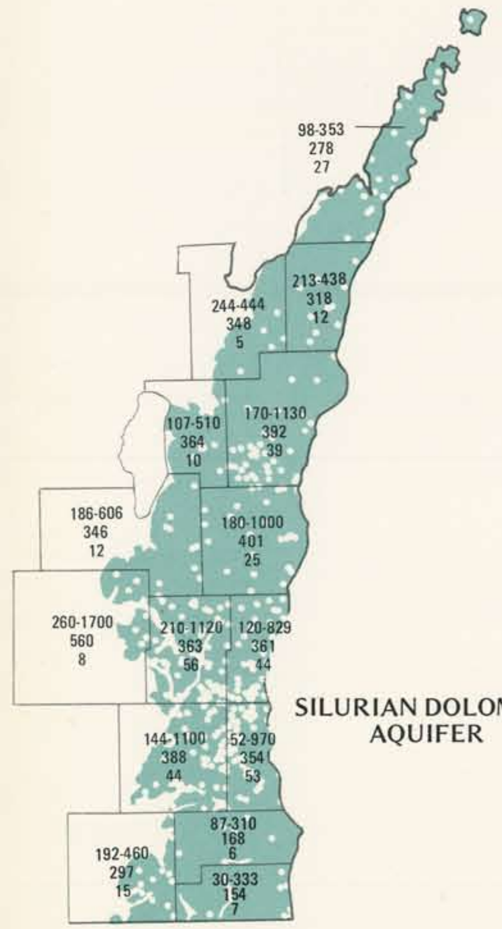
Hardness as $CaCO_3$, in milligrams per liter

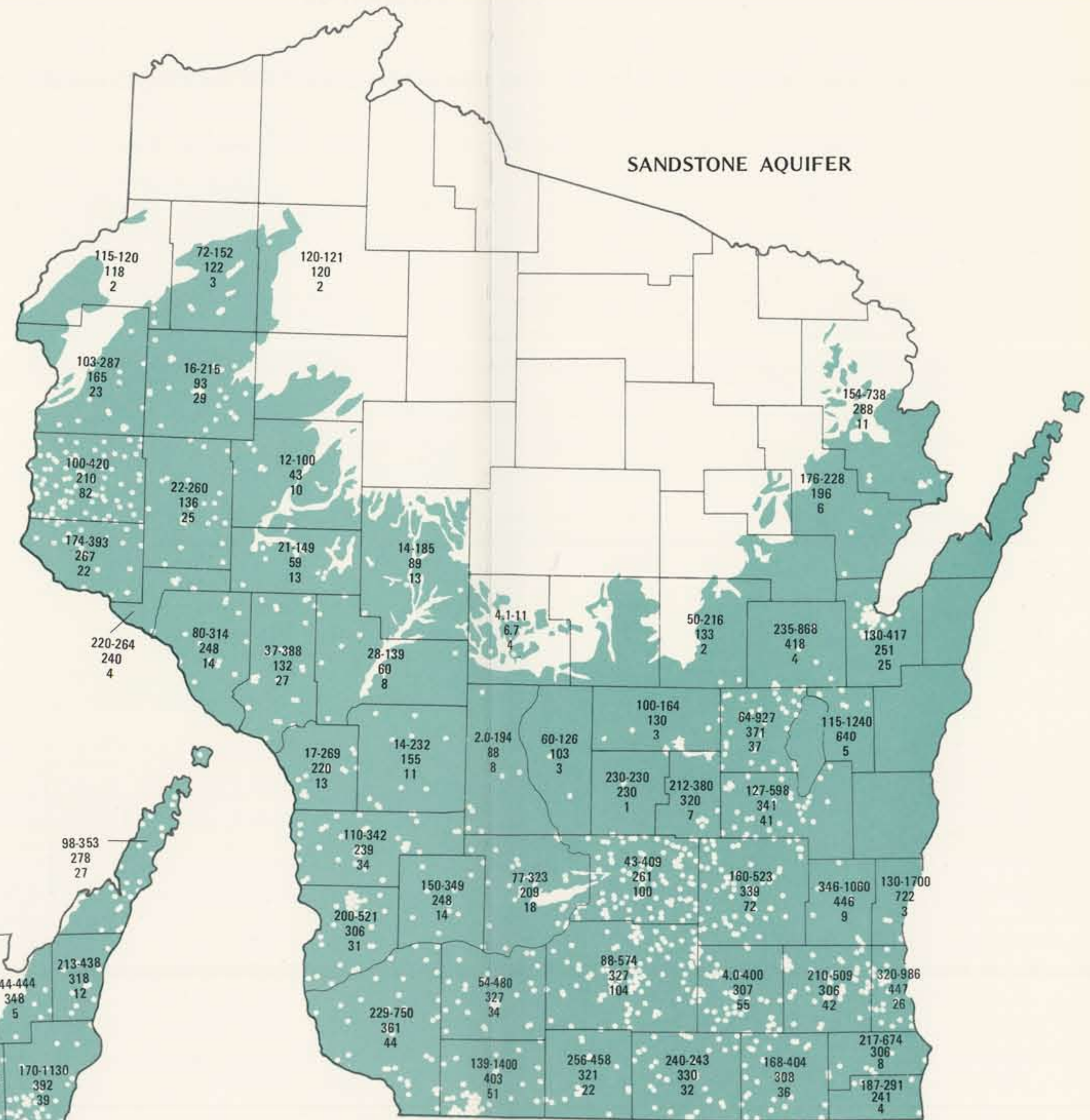
- Minimum-Maximum hardness
- Mean hardness
- Number of wells
- Location of sampled well

Color indicates area where aquifer is present









SUMMARY OF HARDNESS

3.0 GROUND-WATER-QUALITY DATA–Continued
3.1 Properties of ground water--Continued
3.1.3 Hardness

Alkalinity is a Measure of Acid-Neutralizing Constituents in Water

Alkalinity is due primarily to bicarbonate, which is one of the three major dissolved constituents (along with calcium and magnesium) in Wisconsin's ground water. Alkalinity presents no problem with respect to drinking-water quality in Wisconsin.

Current national drinking-water regulations (Environmental Protection Agency, 1975) do not specify allowable alkalinity concentrations, but low alkalinity waters may present water-treatment problems. Waters with alkalinities below 25 mg/L as calcium carbonate may become corrosive when chlorinated due to their low buffering capacity (National Academy of Sciences, National Academy of Engineering, 1973, p. 54). The alkalinity of ground water in Wisconsin generally exceeds this value; of the 1,942 wells for which alkalinity data are available, only 59 (3 percent) had alkalinities less than 25 mg/L.

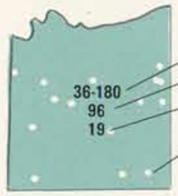
Alkalinities are generally lowest in the sand-and-gravel aquifer in the northern part of the State, where the aquifer lies directly on Precambrian rocks, which are primarily silicates. Higher alkalinities are found in the Silurian and sandstone aquifers, where carbonate minerals are abundant and contribute to alkalinity.

SUMMARY BY AQUIFER OF THE ALKALINITY OF WISCONSIN'S GROUND WATER
(All alkalinity values in milligrams per liter as $CaCO_3$)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum alkalinity		420	469	433
Minimum alkalinity		2	86	7
Mean alkalinity		169	262	238
Number of wells		628	303	1011
Percent of wells where indicated alkalinity value was equaled or exceeded	10%	309	336	324
	25%	262	303	299
	50%	160	267	260
	75%	80	222	190
	90%	32	170	119

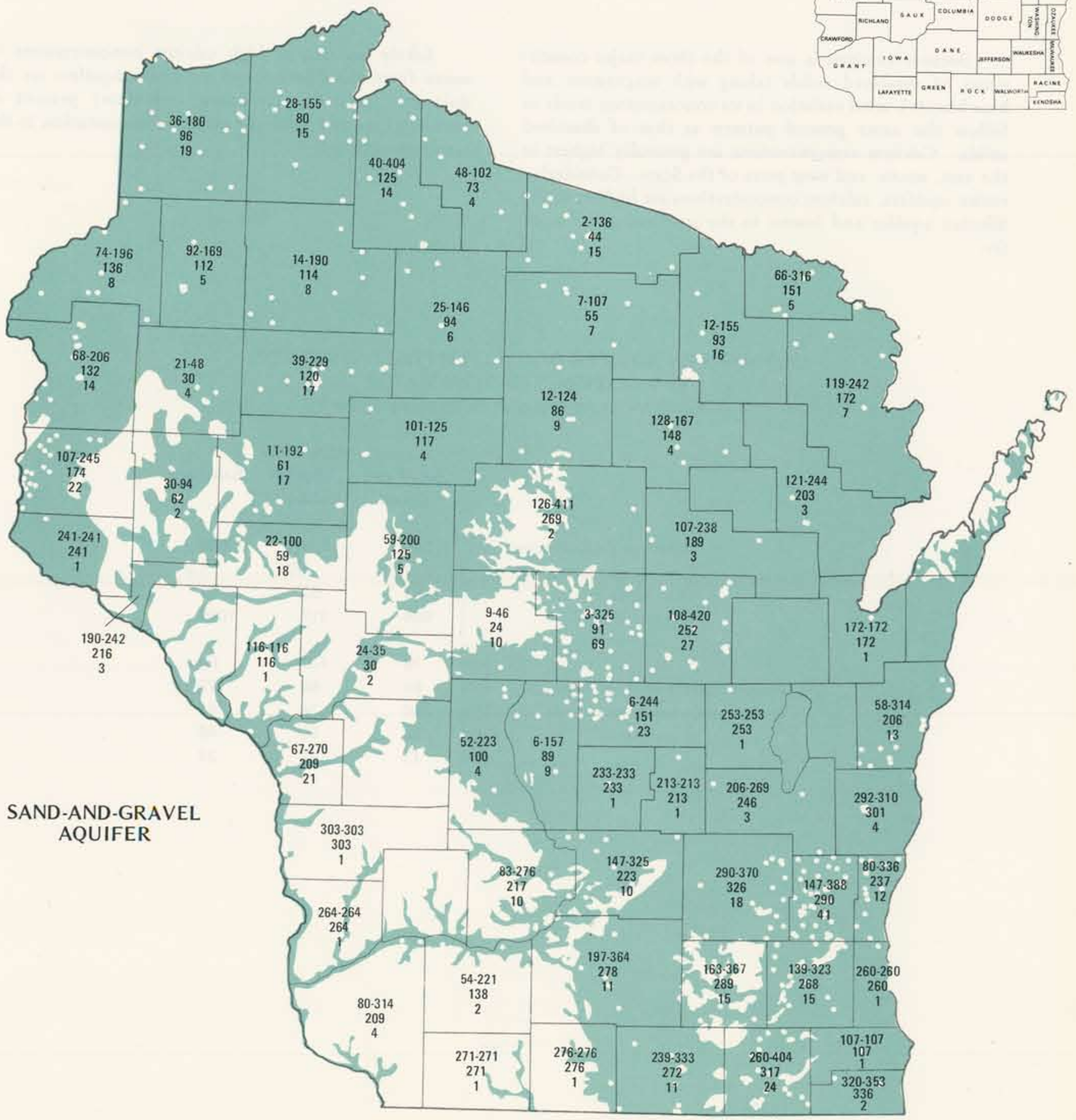
EXPLANATION

Alkalinity as $CaCO_3$, in milligrams per liter

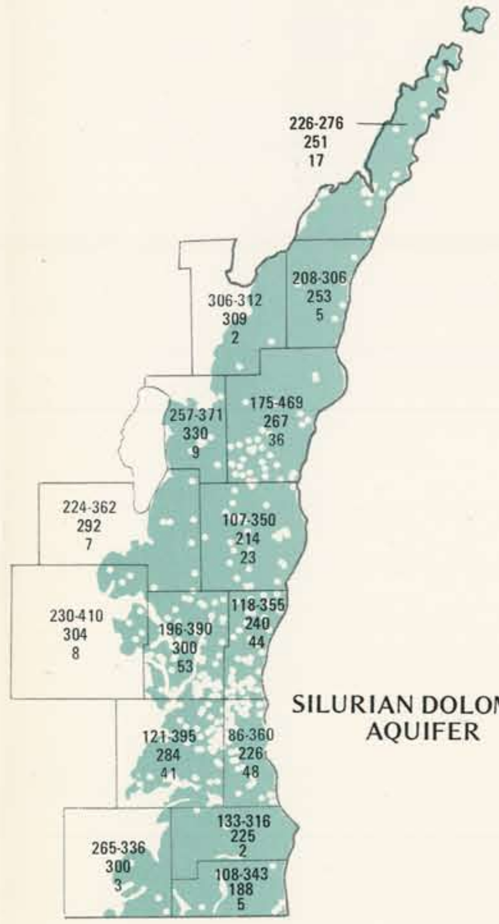


Minimum-Maximum alkalinity
Mean alkalinity
Number of wells
Location of sampled well
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES
0 20 40 60 80 100 120 140 160 180 KILOMETERS

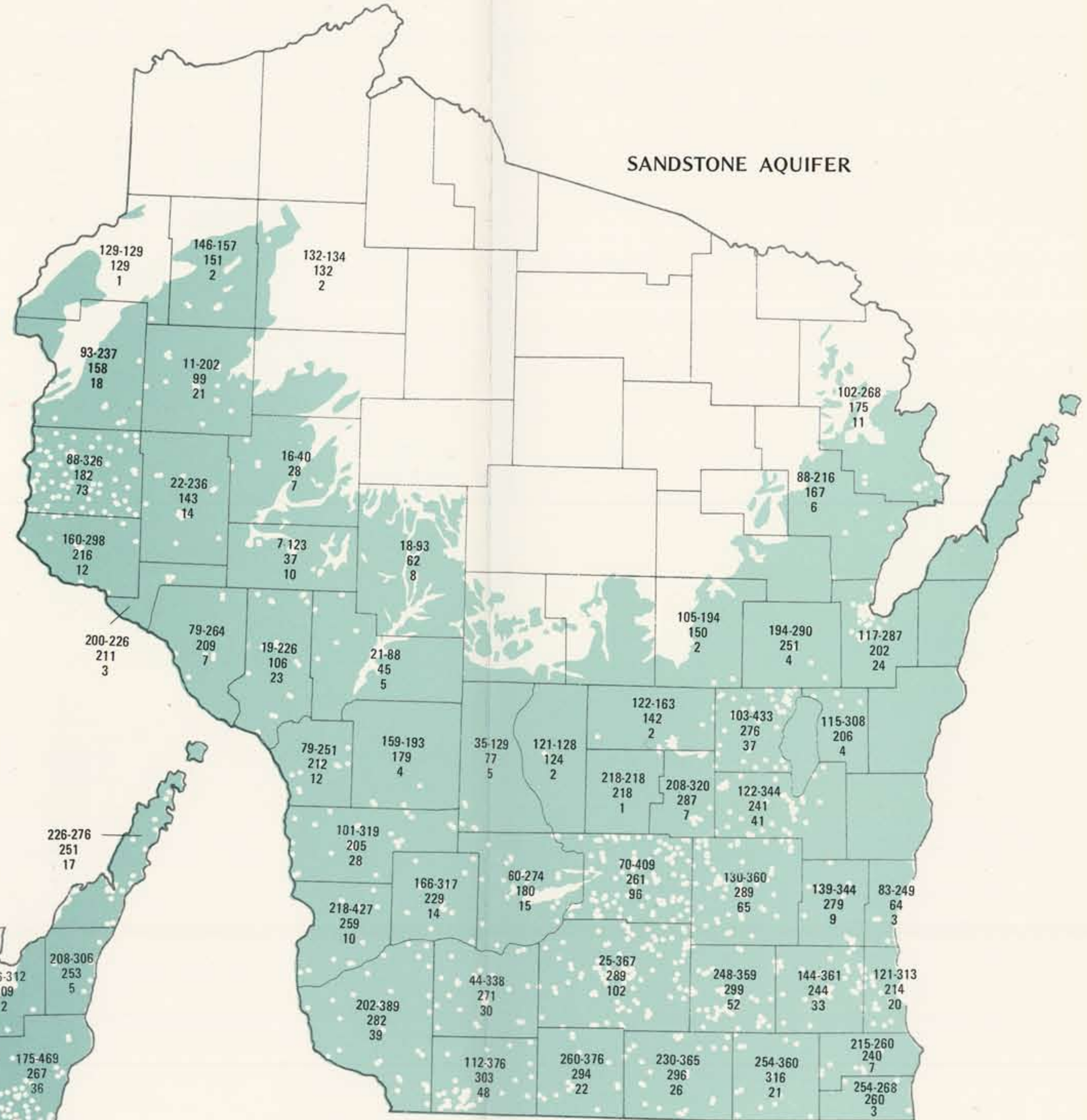


SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER

SANDSTONE AQUIFER



SUMMARY OF ALKALINITY

Calcium is a Major Constituent in Wisconsin's Ground Water

Calcium is widely distributed in the rocks and soils of the State, and it is generally the predominant cation in the ground water. Calcium concentrations are generally not a problem with respect to water quality, except as they contribute to hardness.

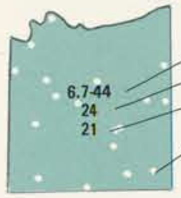
Because calcium is one of the three major constituents of dissolved solids (along with magnesium and bicarbonate), areal variation in its concentration tends to follow the same general pattern as that of dissolved solids. Calcium concentrations are generally highest in the east, south, and west parts of the State. Considering entire aquifers, calcium concentrations are highest in the Silurian aquifer and lowest in the sand-and-gravel aquifer.

Likely sources of high calcium concentrations in water from the Silurian and sandstone aquifers are the dolomite (calcium magnesium carbonate) present in both aquifers and calcium-carbonate cementation in the sandstone aquifer.

SUMMARY BY AQUIFER OF CALCIUM CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		240	530	620
Minimum concentration		1.2	1.0	1.3
Mean concentration		43	82	63
Number of wells		694	317	1066
Percent of wells where indicated concentration value was equaled or exceeded	10%	76	127	88
	25%	61	88	72
	50%	40	74	61
	75%	23	58	46
	90%	13	42	27

EXPLANATION



Calcium concentration, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

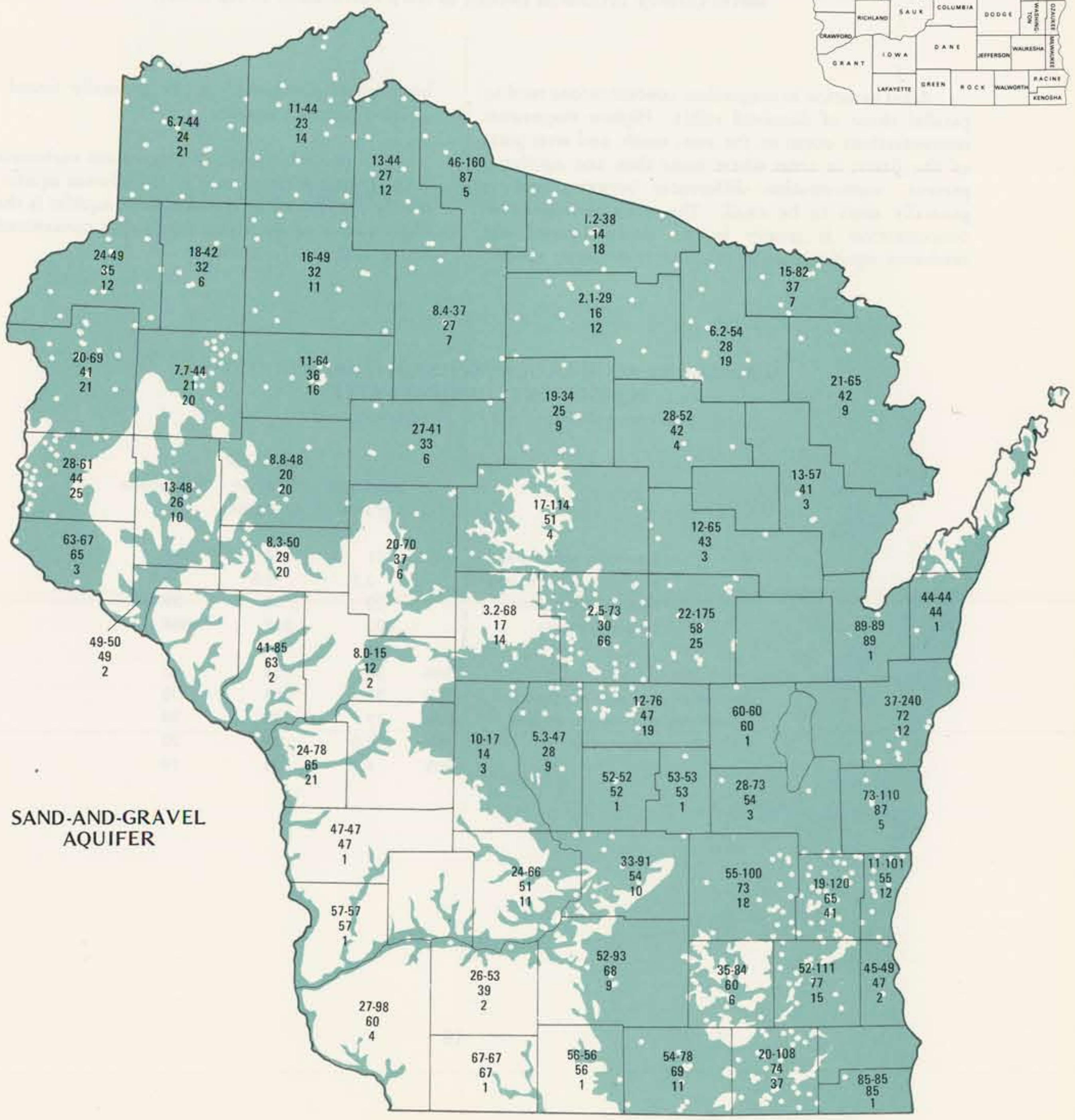
Number of wells

Location of sampled well

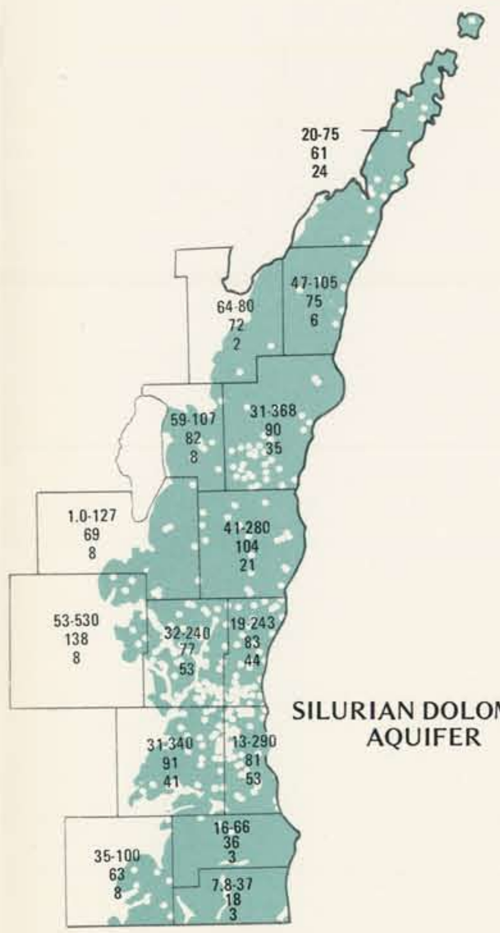
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

0 20 40 60 80 100 120 140 160 180 KILOMETERS

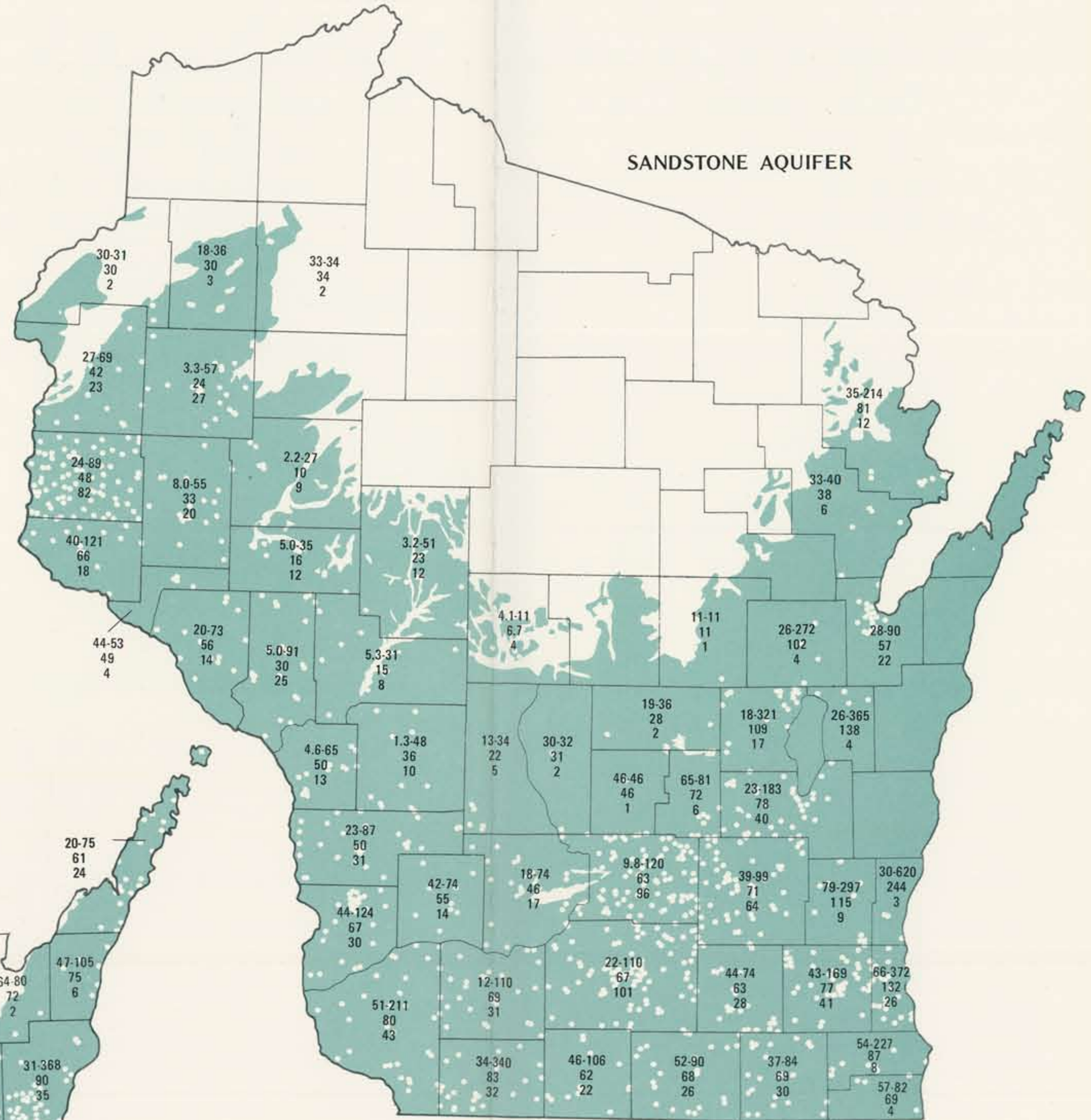


SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER

SANDSTONE AQUIFER



SUMMARY OF CALCIUM CONCENTRATIONS

Magnesium is a Major Constituent in Wisconsin's Ground Water

Magnesium, like calcium, is widely distributed in the rocks and soils of the State, as well as in the ground water. Although concentrations are generally less than those of calcium, magnesium is a major contributor to dissolved solids. Magnesium concentrations generally present no water-quality problems except as they contribute to hardness.

Areal variation in magnesium concentrations tend to parallel those of dissolved solids. Highest magnesium concentrations occur in the east, south, and west parts of the State; in areas where more than one aquifer is present, concentration differences between aquifers generally seem to be small. The range of magnesium concentration is greater in the sand-and-gravel and sandstone aquifers than in the Silurian dolomite aquifer, but highest concentrations are generally found in the Silurian dolomite aquifer.

The dolomite (calcium magnesium carbonate) that is the principal component of the Silurian aquifer and is widely distributed in the sandstone aquifer is the most likely source of the higher magnesium concentrations in water from these systems.

SUMMARY BY AQUIFER OF MAGNESIUM CONCENTRATIONS
IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

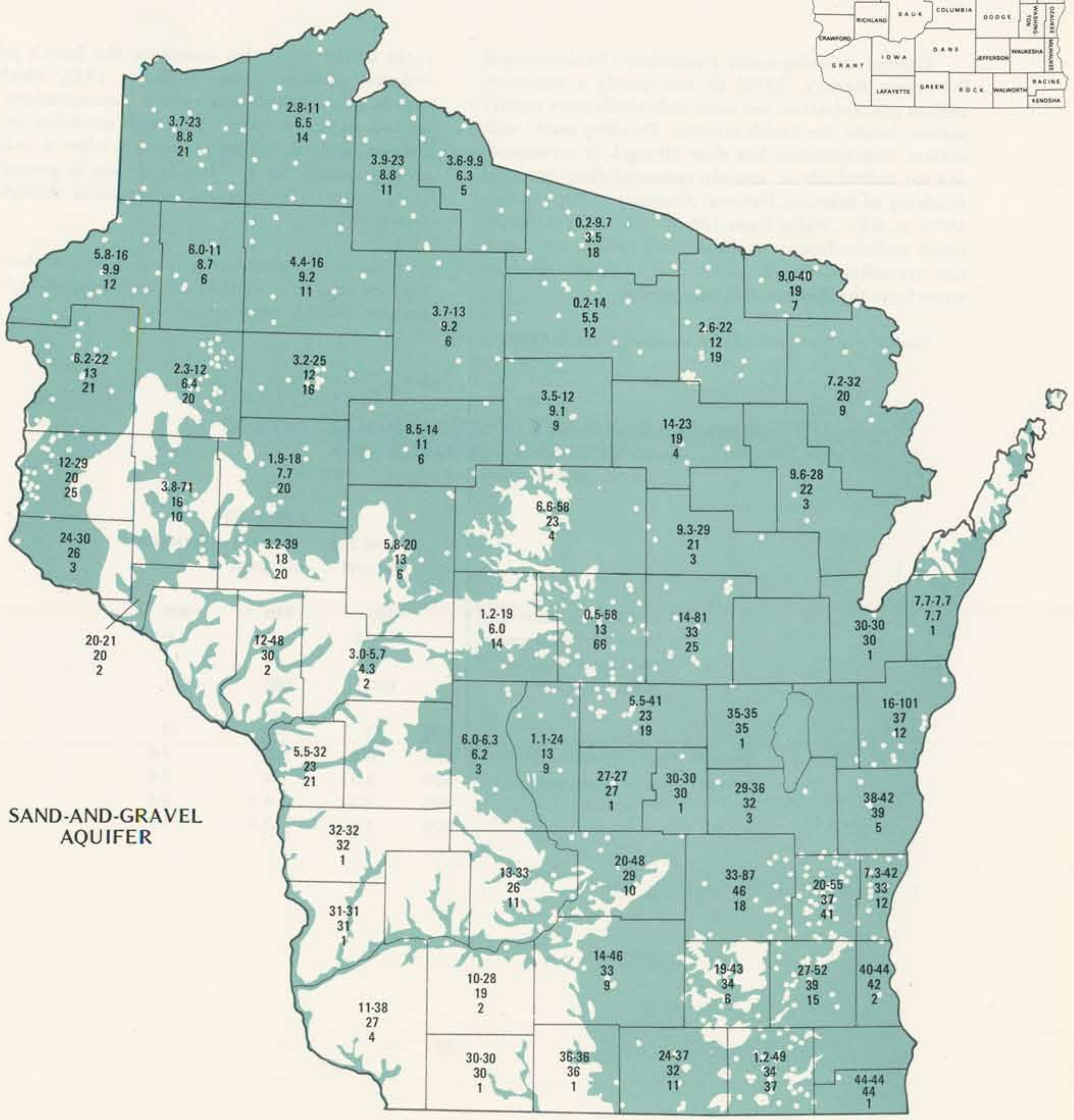
		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		101	86	187
Minimum concentration		0.2	2.5	0.0
Mean concentration		20	38	29
Number of wells		692	317	1064
Percent of wells where indicated concentration value was equaled or exceeded	10%	39	52	43
	25%	32	44	36
	50%	17	38	30
	75%	8.0	32	20
	90%	4.3	26	10

EXPLANATION

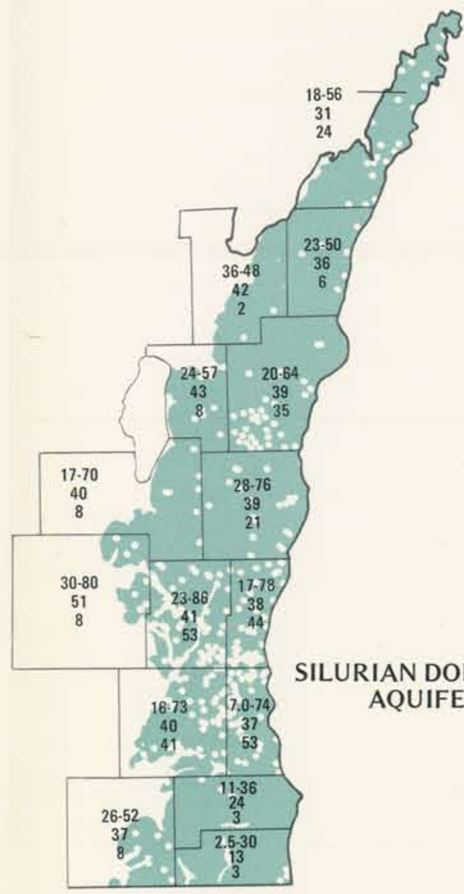
Magnesium concentration, in milligrams per liter

Minimum-Maximum concentration
Mean concentration
Number of wells
Location of sampled well
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES
0 20 40 60 80 100 120 140 160 180 KILOMETERS

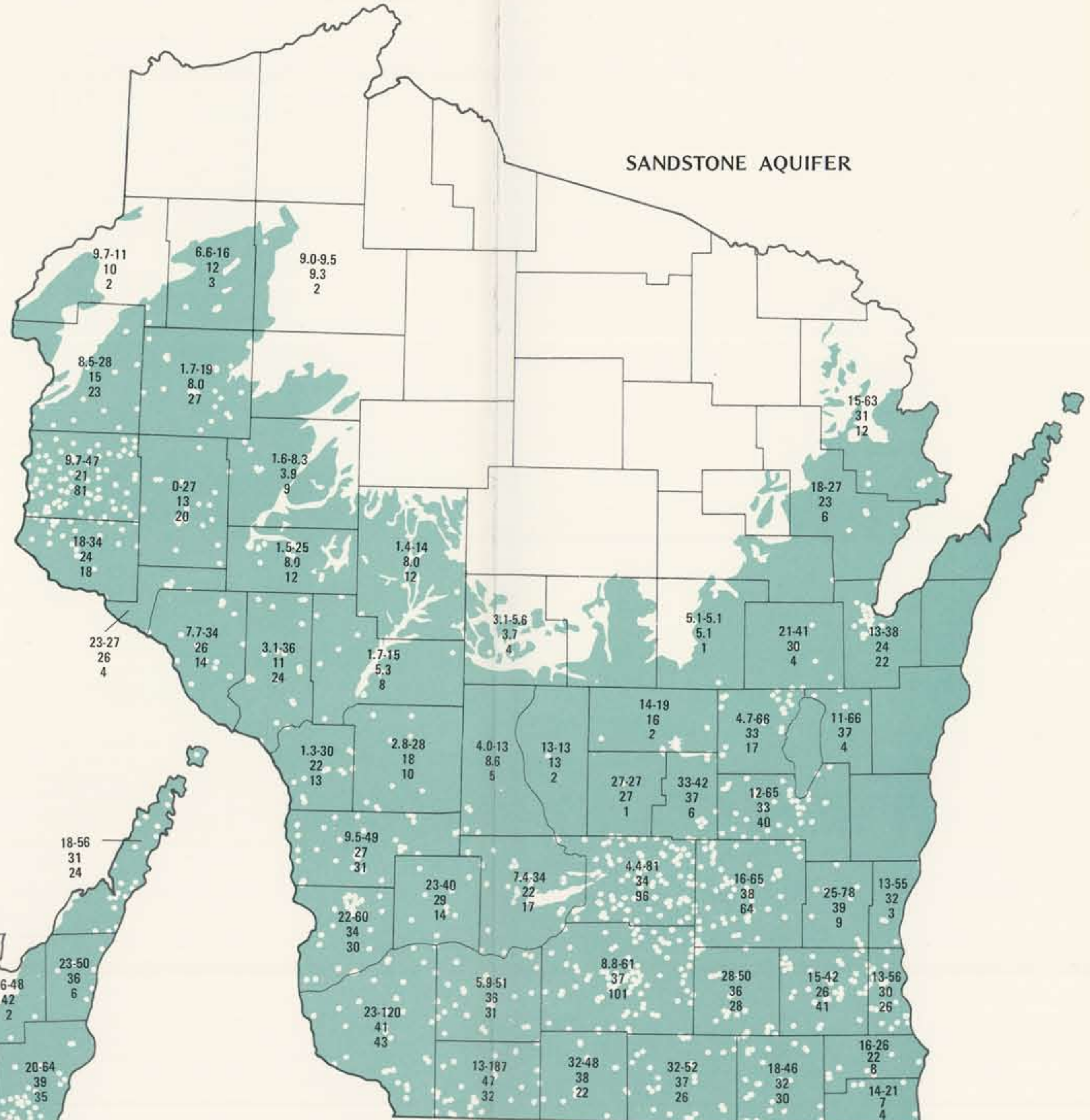


SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER

SANDSTONE AQUIFER



SUMMARY OF MAGNESIUM CONCENTRATIONS

Sodium is a Minor Constituent in Wisconsin's Ground Water

Sodium concentrations in the State's ground water are generally low, although high concentrations are found in some areas. Sodium concentrations seldom present quality problems in Wisconsin's ground water.

Current drinking-water regulations (Environmental Protection Agency, 1975) do not specify a maximum sodium concentration, but some individuals must restrict sodium intake for health reasons. Drinking water with sodium concentration less than 20 mg/L is recommended for individuals on severely restricted diets (National Academy of Sciences, National Academy of Engineering, 1973, p. 88). Water from 186 of the 1,779 wells for which sodium data are available has a sodium concentration exceeding 20 mg/L; almost half of these wells draw water from the Silurian dolomite aquifer.

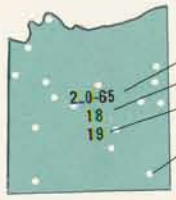
Sodium is not particularly abundant in sedimentary rocks of the types that constitute the State's principal bedrock aquifers (Hem, 1970, p. 145), which may explain the relatively low sodium concentrations in the ground water. Because of its high solubility in water, sodium tends to remain in solution after it enters the ground water. Sodium concentrations in ground water may, however, be increased or decreased through interaction with clay.

Sodium concentrations are generally highest along the east edge of the State, although isolated high values are also found in other areas.

SUMMARY BY AQUIFER OF SODIUM CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		107	240	800
Minimum concentration		0.0	0.5	0.5
Mean concentration		6.6	18	11
Number of wells		603	295	881
Percent of wells where indicated concentration value was equaled or exceeded	10%	13	43	17
	25%	5.5	22	7.6
	50%	3.3	10	3.6
	75%	2.3	4.7	2.3
	90%	1.6	3.1	1.7

EXPLANATION



Sodium concentration, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

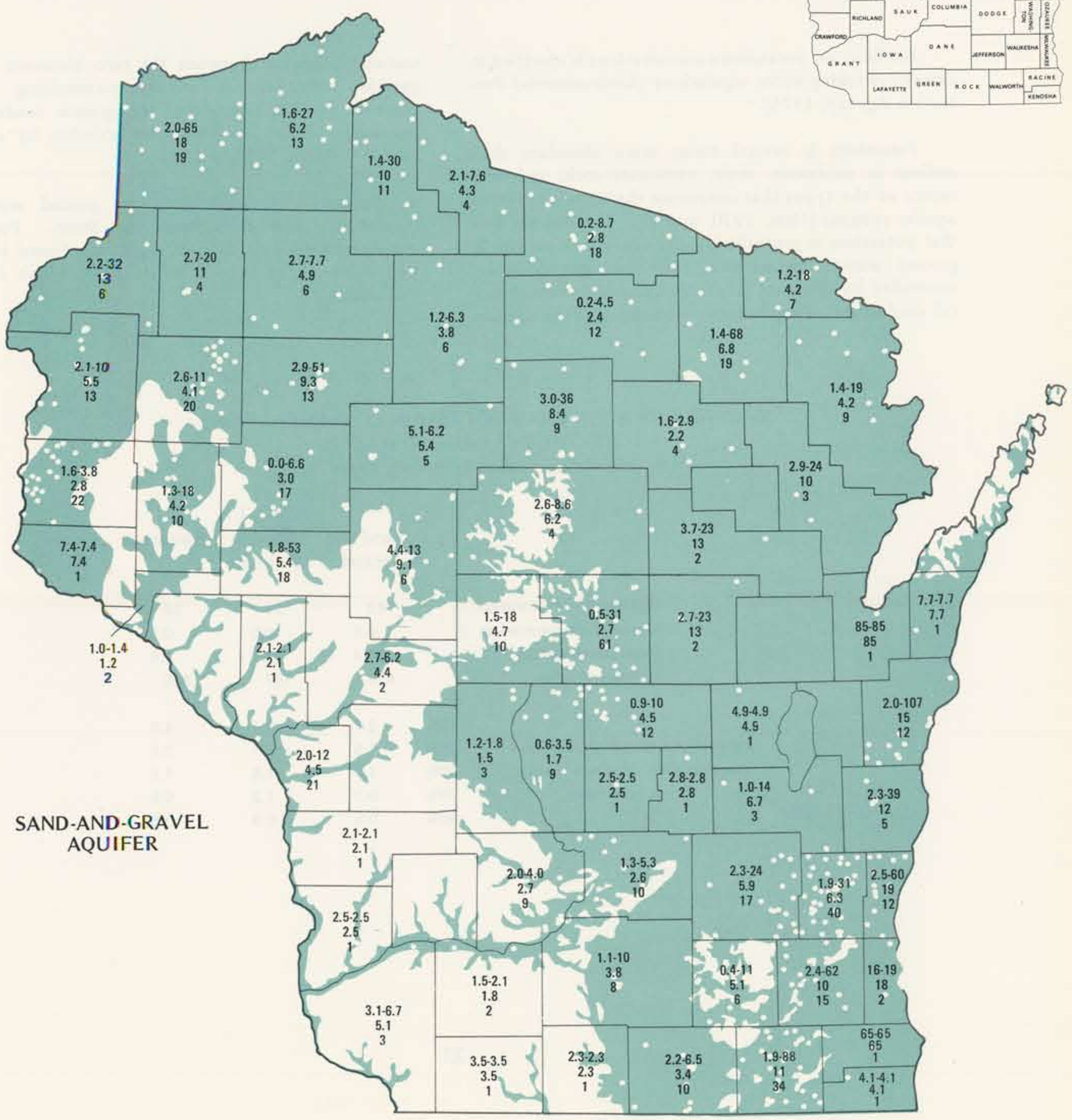
Number of wells

Location of sampled well

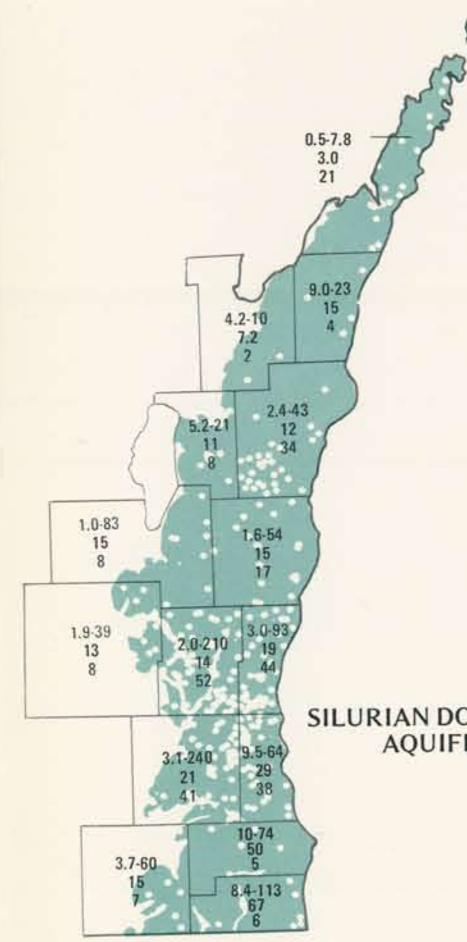
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

0 20 40 60 80 100 120 140 160 180 KILOMETERS

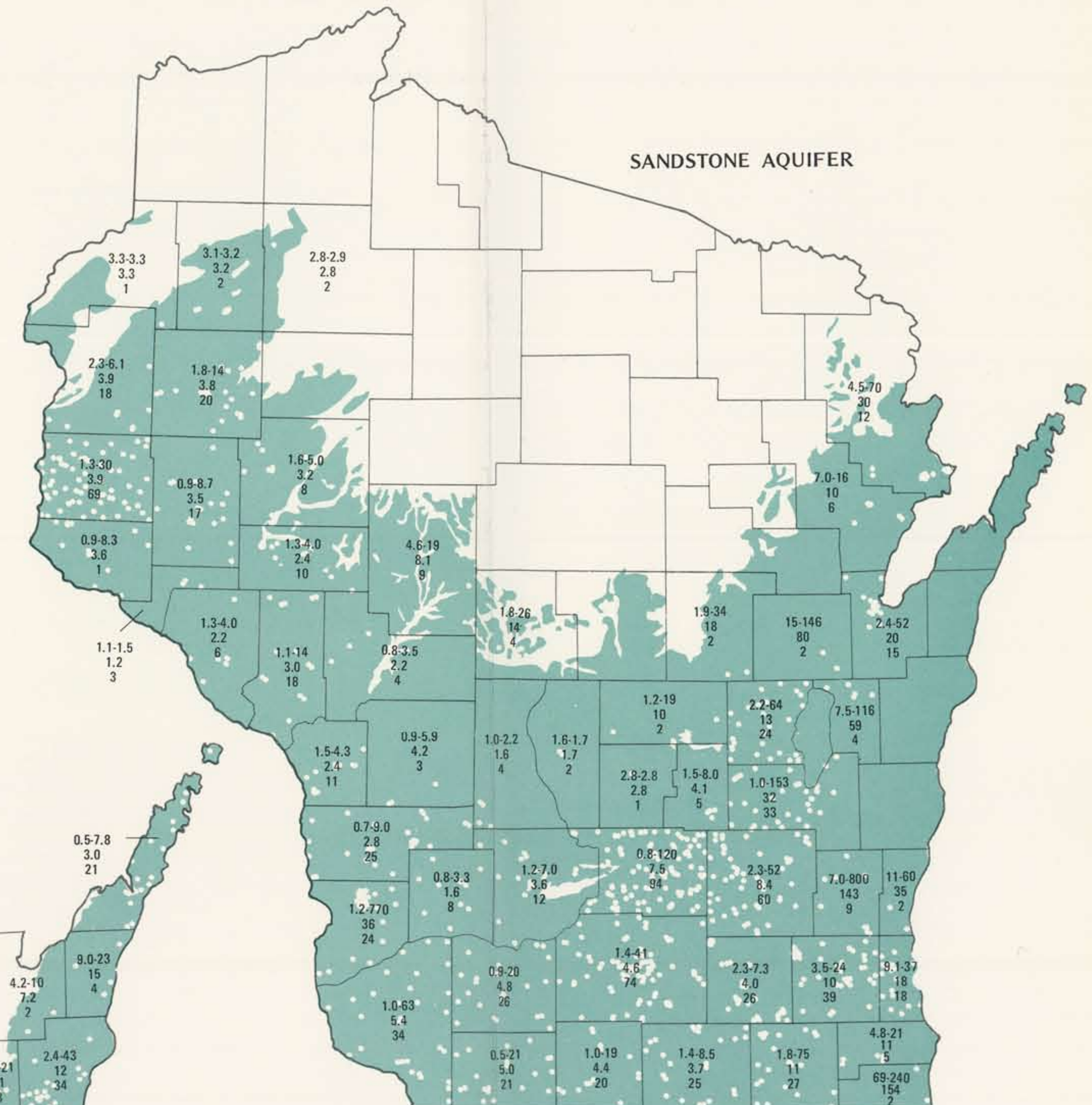


SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER

SANDSTONE AQUIFER



SUMMARY OF SODIUM CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA--Continued
3.2 Common inorganic constituents--Continued
3.2.3 Sodium

Potassium Concentrations in Wisconsin's Ground Water are Low

Potassium concentrations in the ground water are generally less than those of sodium. Potassium concentrations generally vary over a fairly narrow range in most waters and rarely cause water-quality problems.

No limit on potassium concentrations is specified in current drinking-water regulations (Environmental Protection Agency, 1975).

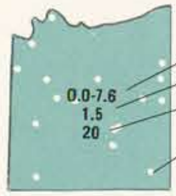
Potassium is several times more abundant than sodium in sandstone, shale, carbonate rock, and sediments of the types that constitute the State's principal aquifer systems (Hem, 1970, p. 150). This and the fact that potassium is generally less abundant than sodium in ground water suggests that their concentrations are controlled by different mechanisms despite their chemical similarities. Two factors contributing to the concentration difference between the two elements are the greater resistance of potassium-containing silicate minerals to weathering and the greater tendency of potassium to be removed from solution by sorption reactions (Hem, 1970, p. 151).

Potassium concentrations in ground water are consistently low throughout the State. Potassium concentrations exceeding 10 mg/L are found in water from only 12 of the 1,114 wells for which data are available.

SUMMARY BY AQUIFER OF POTASSIUM CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		42	27	24
Minimum concentration		0.0	0.0	0.0
Mean concentration		1.4	2.0	1.9
Number of wells		439	187	488
Percent of wells where indicated concentration value was equaled or exceeded	10%	2.1	3.4	4.0
	25%	1.5	2.1	2.1
	50%	1.0	1.5	1.1
	75%	0.7	1.2	0.8
	90%	0.5	0.9	0.5

EXPLANATION



Potassium concentration, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

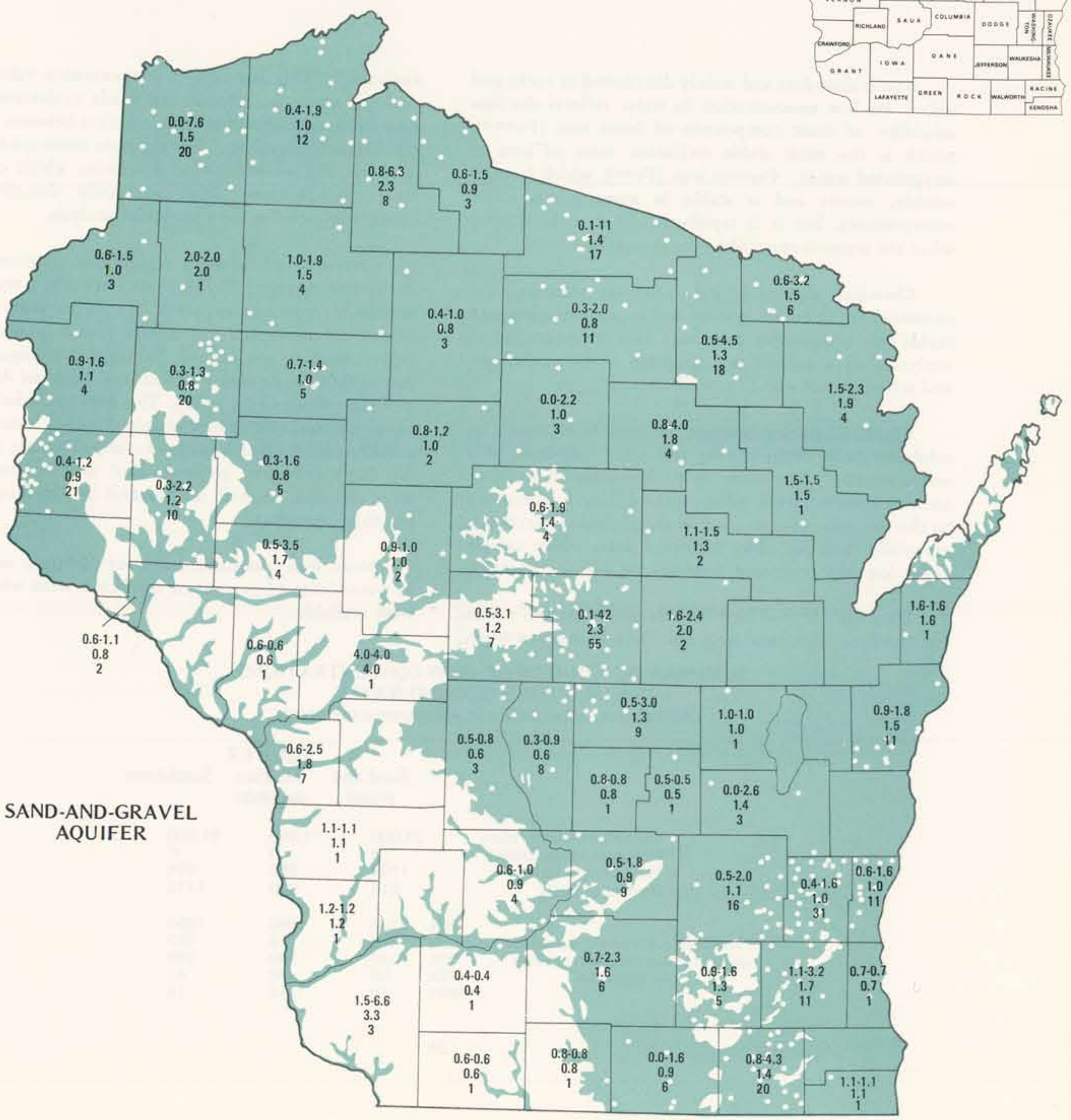
Number of wells

Location of sampled well

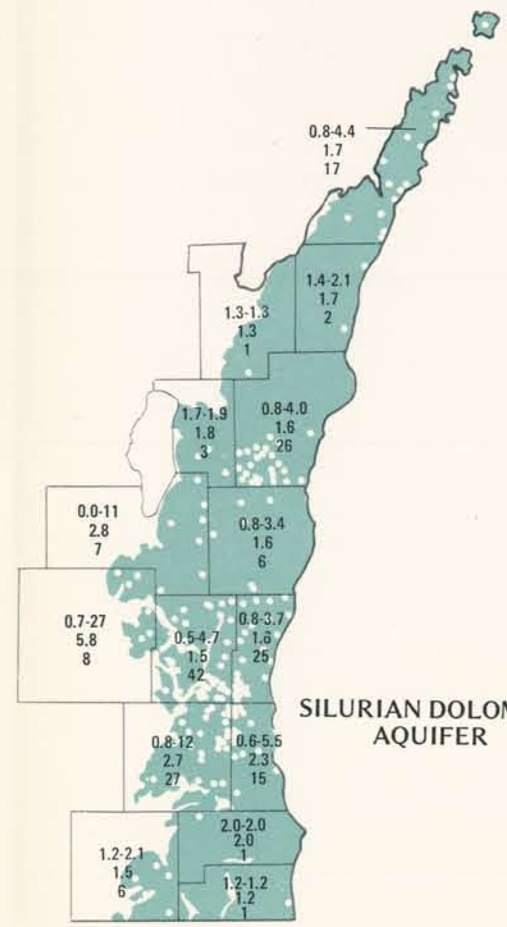
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

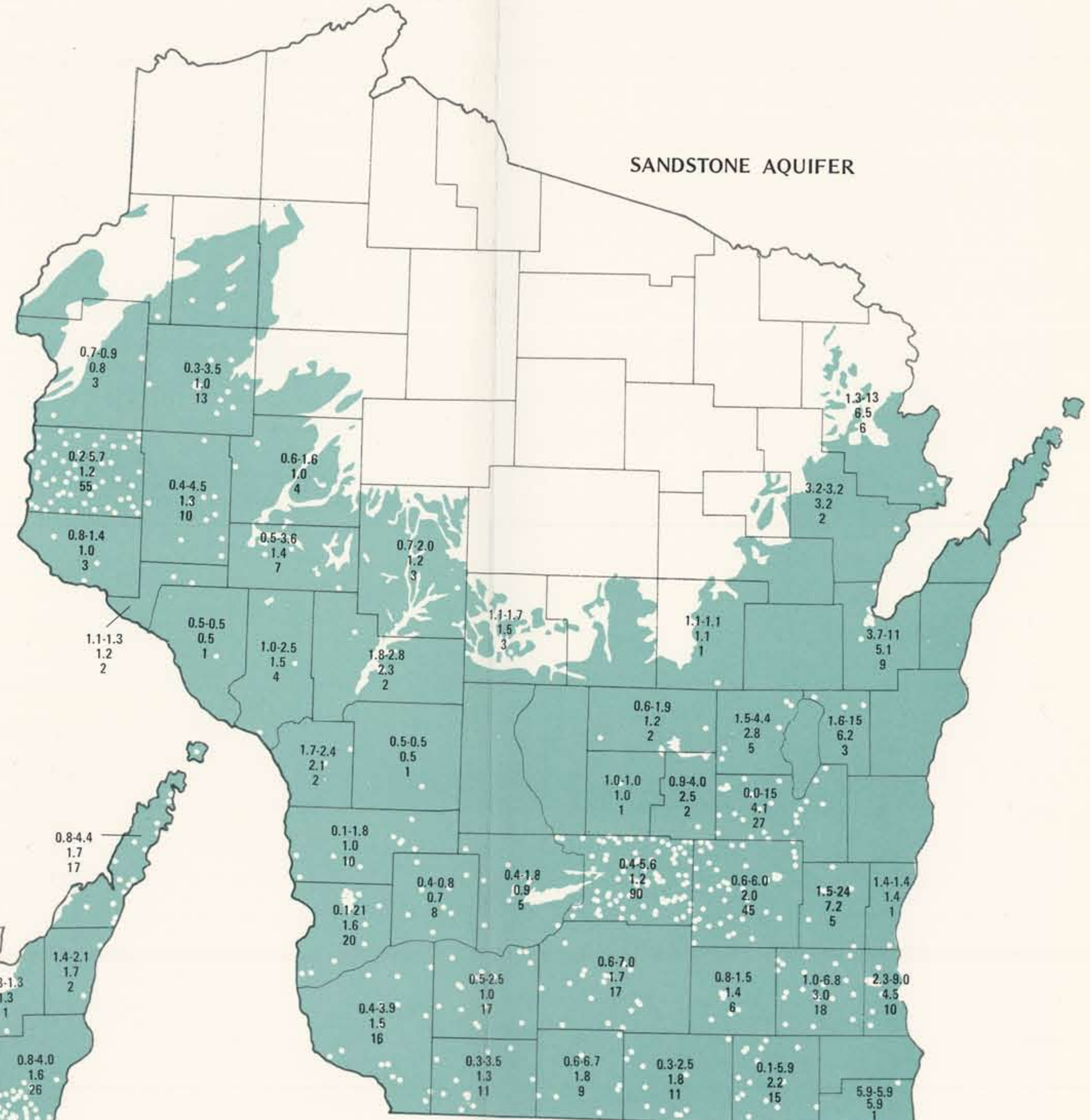
0 20 40 60 80 100 120 140 160 180 KILOMETERS



SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER



SANDSTONE AQUIFER

SUMMARY OF POTASSIUM CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA--Continued

3.2 Common inorganic constituents--Continued

3.2.4 Potassium

The Range of Iron Concentrations Found in Wisconsin's Ground Water is Large

Even small concentrations of iron can make water unsuitable for many uses. Iron concentrations in water from many wells sampled are high enough to cause water-quality problems.

Iron is abundant and widely distributed in rocks and soils. Its low concentration in water reflects the low solubility of most compounds of ferric iron (Fe+++), which is the most stable oxidation state of iron in oxygenated water. Ferrous iron (Fe++), which is more soluble, occurs and is stable in some ground-water environments, but it is rapidly oxidized to ferric iron when the water is exposed to the atmosphere.

Chemical and biological processes affecting the chemistry of iron in ground water are complex and rapid; this complicates collection and interpretation of analytical data as well as description of the occurrence and movement of iron in ground water.

Chemical transformations of iron that affect its solubility may occur during and after collection of a water sample. As a result, it is often difficult to relate an iron concentration value received from a laboratory to the original concentration in the ground water; this is especially true for older historical data, where sample collection and treatment methods are not documented.

Data summarized here include concentration values for dissolved iron, total iron, and "iron in solution when analyzed". This last type of concentration value is for analyses where no attempt was made to determine the amount of iron removed from solution between sample collection and analysis. For the data summarized here, it is not always possible to determine which of these three classifications most accurately describes the concentration value for a particular analysis.

Current drinking-water regulations (Environmental Protection Agency, 1975) do not specify a maximum permissible iron concentration, but earlier water-quality criteria recommended that soluble iron in public water-supply sources not exceed 300 μg/L (micrograms per liter) (National Academy of Sciences, National Academy of Engineering, 1973, p. 69). This recommended limit is based on esthetic (taste, staining) rather than health considerations. Iron can also be objectionable in water for many industrial processes and may accumulate as solid deposits on well screens and in distribution and plumbing systems.

Mean iron concentrations were 300 μg/L or greater in water from 44 percent of the 2,349 wells where data were available.

SUMMARY BY AQUIFER OF IRON CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in micrograms per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		21,000	11,000	61,000
Minimum concentration		0	0	0
Mean concentration		1109	662	834
Number of wells		816	360	1173
Percent of wells where indicated concentration value was equaled or exceeded	10%	3100	1650	1850
	25%	910	710	752
	50%	135	290	228
	75%	30	60	43
	90%	10	10	15

EXPLANATION

Iron concentration, in micrograms per liter

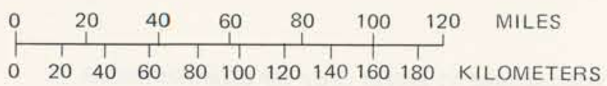
Minimum-Maximum concentration

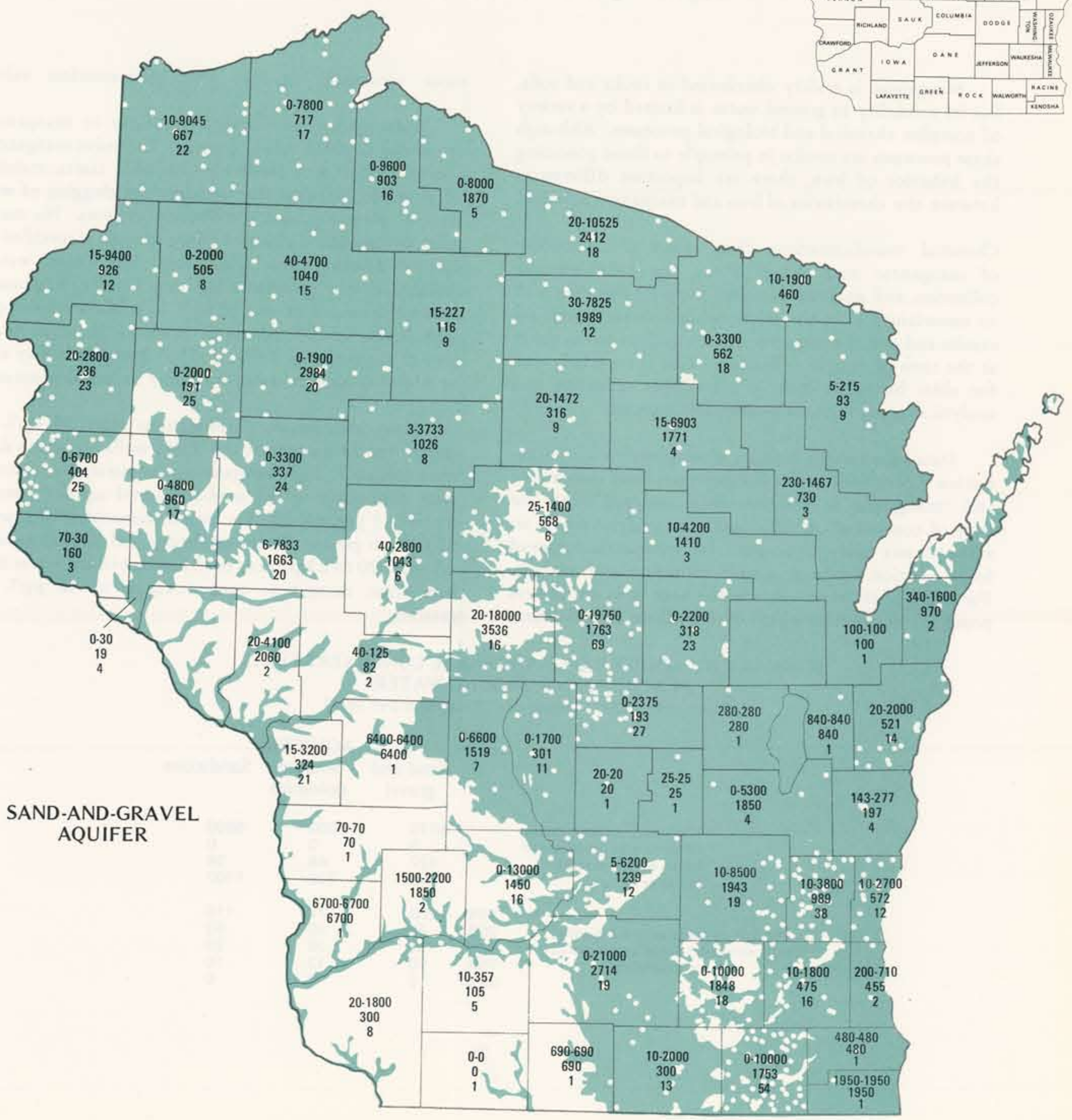
Mean concentration

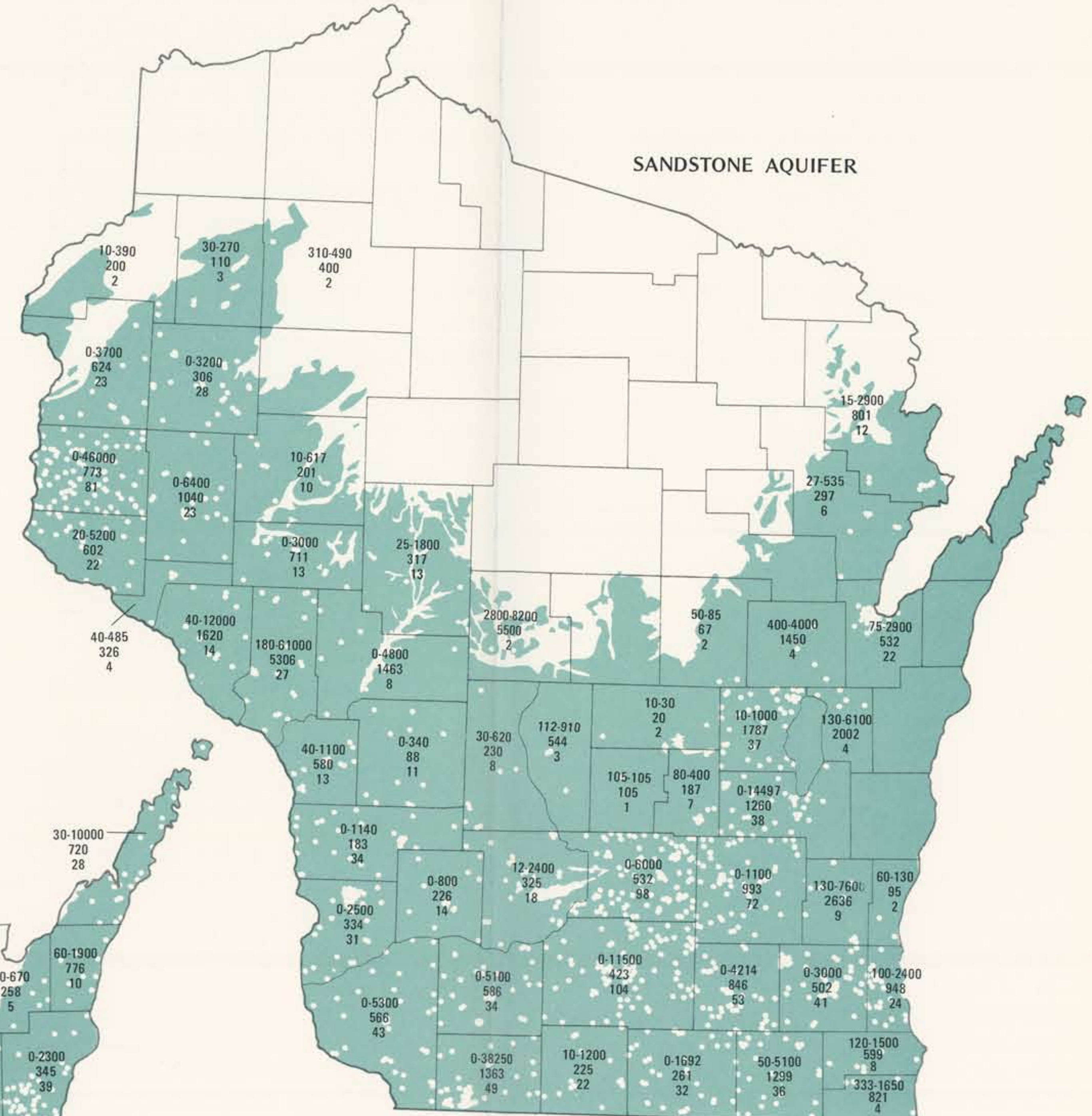
Number of wells

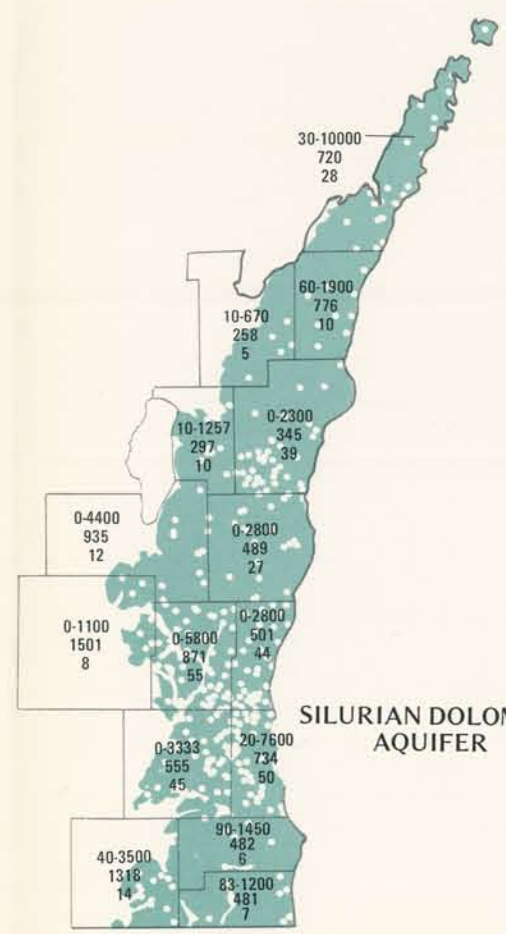
Location of sampled well

Color indicates area where aquifer is present









SUMMARY OF IRON CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA--Continued

3.2 Common inorganic constituents--Continued

3.2.5 Iron

A Wide Range of Manganese Concentrations is Found in Wisconsin's Ground Water

Even small concentrations of manganese in water may be objectionable. Manganese concentrations in water from many wells in Wisconsin are high enough to cause water-quality problems.

Manganese is widely distributed in rocks and soils, but its solubility in ground water is limited by a variety of complex chemical and biological processes. Although these processes are similar in principle to those governing the behavior of iron, there are important differences between the chemistries of iron and manganese in water.

Chemical transformations that affect the solubility of manganese may occur during the time between collection and analysis of water samples; this may lead to uncertainty as to the relationship between analytical results and actual manganese concentrations in the water at the time of sample collection. This is especially true for older historical data, where sample collection and analytical procedures are poorly documented.

Data summarized here are a combination of concentration values for dissolved manganese, total manganese, and "manganese in solution when analyzed"; this last type of concentration value applies to analyses where no attempt was made to account for manganese removed from solution between sample collection and analysis. For some of the data summarized here, it is not always possible to determine which of these three classifications most accurately describe the concentration value.

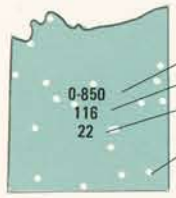
Water-quality problems attributable to manganese are similar to those caused by iron. Excessive manganese concentrations may cause objectionable tastes, staining of plumbing fixtures and laundry, and clogging of well screens, plumbing, and distribution systems. No maximum permissible manganese concentration is specified in current drinking-water regulations, but earlier water-quality criteria recommended that soluble manganese concentration not exceed 50 μg/L in public water-supply sources (National Academy of Sciences, National Academy of Engineering, 1973, p. 71). Manganese may also be objectionable in water for many industial processes.

Mean manganese concentrations were 50 μg/L or greater for 28 percent of the 2,241 wells for which data were available. High manganese concentrations occurred most commonly in the sand-and-gravel aquifer system, where 41 percent of the mean concentrations were 50 μg/L or greater. In the sandstone and Silurian aquifer systems, 20 to 22 percent of the wells yielded water that had mean manganese concentrations of 50 μg/L or greater.

SUMMARY BY AQUIFER OF MANGANESE CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in micrograms per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		5170	3300	5900
Minimum concentration		0	0	0
Mean concentration		127	45	54
Number of wells		799	335	1107
Percent of wells where indicated concentration value was equaled or exceeded	10%	260	70	110
	25%	90	40	42
	50%	33	30	23
	75%	10	12	10
	90%	0	0	0

EXPLANATION

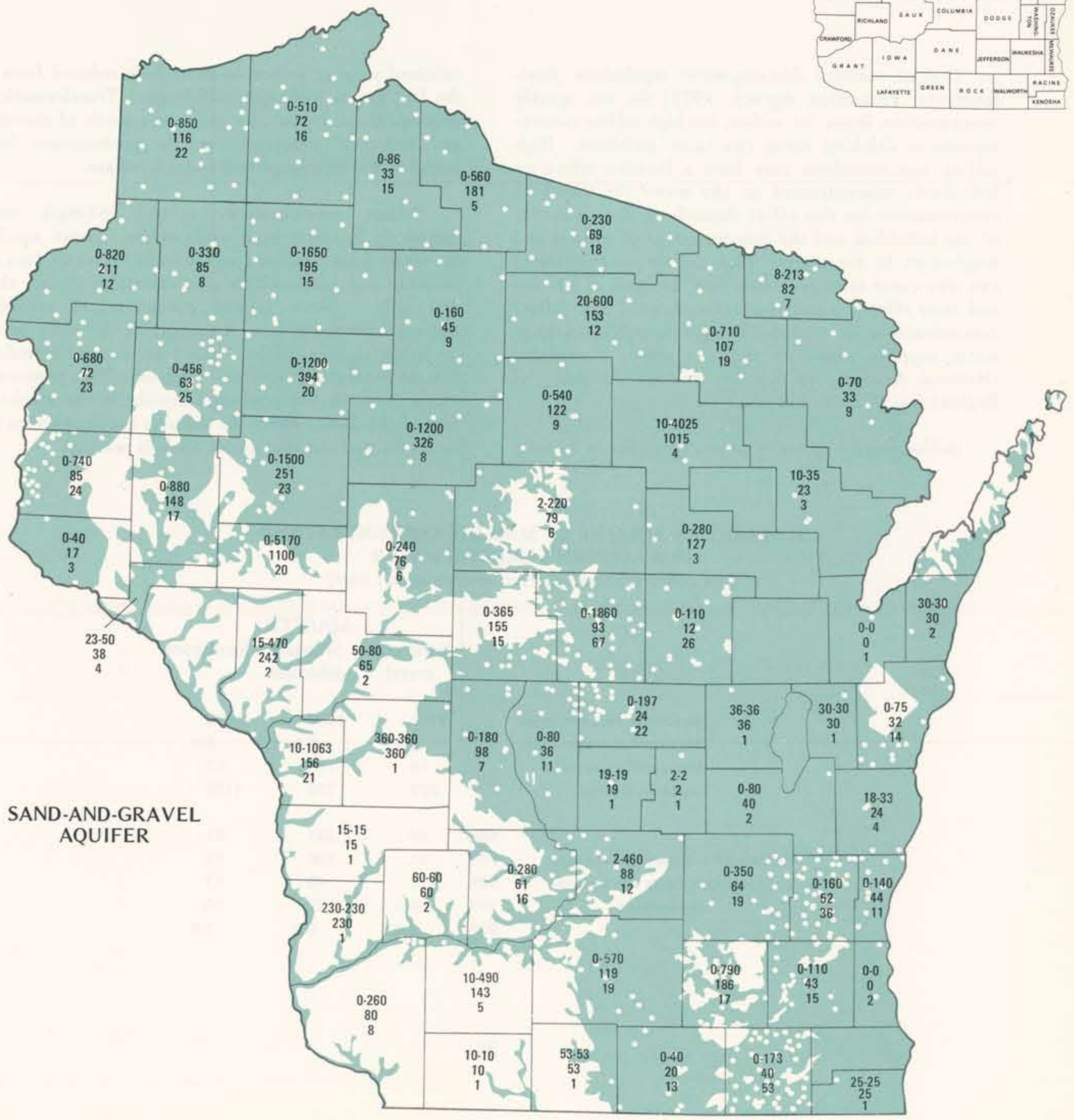


Manganese concentration, in micrograms per liter
- Minimum-Maximum concentration
- Mean concentration
- Number of wells
- Location of sampled well

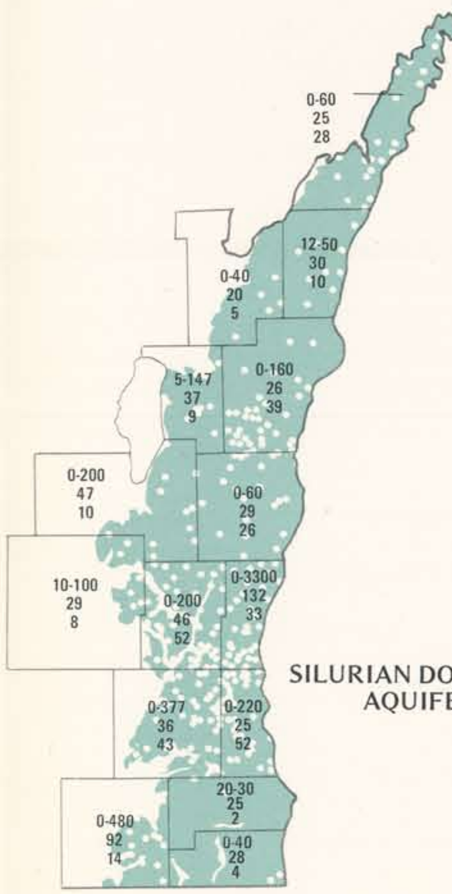
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

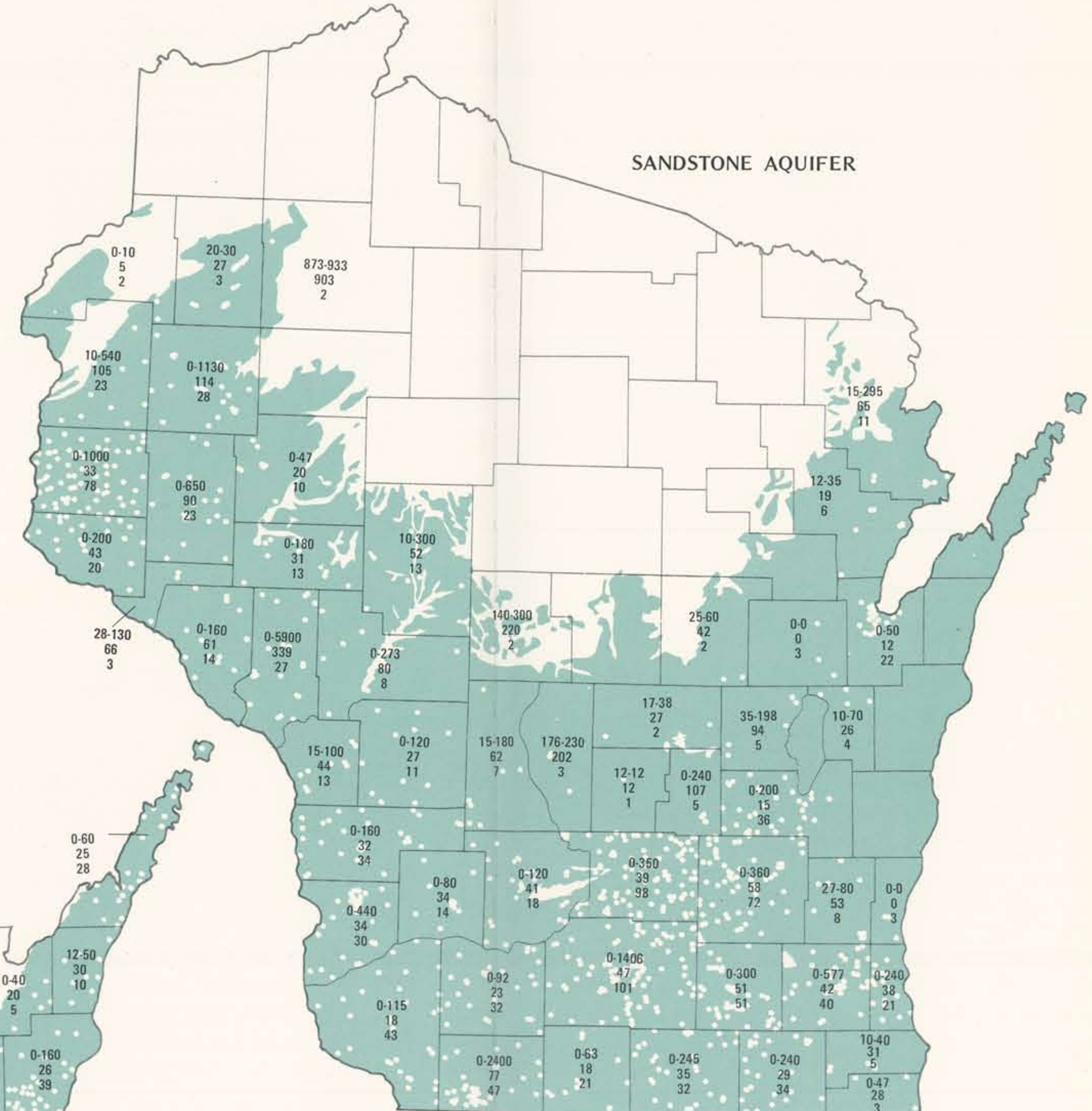
0 20 40 60 80 100 120 140 160 180 KILOMETERS



SAND-AND-GRAVEL AQUIFER



SILURIAN DOLOMITE AQUIFER



SANDSTONE AQUIFER

SUMMARY OF MANGANESE CONCENTRATIONS

3.0-GROUND-WATER-QUALITY DATA-- Continued
3.2 Common inorganic constituents--Continued
3.2.6 Manganese

Sulfate Concentrations are Generally Low, but Higher Concentrations Occur in some Areas

Mineral sources of sulfate (primarily metallic sulfides and gypsum) are distributed widely in Wisconsin's aquifers. Although concentrations have a wide range, sulfate causes few water-quality problems in Wisconsin.

Current national drinking-water regulations (Environmental Protection Agency, 1975) do not specify concentration limits for sulfate, but high sulfate concentrations in drinking water can cause problems. High sulfate concentrations may have a laxative effect on individuals unaccustomed to the water–the threshold concentration for this effect depends on the sensitivity of the individual and the concentrations of sodium and magnesium in the water. High sulfate concentrations can also cause taste problems. On the basis of laxative and taste effects, it has been recommended that sulfate concentrations not exceed 250 mg/L in public drinking-water supplies where an alternate source is available (National Academy of Science, National Academy of Engineering, 1973, p. 89).

Sulfur in ground water generally occurs in its fully oxidized state as sulfate or in its fully reduced form as the HS^- ion or hydrogen sulfide gas. Transformations between these forms take place as a result of chemical and biological processes, but the predominant form found in Wisconsin's ground water is sulfate.

Sulfate concentrations exceed 250 mg/L most frequently in water from wells in the Silurian aquifer; the water from 9 percent of the wells for which data are available had mean sulfate concentrations greater than 250 mg/L. Mean sulfate concentrations exceeded 250 mg/L in water from 4 percent of the wells in the sandstone aquifer and less than 1 percent of the wells in the sand-and-gravel aquifer. Highest sulfate concentra-tions occur in the sandstone aquifer in the southeast part of the State, where the Silurian aquifer overlies the sandstone and the Maquoketa Shale is present.

SUMMARY BY AQUIFER OF SULFATE CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		1100	1400	1650
Minimum concentration		0.0	0.4	0.0
Mean concentration		19	101	47
Number of wells		823	359	1179
Percent of wells where indicated concentration value was equaled or exceeded	10%	40	231	91
	25%	21	106	35
	50%	11	48	17
	75%	6.0	22	10
	90%	3.0	8.0	5.0

EXPLANATION

Sulfate concentration, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

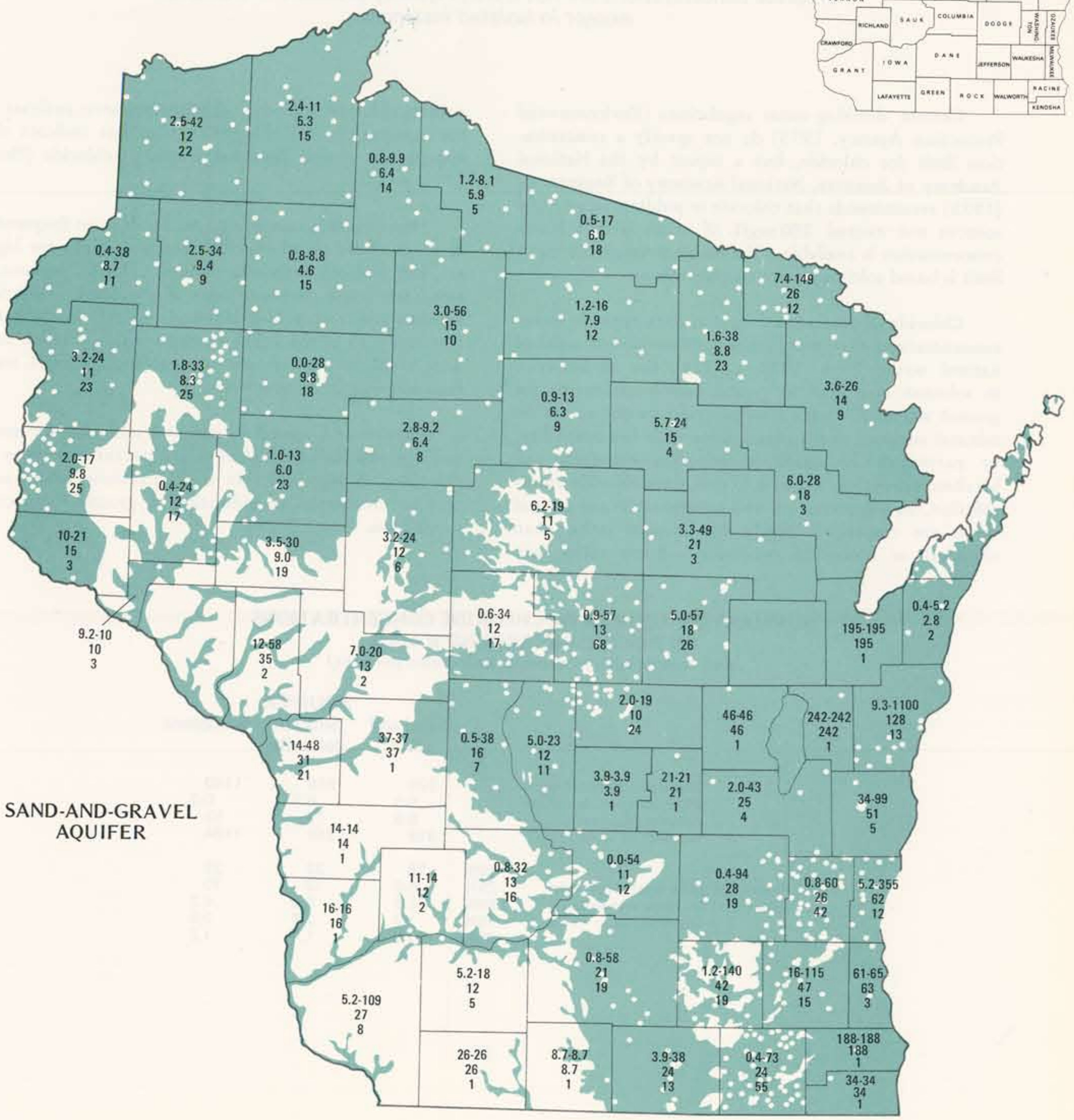
Number of wells

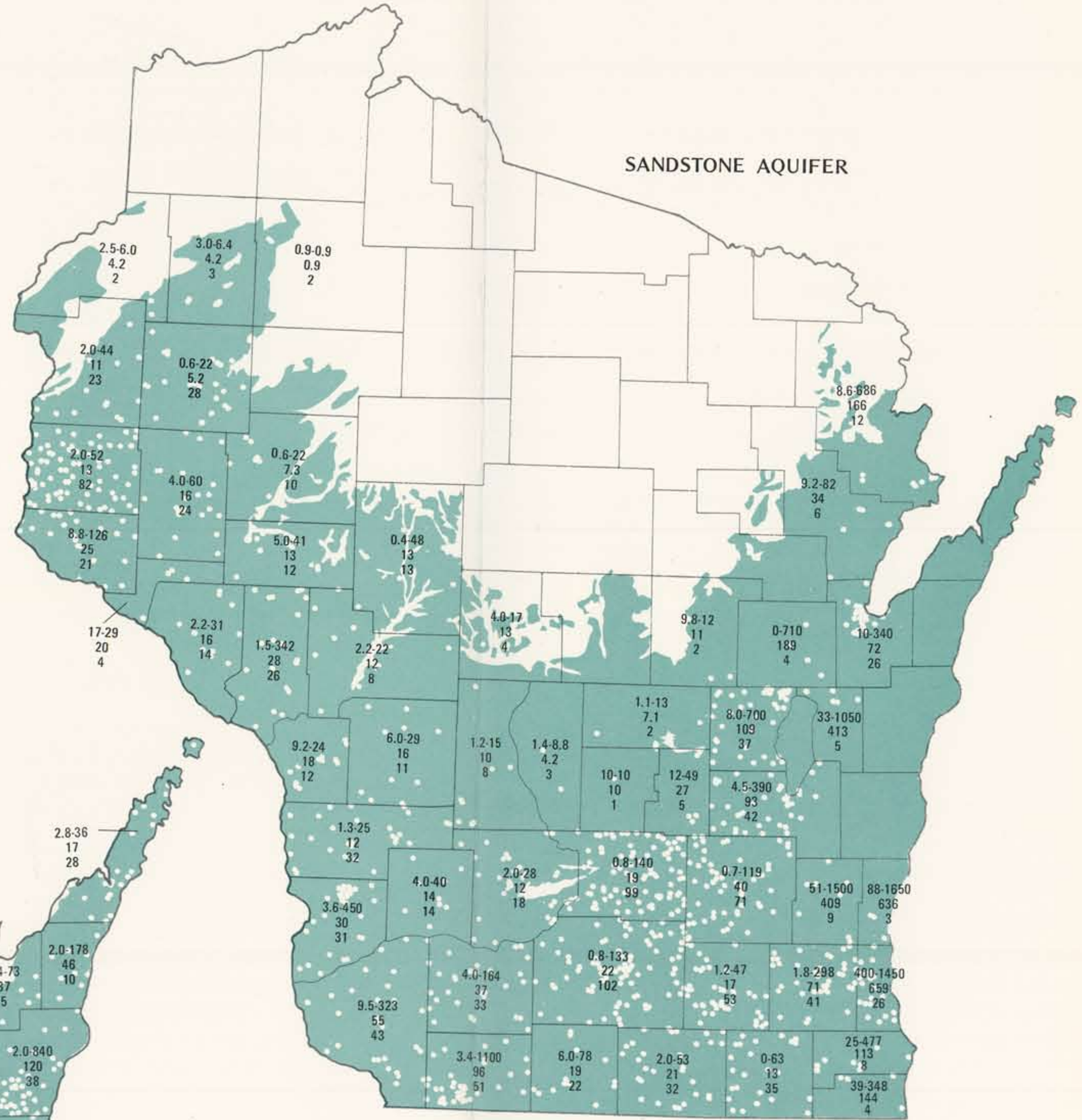
Location of sampled well

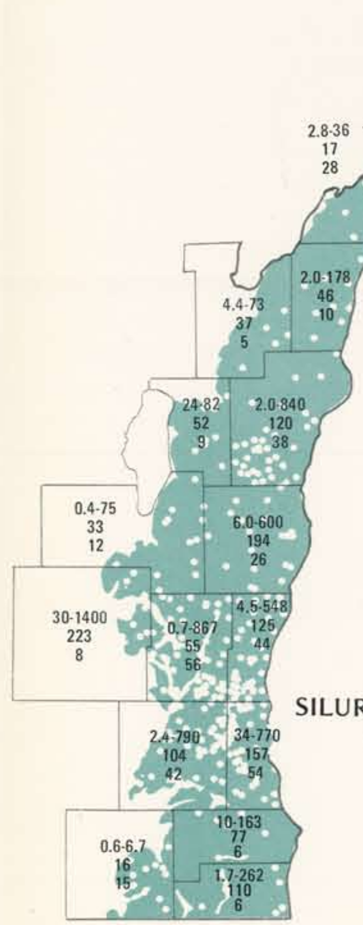
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

0 20 40 60 80 100 120 140 160 180 KILOMETERS







SUMMARY OF SULFATE CONCENTRATIONS

Chloride Concentrations in Wisconsin's Ground Water are Generally Low

The low chloride concentrations in the ground water are due primarily to the relatively low chloride concentrations in common rock types. High chloride concentrations are not a water-quality problem in Wisconsin except in isolated instances.

Current drinking-water regulations (Environmental Protection Agency, 1975) do not specify a concentration limit for chloride, but a report by the National Academy of Sciences, National Academy of Engineering (1973) recommends that chloride in public water-supply sources not exceed 250 mg/L if water with a lower concentration is available. The recommended 250 mg/L limit is based solely on taste considerations.

Chloride is present in common rock types in lower concentrations than most other common constituents of natural water (Hem, 1970, p. 173), but its behavior in solution may lead to greater concentrations in the ground water. Chloride ions generally do not adsorb on mineral surfaces, form precipitates with low solubility, or participate in oxidation-reduction reactions and biochemical cycles. Because of this, once chloride enters solution, its concentration and movement in the ground water are controlled largely by physical rather than chemical or biological processes. Some rocks may contain chloride in residual or connate water; analyses of the composition of the rocks may not indicate the importance of this potential source of chloride (Hem, 1970, p. 171).

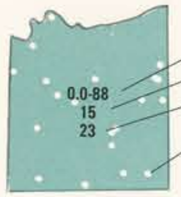
High chloride concentrations occur most frequently in areas where dissolved-solids concentrations are highest, but isolated instances of high chloride concentrations are found in most parts of the State. Chloride concentrations exceeding 100 mg/L were found in water from only 35 of the 2,342 wells for which chloride data were available; concentrations exceeding 250 mg/L were found in only 7 of these wells.

Human and animal wastes and salt used for snow and ice removal on highways are potential sources of chloride, so high chloride concentrations in an area may be considered an indication of ground-water contamination.

SUMMARY BY AQUIFER OF CHLORIDE CONCENTRATIONS IN WISCONSIN'S GROUND WATER
(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		325	510	1140
Minimum concentration		0.0	0.7	0.0
Mean concentration		8.6	17	13
Number of wells		819	359	1164
Percent of wells where indicated concentration value was equaled or exceeded	10%	18	32	22
	25%	8.0	12	10
	50%	3.5	5.0	4.2
	75%	1.7	2.6	2.0
	90%	1.0	1.4	1.0

EXPLANATION



Chloride concentration, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

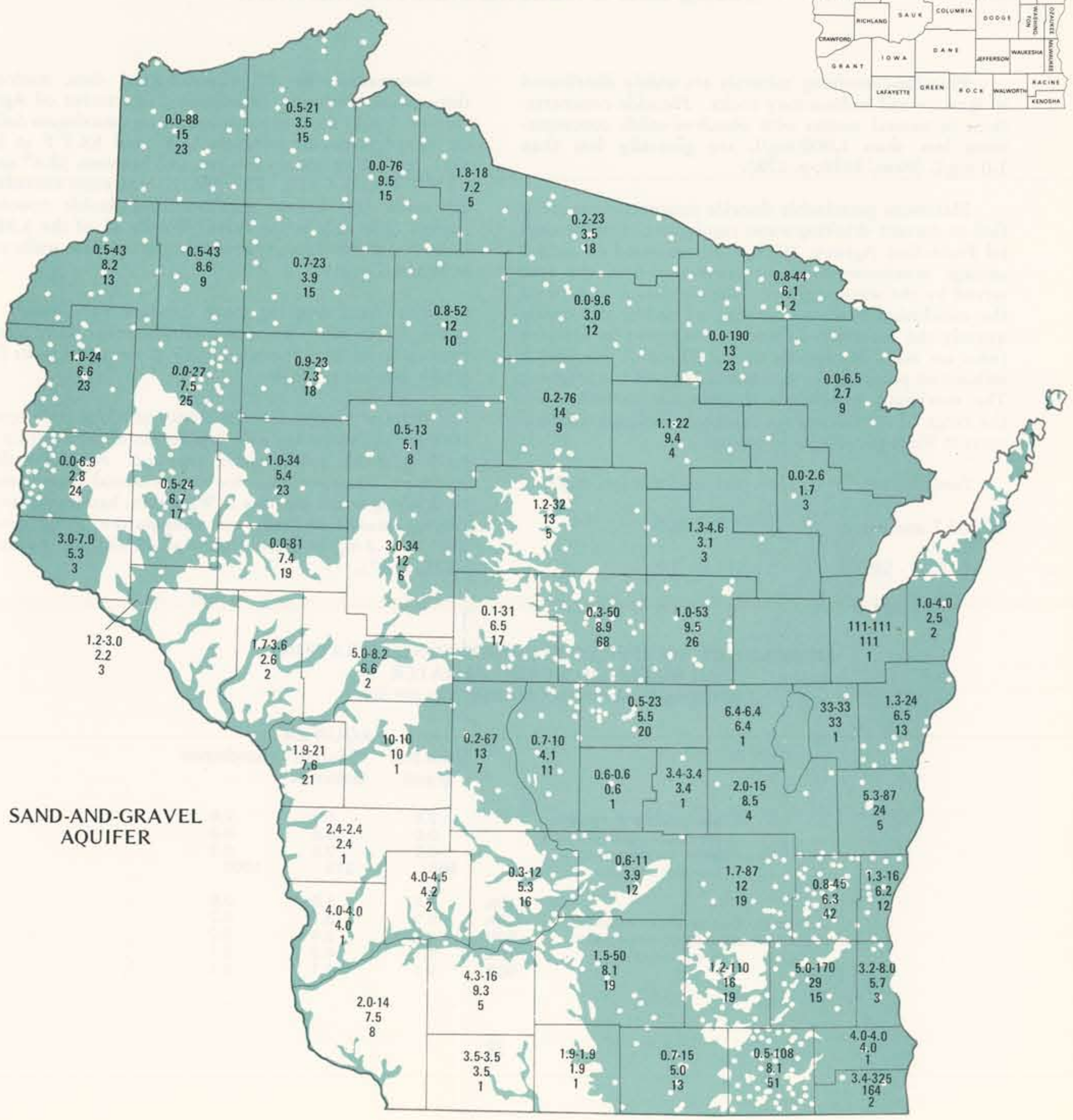
Number of wells

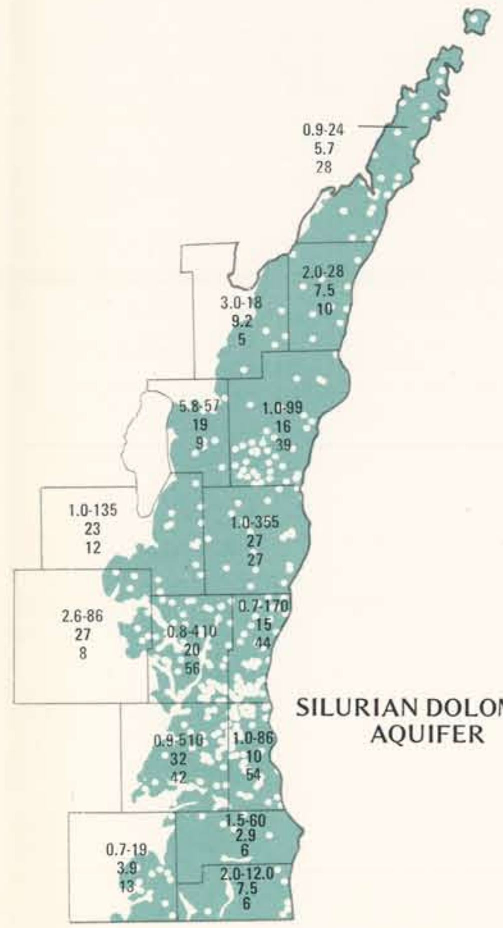
Location of sampled well

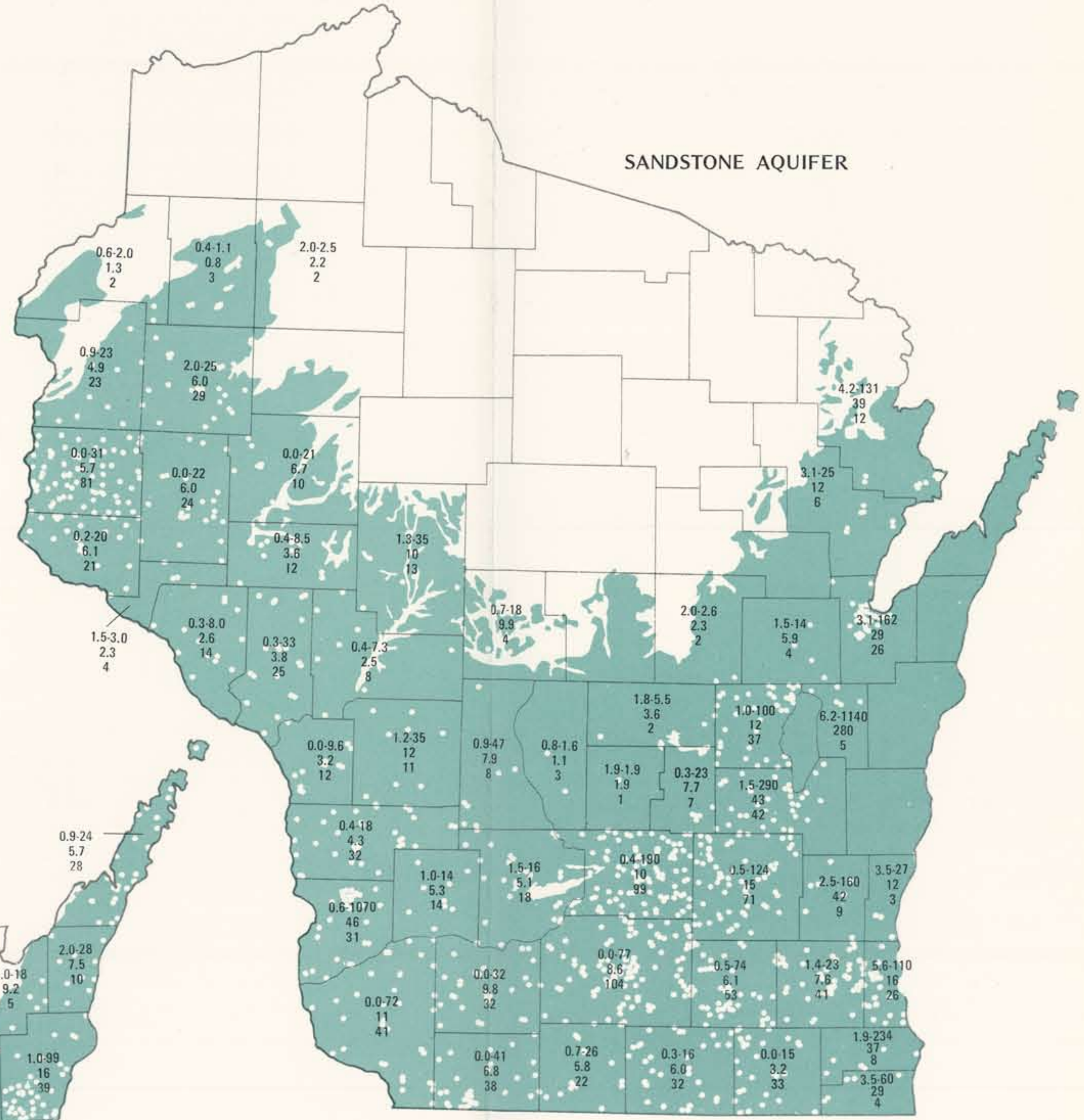
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

0 20 40 60 80 100 120 140 160 180 KILOMETERS







SUMMARY OF CHLORIDE CONCENTRATIONS

Fluoride Concentrations are Low in Wisconsin's Ground Water

Fluoride in drinking water in small concentrations has potential beneficial effects (reduced incidence of tooth decay), but higher concentrations can cause discoloration of tooth enamel. Concentrations in Wisconsin's ground water are generally less than those recommended for drinking water to realize maximum beneficial effects.

Fluoride-containing minerals are widely distributed in igneous and sedimentary rocks. Fluoride concentrations in natural waters with dissolved-solids concentrations less than 1,000 mg/L are generally less than 1.0 mg/L (Hem, 1970, p. 178).

Maximum permissible fluoride concentrations specified in current drinking-water regulations (Environmental Protection Agency, 1975, p. 5) are based on annual average maximum daily air temperature in the area served by the water supply. The regulation is based on the conclusion that the amount of water, and consequently the amount of fluoride, consumed by children (who are most susceptible to the effects of fluoride) is influenced primarily by maximum daily air temperature. The maximum permissible fluoride concentrations for the range of annual average maximum daily air temperatures in Wisconsin are listed below.

Temperature, $^{\circ}F$	Fluoride concentration, mg/L
53.7 and below	2.4
53.8 - 58.3	2.2
58.4 - 63.8	2.0

Summaries for 71 climatological data stations throughout Wisconsin (Wisconsin Department of Agriculture, 1961) show that annual average maximum daily air temperatures are between 53.8° and 58.3°F at 52 sites, 53.7°F or less at 13 sites, and between 58.4° and 63.8°F at only 6 sites. Fluoride concentration exceeded 2.0 mg/L (the lowest maximum permissible concentration applicable in the State) in only 11 of the 1,984 wells for which data are available; 10 of these wells are in Brown County.

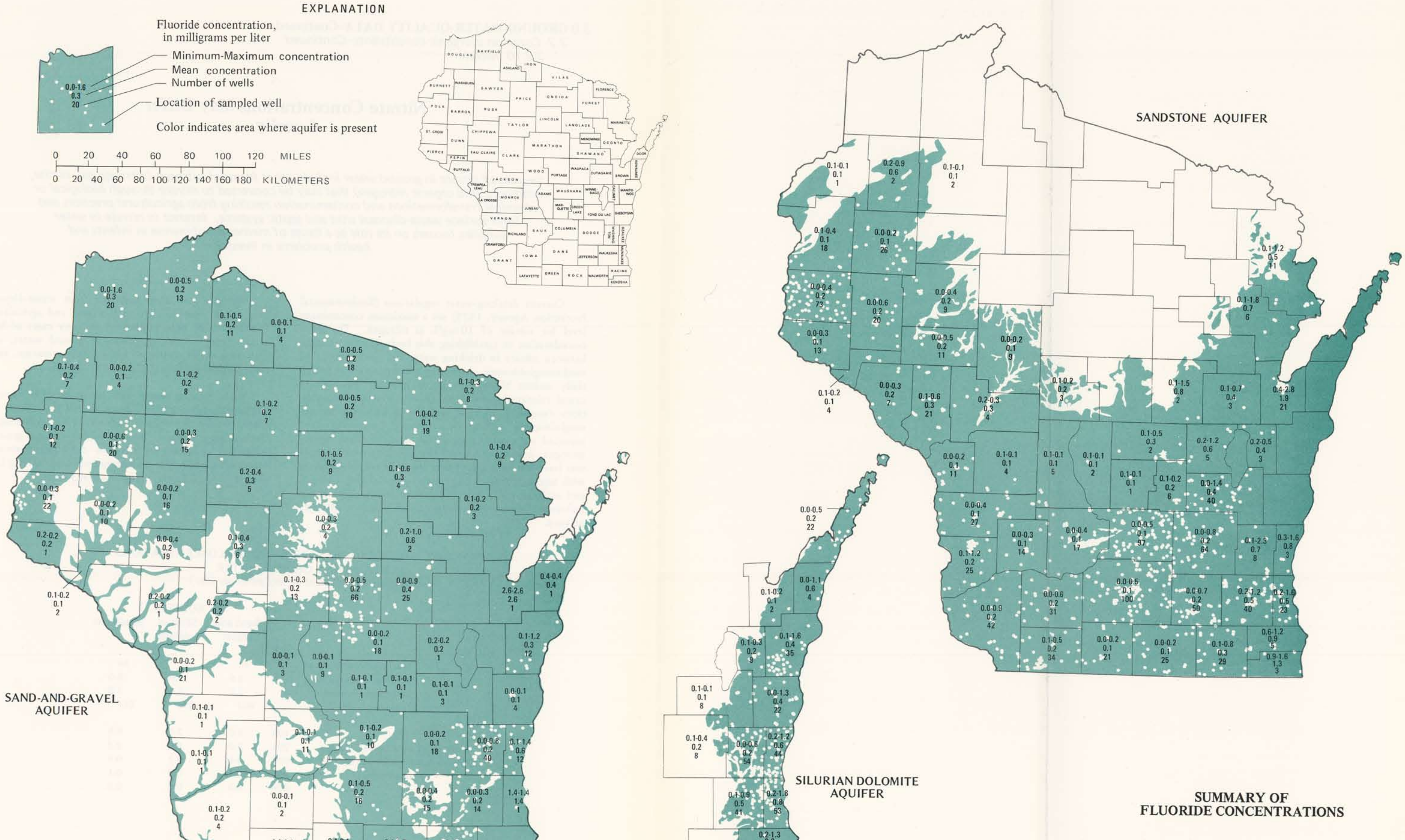
The State drinking-water standard for fluoride is 2.2 mg/L (Department of Natural Resources, 1978); this value is equaled or exceeded in 10 of the 1,984 wells for which data are available.

Because natural fluoride concentrations in Wisconsin's ground water are low, supplemental fluoridation is used in many public water supplies. Recommended optimum concentrations for supplemental fluoridation of drinking-water supplies in Wisconsin, based on annual average maximum daily air temperature, range from 1.0 to 1.2 mg/L (Environmental Protection Agency, 1975, p. 67).

SUMMARY BY AQUIFER OF FLUORIDE CONCENTRATIONS IN WISCONSIN'S GROUND WATER

(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		2.6	1.8	2.8
Minimum concentration		0.0	0.0	0.0
Mean concentration		0.2	0.5	0.2
Number of wells		666	315	1003
Percent of wells where indicated concentration value was equaled or exceeded	10%	0.4	1.0	0.5
	25%	0.2	0.7	0.2
	50%	0.2	0.4	0.2
	75%	0.1	0.2	0.1
	90%	0.1	0.1	0.1



SUMMARY OF FLUORIDE CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA--Continued
3.2 Common inorganic constituents--Continued
3.2.9 Fluoride

Nitrate Concentrations May Differ Locally

Sources of nitrate in ground water include other forms of nitrogen (nitrogen gas, nitrite, ammonia, and organic nitrogen) that may be converted to nitrate through biological or chemical transformations and contamination resulting from agricultural practices and from surface waste-disposal sites and septic systems. Interest in nitrate in water supplies focuses on its role as a cause of methemoglobinemia in infants and health problems in livestock.

Current drinking-water regulations (Environmental Protection Agency, 1975) set a maximum contaminant level for nitrate of 10 mg/L as nitrogen. The main consideration in establishing this limit was the relation between nitrate in drinking water and the incidence of methemoglobinemia (cyanosis), a temporary but potentially serious blood disorder in infants. No definite causal relationship between nitrate nitrogen concentrations exceeding 10 mg/L and the incidence of methemoglobinemia has been demonstrated, but surveys have reported no occurrences of the disorder when nitrate nitrogen concentration in the drinking-water supply was less than 10 mg/L. Many infants have drunk water with nitrate nitrogen concentration exceeding 10 mg/L and suffered no ill effects. Susceptibility varies and is influenced by several physiological features of early infancy.

Nitrogen-containing materials from waste-disposal sites, septic systems, livestock wastes, and agricultural fertilizers have been implicated in many cases of high nitrate-nitrogen concentrations in ground water, and may be a major source of nitrate contamination, especially in shallow wells (Delfino, 1977, p. 28).

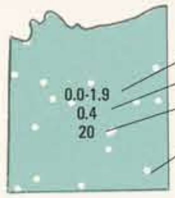
Wells yielding water with nitrate-nitrogen concentration exceeding 10 mg/L are scattered throughout the State, but the incidence of high nitrate-nitrogen concentrations may be higher in areas subject to local ground-water contamination by nitrogen- containing materials. Mean nitrate-nitrogen concentrations were 10 mg/L or greater in 56 (2.9 percent) of the 1,903 wells.

SUMMARY BY AQUIFER OF NITRATE-NITROGEN CONCENTRATIONS IN WISCONSIN'S GROUND WATER

(All concentration values in milligrams per liter)

		AQUIFER		
		Sand and gravel	Silurian dolomite	Sandstone
Maximum concentration		41	21	34
Minimum concentration		0.0	0.0	0.0
Mean concentration		2.2	1.0	1.8
Number of wells		693	296	914
Percent of wells where indicated concentration value was equaled or exceeded	10%	6.0	3.0	5.5
	25%	3.0	0.6	2.2
	50%	0.6	0.2	0.5
	75%	0.1	0.0	0.1
	90%	0.0	0.0	0.0

EXPLANATION



Nitrate as nitrogen, in milligrams per liter

Minimum-Maximum concentration

Mean concentration

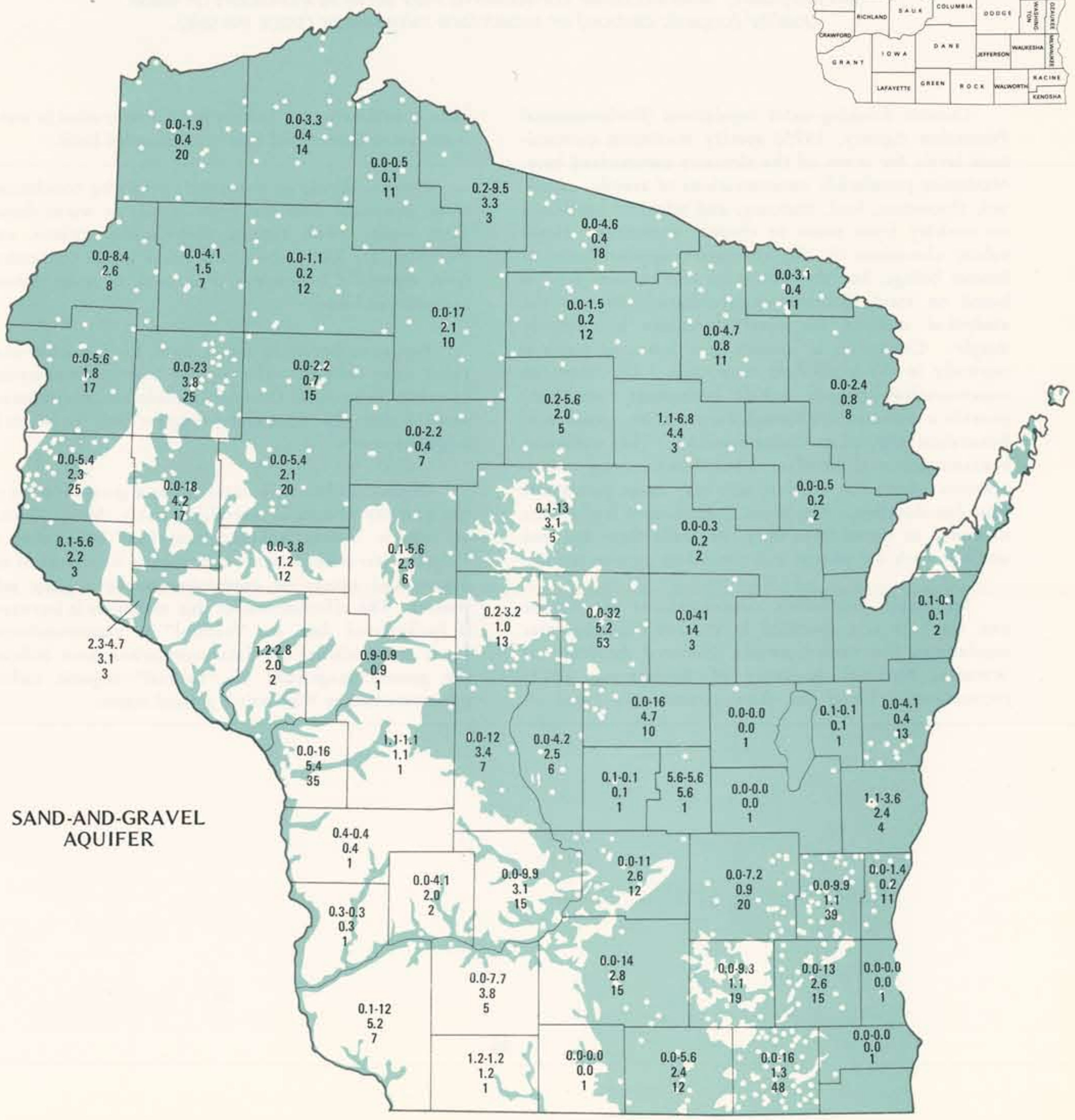
Number of wells

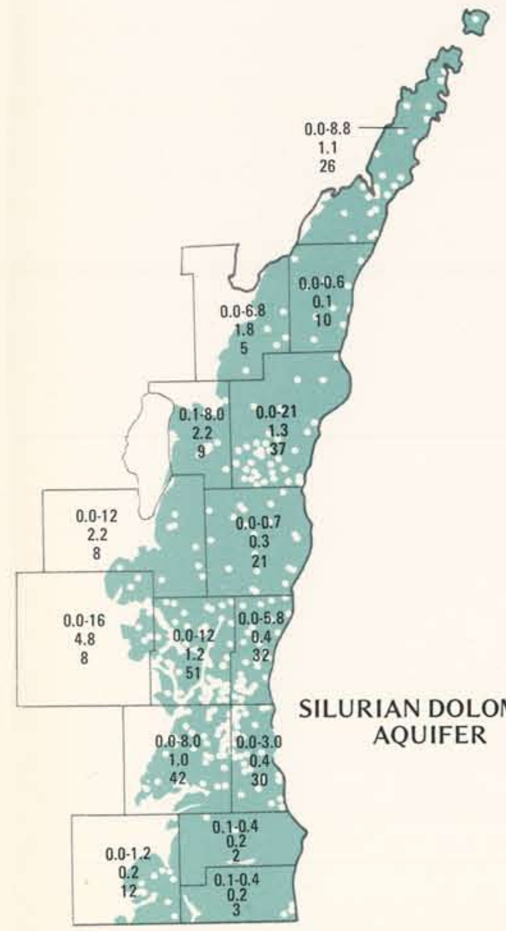
Location of sampled well

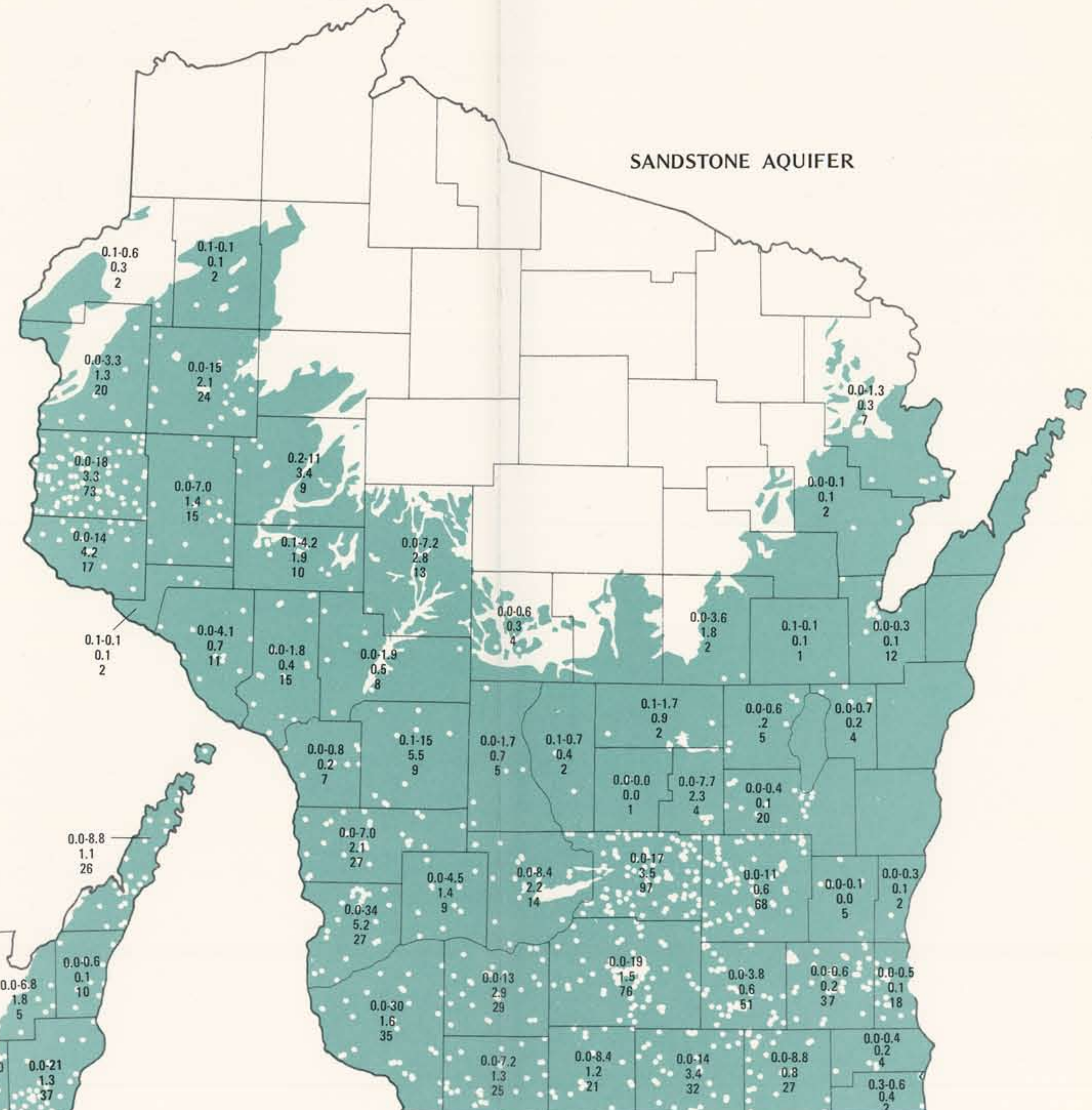
Color indicates area where aquifer is present

0 20 40 60 80 100 120 MILES

0 20 40 60 80 100 120 140 160 180 KILOMETERS







SUMMARY OF NITRATE CONCENTRATIONS

3.0 GROUND-WATER-QUALITY DATA--Continued

3.2 Common inorganic constituents--Continued

3.2.10 Nitrate

Trace Constituents may be of Considerable Importance in Spite of their Small Concentrations

Trace constituents summarized here include metals (cadmium, chromium, cobalt, copper, lead, mercury, nickel, selenium, silver, and zinc), nonmetals (arsenic and boron), and organic carbon. The presence in water of even small concentrations of some of these constituents may limit the usefulness of the water for certain purposes, whereas other constituents may serve as indicators of water quality (organic carbon) or subsurface mineralogy (trace metals).

Current drinking-water regulations (Environmental Protection Agency, 1975) specify maximum contaminant levels for seven of the elements summarized here. Maximum permissible concentrations of arsenic, cadmium, chromium, lead, mercury, and selenium are based on toxicity from acute or chronic exposures. Hexavalent chromium is the chromium species toxic to human beings, but the maximum contaminant level is based on total chromium concentration because the analytical method for total chromium is relatively simple. Chromium in aerobic or chlorinated water is normally in the hexavalent state; thus, total chromium concentrations (which include hexavalent chromium) provide a reasonable, although conservative, estimate of hexavalent chromium concentrations. The maximum contaminant level for silver is based on cosmetic considerations. Ingestion of silver salts may cause permanent skin discoloration. Maximum contaminant levels were exceeded in water from only five wells--three for lead and one each for arsenic and chromium concentrations.

Maximum permissible concentrations for copper and zinc are not specified in current drinking-water regulations, but earlier criteria (National Academy of Sciences, National Academy of Engineering, 1973) recommended limits for these constituents based on taste considerations. The copper concentration in water from one well exceeded this recommended limit.

Caution should be exercised in drawing conclusions from analytical data for trace metals in water drawn from wells. Well casings, distribution systems, and plumbing are likely sources of trace metal contamination, especially for copper, zinc, and, to some extent, cadmium and lead.

Excessive boron in water used for irrigation may cause crop damage. The highest boron concentration found in water from the wells included in this summary was less than the recommended upper limit for boron in irrigation water.

Organic carbon concentration is a gross measure of the quantity of organic material in water. Measurements of organic carbon concentration have been used in various water-pollution investigations as indicators of the degree and extent of contamination by organic substances. The effectiveness of this technique is increased if background data for "natural" or uncontaminated water are available; the data summarized here indicate the general magnitude of "natural" organic carbon concentrations in Wisconsin's ground water.

4.0 NEEDS FOR DATA ON GROUND-WATER QUALITY

Future Investigations of Ground Water Quality may be Directed toward Describing the Relation between Water Quality, Water Movement, and the Hydrogeologic Environment

It is not possible to know the concentration of a particular constituent at every point in an aquifer. Because of this, a thorough ground-water quality investigation must provide water-quality data as well as the supporting hydrogeologic information needed to use these data for estimating water quality throughout the aquifer.

The usefulness of available data on ground-water quality can be increased by relating these data to available hydrogeologic data, including aquifer characteristics and the local and regional flow systems tapped by each well where water-quality data are available. As this is done, specific needs for additional water-quality and hydrogeologic data necessary to define local and regional relations between water quality and hydrogeology become apparent.

With proper planning, most ground-water investigations can provide data useful for describing the relation of ground-water quality to the hydrogeologic environment.

5.0 LITERATURE CITED

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