NATURAL GROUND-WATER QUALITY IN MICHIGAN, 1974-87

By T. Ray Cummings

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CONVERSION FACTORS

Inch-pound units can be converted to metric (International System) units as follows:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
inch (in)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
pound (lb)	453.6	gram (g)

Temperature

Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the following formula:

$$°C = (°F - 32)\ 11.8$$

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ABSTRACT

Wide variations occur in the chemical and physical characteristics of natural ground waters in Michigan. Dissolved-solids concentrations range from 20 to 76,000 milligrams per liter. Waters having low dissolved-solids concentrations are calcium bicarbonate-type waters. Sodium, sulfate, and chloride concentrations increase as mineralization increases. Iron, aluminum, and titanium concentrations are higher at some locations than is common in most natural waters. Lead concentrations exceed those considered suitable for drinking water at some locations in the northern part of the Lower Peninsula. Generalized areal patterns of water quality variation indicate that geology is a primary cause of differences across the State. Examples of chemical associations in water indicate that chemical analyses may be valuable in tracing and identifying mineral deposits.

INTRODUCTION

Information on the natural[1] chemical and physical characteristics of ground water, particularly with respect to substances that occur in trace amounts, does not meet needs in Michigan and in other parts of the nation. Such information is essential for establishing baseline conditions against which long-term changes in water quality can be judged, and for properly evaluating the degree and severity of contamination when it occurs. In addition to supporting management decisions relating to the protection of the water resource, a better definition of natural water quality is necessary for studies of the significance and relation of the geochemical environment to human health and disease. Water-quality information is also important in the identification and development of mineral resources. As economically important minerals become scarce, and as their value increases, chemical analyses of ground water will likely be used even more frequently for this purpose.

In 1974, the Geological Survey Division of the Michigan Department of Natural Resources and the U.S. Geological Survey began a cooperative program to investigate the natural characteristics of water in aquifers in the State. The program is a continuing one in which carefully selected wells are sampled each year. New wells are also drilled to the principal aquifers to monitor both water quality and water levels. The design and construction of these wells is such that they are suitable as long-term observation sites. Site selection is made in all cases so as to avoid known, or even suspected, contamination. Seventeen new wells have been installed specifically for the investigation. Since 1974, 210 wells have been sampled. Information obtained through this program is the basis of this report.

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[1] The term "natural" is used to characterize water exhibiting no readily detectable modification by human activity. It is probable that few, if any, of the ground waters normally sought as supplies are completely free of all cultural influence.

Purpose and Scope

This report updates a preliminary report on chemical and physical characteristics of natural ground waters in Michigan (Cummings, 1980). Although substantial amounts of information have been collected since 1980, definitive statements about waters from many sources and at many locations remain impossible. Interpretations are thus intended to illustrate the direction that studies might take as information accumulates from the continuing program. For this study, maximum and minimum values of individual substances and properties have been determined, as well as how frequently values of a given magnitude may be expected. Water-quality characteristics have been related to geologic source, areal variations identified if possible, and geochemical associations noted. Chemical analyses from other data programs or sources have not been used in this evaluation, largely because it seemed preferable to confine the study to data collected using uniform procedures and techniques, and because no prior analyses for some substances are available.

Methods of Investigation

In conjunction with the Michigan Geological Survey, available information on wells was reviewed each year to select possible wells for sampling. Geologic source, well location, and the probability of obtaining representative water from an aquifer were considered in the selection. Wells were pumped from 1/2 to 1-1/2 hours before sample collection. While at the well site, specific conductance, pH, and temperature were measured. Filtration, treatment, or chilling was also done at the site, as appropriate.

Laboratory analyses of 86 substances or properties generally were made. The major anions and cations, trace metals, pesticides, and other substances of particular significance were included in analytical work. Analyses for bismuth, gallium, germanium, tin, titanium, and zirconium where deleted from the analytical scheme when laboratory costs became prohibitive in 1980. Three hundred eight samples were collected, 98 of which were collected when wells were resampled. The second sample was obtained from some wells when the results of analysis was questionable, or to confirm an unusual quality characteristic. Other wells have been resampled at 5- year intervals to monitor changes in water quality. Analyses of water from nine wells have not been used in this study because, in the author's judgment, modification of natural water quality is detectable. If trace amounts of pesticides were detected, the entire analysis was eliminated from the data. This occurred in seven instances. In tabulating maximum and minumum values, 299 analyses have been used. For all other evaluations of data, only one analysis of water from a well has been used to prevent distortions in mean, median, and frequency computations. Thus, most conclusions are based on analyses of 201 samples. Complete chemical analyses of water from each well and exact well locations have been published in annual reports by Huffman (1979a,b, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1988) and by Huffman and Whited (1988). These reports, available from the U.S. Geological Survey in Lansing, may be inspected for more complete and specific information. A description of laboratory methods used by the U.S. Geological Survey in the analysis of samples is given in Barnett and Mallory (1971), Fishman and

Friedman (1985), Thatcher and others (1977), Friedman and Erdmann (1982), and Wershaw and others (1983).

Samples were obtained from wells in 77 of Michigan's 83 counties at locations distributed throughout the State. Geologically, water samples were obtained from 45 different glacial and bedrock deposits. (See Appendix.) If no firm characterization of the composition or texture of glacial deposits could be made, the source of water has been identified as "Glacial deposits, undifferentiated."

GENERAL WATER-QUALITY CONDITIONS

Considerable variation occurs in the quality of ground water from place to place throughout the State. Table 1 lists the maximum and minimum values for all substances and properties other than pesticides. Maximum and minimum dissolved-solids concentrations differ by a factor of about 3,000-4,000, due to the occurrence of natural brines at some locations. The concentrations of most individual substances are within the range common for ground waters, with the exception of those of iron, aluminum, and titanium. The maximum concentrations of each were: iron, 150,000 μg/L (micrograms per liter); aluminum, 44,000 μg/L; and titanium, 3,600 μg/L.

Waters having a low dissolved-solids concentration generally are calcium bicarbonate-type waters--that is, the calcium constitutes more than 50 percent of the cations and bicarbonate constitutes more than 50 percent of the anions. As the dissolved-solids concentration of a typical water increases, the proportion of sodium, sulfate, and chloride increases. Figure 1 illustrates generalized changes in chemical composition as dissolved-solids increases from 100 to about 2,000 mg/L (milligrams per liter).

Sulfate and chloride increase most rapidly as dissolved solids increase, accompanied by a proportional decrease in bicarbonate. A decrease in calcium is balanced by a corresponding increase in sodium. Magnesium does not change appreciably. Natural brines are predominately sodium chloride-type waters.

In general, the concentrations of major dissolved substances increase as dissolved solids increase. Concentrations of most trace substances, however, seem to be unrelated to the dissolved-solids concentration of the water. For example, no correlation was detected between dissolved-solids concentration and aluminum, barium, boron, cadmium, chromium, copper, iron, lead, manganese, nitrogen, silica, titanium, vanadium, uranium, or zinc when the dissolved-solids concentration was less than 2,000 mg/L. Strontium, an exception, does increase as dissolved solids increase. Brines, however, commonly have higher concentrations of most trace substances.

Specific conductance, which is a measure of the ability of water to conduct an electrical current, is frequently used to estimate dissolved-solids concentration. The relation of dissolved solids to specific conductance is determined by the amount and type of substances in solution. Generally, water composed predominately of divalent ions will have a dissolved solids-specific conductance ratio greater than a water composed predominately of univalent ions. Figure 2 shows the relation of specific conductance and dissolved-solids concentration based on samples collected for this study.

Polychlorinated biphenyls, polychlorinated napthalenes, and 24 pesticides were determined on each sample. Analyses were made for each

Table 1.--Maximum and minimum values of chemical and physical characteristics of ground water

[mg/L is milligrams per liter. µg/L is micrograms per liter. < means less than]

Constituent or property	Maximum	Minimum
Alkalinity (mg/L as $CaCO_3$)	484	7
Aluminum, total recoverable (µg/L as Al)	44,000	<10
Arsenic, total (µg/L as As)	61	0
Barium, total recoverable (µg/L as Ba)	4,100	8
Beryllium, total recoverable (µg/L as Be)	30	0
Bicarbonate (mg/L as HCO_3)	590	8
Bismuth, total (µg/L as Bi)	<40	<1
Boron, total recoverable (µg/L as B)	2,800	0
Cadmium, total recoverable (µg/L as Cd)	21	0
Calcium, dissolved (mg/L as Ca)	1,300	2.4
Carbon, organic dissolved (mg/L as C)	28	<.1
Carbon dioxide, dissolved (mg/L as CO_2)	187	<.1
Carbonate (mg/L as CO_3)	24	0
Chloride, dissolved (mg/L as Cl)	50,000	.4
Chromium, total recoverable (µg/L as Cr)	180	0
Cobalt, total recoverable (µg/L as Co)	50	0
Color (platinum cobalt units)	500	0
Copper, total recoverable (µg/L as Cu)	1,900	0
Cyanide, total (mg/L as CN)	.06	.00
Fluoride, dissolved (mg/L as F)	2.0	<.10
Gallium, total (µg/L as Ga)	<20	<1
Germanium, total (µg/L as Ge)	<50	<1
Hardness (mg/L as $CaCO_3$)	5,300	9
Hardness, noncarbonate (mg/L as $CaCO_3$)	5,200	0
Iron, dissolved (µg/L as Fe)	23,000	0
Iron, total recoverable (µg/L as Fe)	150,000	<10
Lead, total recoverable (µg/L as Pb)	500	0
Lithium, total recoverable (µg/L as Li)	290	0
Manganese, dissolved (µg/L as Mn)	710	0
Manganese, total recoverable (µg/L as Mn)	1,100	0
Magnesium, dissolved (mg/L as Mg)	510	0.4
Mercury, total recoverable (µg/L as Hg)	2.1	<.10
Molybdenum, total recoverable (µg/L as Mo)	40	0
Nickel, total recoverable (µg/L as Ni)	50	0
Nitrogen, total (mg/L as N)	7.6	<.01
Nitrogen, ammonia, total (mg/L as N)	9.2	.00
Nitrogen, nitrate, total (mg/L as N)	7.0	.00
Nitrogen, nitrite, total (mg/L as N)	.21	.00

Table 1.--Maximum and minimum values of chemical and physical characteristics of ground water--Continued

Constituent or property	Maximum	Minimum
Nitrogen, organic, total (mg/L as N)	4.5	0.00
pH (units)	9.5	6.0
Phenols (μg/L)	250	0
Phosphorus, total (mg/L as P)	.59	.00
Phosphorus, ortho, total (mg/L as P)	.46	.00
Potassium, dissolved (mg/L as K)	120	.1
Selenium, total (μg/L as Se)	10	0
Silica, dissolved (mg/L as SiO_2)	26	.3
Silver, total recoverable (μg/L as Ag)	13	0
Sodium, dissolved (mg/L as Na)	28,000	.5
Solids, residue at 180°C, dissolved (mg/L)	76,000	20
Solids, sum of constituents, dissolved (mg/L)	80,200	23
Specific conductance (microsiemens)	158,000	37
Strontium, total recoverable (μg/L as Sr)	39,000	10
Sulfate, dissolved (mg/L as SO_4)	1,200	.7
Temperature (deg C)	18.5	6.0
Tin, total recoverable (μg/L as Sn)	<40	<1
Titanium, total (μg/L as Ti)	3,600	0
Tritium, total (pCi/L)	470	13
Turbidity (FTU)	220	.10
Uranium, dissolved, extraction (μg/L as U)	11	.01
Vanadium, total (μg/L as V)	52	0
Zinc, total recoverable (μg/L as Zn)	47,000	0
Zirconium, total (μg/L as Zr)	80	<1

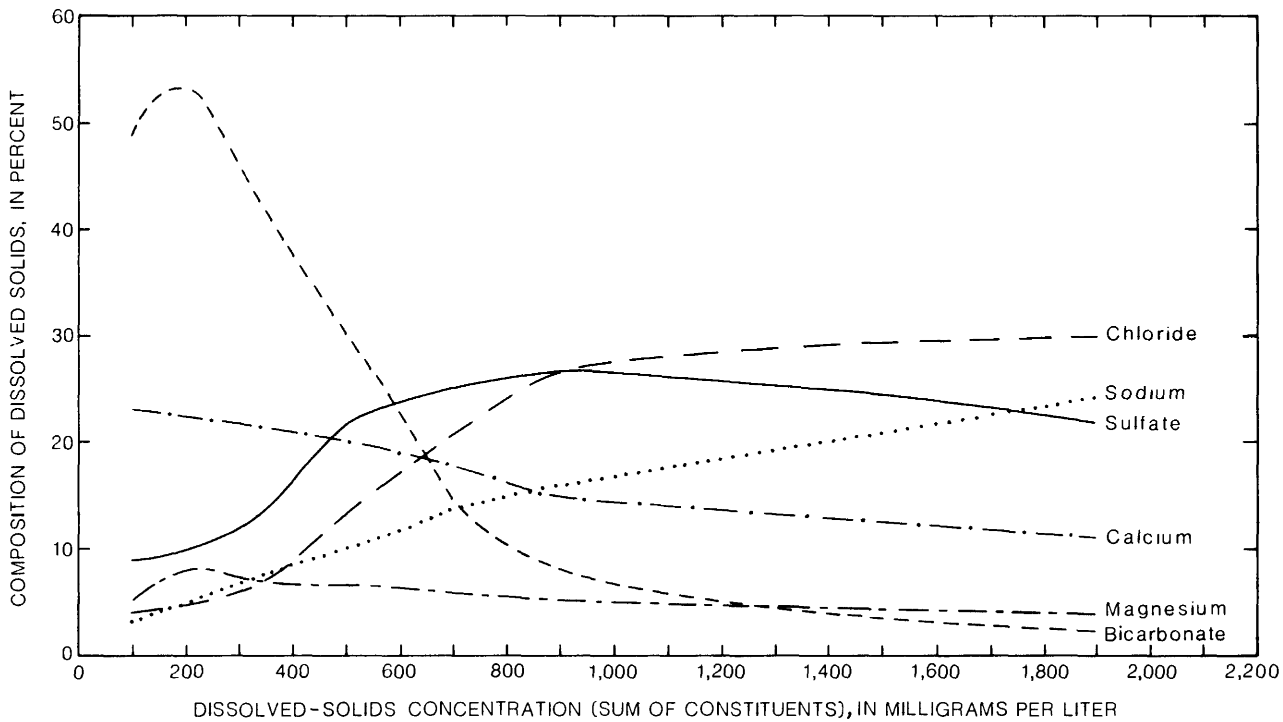

Figure 1.--Relation of dissolved-solids concentration to chemical characteristics of water.

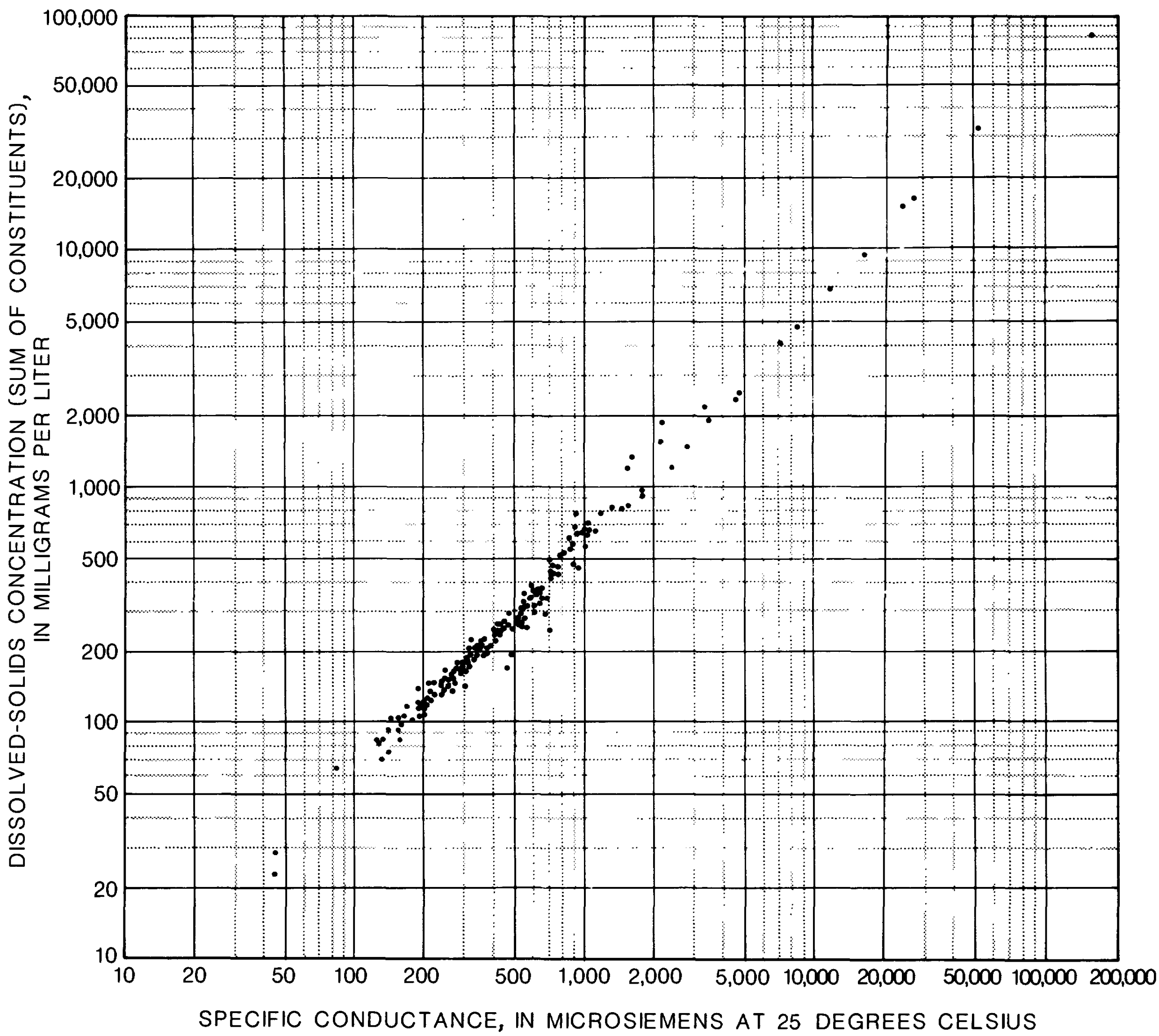

Figure 2.--Relation of specific conductance to dissolved-solids concentration of water.

of the following substances from 1974 to 1984:[2]

Aldrin	Malathion
Chlordane	Methoxychlor
DDD	Methyl parathion
DDE	Methyl trithion
DDT	Parathion
Diazinon	Silvex
Dieldrin	Trithion
Endosulfan	Toxaphene
Endrin	2,4-D
Ethion	2,4-DP
Heptachlor	2,4,5-T
Heptachlor epoxide	Polychlorinated napthalenes
Lindane	Polychlorinated biphenyls (PCB)

Pesticides were detected in water from seven wells. Water from these wells contained trace amounts of PCB, DDD, 2,4-D, 2,4-DP, 2,4,5-T, and Diazinon. In most instances, concentrations were less than 0.1 μg/L. Resampling and analysis of water from three of the wells showed no detectable pesticide levels. Other chemical characteristics of water from these wells indicated, however, that the water was not representative of natural conditions, and thus the analyses were not included in data summarized in this report.

Frequency distributions showing the percentage of ground waters having a value equal to or less than a specified amount were prepared for most substances and properties. Values occurring at the 10, 25, 50, 75, and 90 percentiles were determined (table 2).[3] Results indicate how often values of a given magnitude may be expected in uncontaminated ground waters of Michigan, and thus provide a preliminary basis for judging the modification of water-quality characteristics. For example, 10 percent of the chloride concentrations are equal to or less than 0.8 mg/L; 90 percent of the concentrations are equal to or less than 270 mg/L. Similarly, nitrate, which in high concentration commonly indicates contamination, is equal to or less than 0.59 mg/L in 90 percent of the waters.

A comparison of frequency data to drinking water regulations of the U.S. Environmental Protection Agency (1986a,b) is shown in table 3. Both maximum contaminant levels for inorganic chemicals and secondary maximum contaminant levels were referred to frequency curves and the percentage of time the level was equaled or exceeded determined. Lead concentrations exceeded the 50 μg/L maximum contaminant level in 6.9 percent of the ground

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[2] Beginning in 1985, analyses for 2,4-D, 2,4-DP, 2,4,5-T, and Silvex only were made.

[3] Frequency data for some substances are reported as "less than (<)" values. For these substances, low concentrations are reported by the laboratory in a qualitative manner because of the expense of precise quantitive analyses. Frequency distributions prepared for these substances represent a distribution of the most frequently reported "less than" results, and thus values given in table 2 may or may not correspond to concentrations that occur at the indicated frequency.

Table 2.--Frequency data for chemical and physical characteristics of ground water

[mg/L is milligrams per liter. µg/L is micrograms per liter. < means less than]

Constituent or property	Percent of ground waters having a value equal to or less than that indicated				
	10	25	50	75	90
Alkalinity (mg/L as $CaCO_3$)	70	105	155	212	295
Aluminum, total recoverable (µg/L as Al)	<10	10	30	60	220
Arsenic, total (µg/L as As)	<1	<1	1	2	5
Barium, total recoverable (µg/L as Ba)	<100	<100	<100	<100	100
Beryllium, total recoverable (µg/L as Be)	<1	<10	<10	<10	<10
Bicarbonate (mg/L as HCO_3)	90	130	200	270	380
Bismuth, total (µg/L as Bi)	<1	<2	<4	<7	<17
Boron, total recoverable (µg/L as B)	<10	<10	27	140	520
Cadmium, total recoverable (µg/L as Cd)	<1	<1	<1	1	4
Calcium, dissolved (mg/L as Ca)	22	34	50	75	130
Carbon, organic dissolved (mg/L as C)	.9	1.3	2.1	3.8	6.8
Carbon dioxide, dissolved (mg/L as CO_2)	1.2	2.5	5.6	11	25
Carbonate (mg/L as CO_3)	0	0	0	0	0
Chloride, dissolved (mg/L as Cl)	.8	1.3	4.4	26	270
Chromium, total recoverable (µg/L as Cr)	<20	<20	<20	<20	20
Cobalt, total recoverable (µg/L as Co)	<1	<1	<1	1	3
Color (platinum cobalt units)	<1	1	4	5	10
Copper, total recoverable (µg/L as Cu)	1	3	5	12	36
Cyanide, total (mg/L as CN)	.00	.00	.00	<.01	<.01
Fluoride, dissolved (mg/L as F)	<.1	<.1	.1	.4	.7
Gallium, total (µg/L as Ga)	<1	<1	<1	<2	<10
Germanium, total (µg/L as Ge)	<2	<3	<5	<9	<22
Hardness (mg/L as $CaCO_3$)	85	130	200	305	520
Hardness, noncarbonate (mg/L as $CaCO_3$)	0	1	12	76	289
Iron, dissolved (µg/L as Fe)	6	20	90	560	1,800
Iron, total recoverable (µg/L as Fe)	40	120	560	1,700	3,700
Lead, total recoverable (µg/L as Pb)	1	1	5	13	35
Lithium, total recoverable (µg/L as Li)	<10	<10	<10	10	40
Manganese, dissolved (µg/L as Mn)	<10	3	19	50	130
Manganese, total recoverable (µg/L as Mn)	<10	<10	22	86	170
Magnesium, dissolved (mg/L as Mg)	5.8	8.8	17	28	46
Mercury, total recoverable (µg/L as Hg)	<.50	<.50	<.50	<.50	<.50
Molybdenum, total recoverable (µg/L as Mo)	<1	<1	1	3	8
Nickel, total recoverable (µg/L as Ni)	<1	1	2	6	10

Table 2.--Frequency data for chemical and physical characteristics of ground water--Continued

Constituent or property	Percent of ground waters having a value equal to or less than that indicated				
	10	25	50	75	90
Nitrogen, total (mg/L as N)	0.02	0.15	0.29	0.71	1.1
Nitrogen, ammonia, total (mg/L as N)	<.01	<.01	.05	.19	.51
Nitrogen, nitrate, total (mg/L as N)	.00	.00	.01	.13	.59
Nitrogen, nitrite, total (mg/L as N)	<.01	<.01	<.01	<.01	.01
Nitrogen, organic, total (mg/L as N)	.00	.05	.13	.29	.63
pH (units)	7.1	7.4	7.7	7.9	8.2
Phenols (μg/L)	0	0	<1	2	5
Phosphorus, total (mg/L as P)	<.01	<.01	<.01	.01	.05
Phosphorus, ortho, total (mg/L as P)	<.01	<.01	<.01	.01	.02
Potassium, dissolved (mg/L as K)	.5	.7	1.4	2.9	6.4
Selenium, total (μg/L as Se)	<1	<1	<1	<1	<1
Silica, dissolved (mg/L as SiO_2)	5.7	7.4	11	14	18
Silver, total recoverable (μg/L as Ag)	0	<1	<1	<1	<1
Sodium, dissolved (mg/L as Na)	1.3	2.4	6.8	27	140
Solids, residue at 180°C, dissolved (mg/L)	123	159	244	430	1,250
Solids, sum of constituents, dissolved (mg/L)	114	158	240	378	934
Specific conductance (microsiemens)	191	273	426	709	1,610
Strontium, total recoverable (μg/L as Sr)	36	60	150	700	2,600
Sulfate, dissolved (mg/L as SO_4)	4.3	7.0	13	37	180
Temperature (deg C)	7.5	8.0	9.5	10.5	12.0
Tin, total recoverable (μg/L as Sn)	<1	<2	<3	<6	<10
Titanium, total (μg/L as Ti)	<1	<2	2	10	140
Tritium, total (pCi/L)	<200	<200	<200	<200	<200
Turbidity (FTU)	.2	.3	1.5	6.4	25
Uranium, dissolved, extraction (μg/L as U)	.00	.04	.14	.32	.78
Vanadium, total (μg/L as V)	0	0	<1	4	10
Zinc, total recoverable (μg/L as Zn)	<10	20	60	290	980
Zirconium, total (μg/L as Zr)	<2	<3	<5	<10	<30

Table 3.--Comparison of natural water quality to drinking water regulations of the U.S. Environmental Protection Agency

	U.S. Environmental Protection Agency Regulations (1986a,b)		Natural water quality
Contaminant	Maximum contaminant levels for inorganic chemicals	Secondary maximum contaminant levels	Percentage of values equaling or exceeding maximum level [a/]
Arsenic (As)	50 µg/L		0.5
Barium (Ba)	1,000 µg/L		1.1
Cadmium (Cd)	10 µg/L		1.6
Chloride (Cl)		250 mg/L	1.1
Chromium (Cr)	50 µg/L		1.6
Color (units)		15 units	9.4
Copper (Co)		1 mg/L	0
Fluoride (F)	4 mg/L	2 mg/L	0.5 exceed 2.0 mg/L; no values greater than 4.0 mg/L
Iron (Fe)		300 µg/L	34 (dissolved Fe) 60 (total Fe)
Lead (Pb)	50 µg/L		6.9
Manganese (Mn)		50 µg/L	22 (dissolved Mn) 31 (total Mn)
Mercury (Hg)	2 µg/L		0.5
Nitrate (NO_3 as N)	10 mg/L		0
pH (units)		6.5 to 8.5 units	3.9 exceed 8.5 units; 1.1 are less than 6.5 units
Selenium (Se)	10 µg/L		0.5
Silver (Ag)	50 µg/L		0
Sulfate (SO_4)		250 mg/L	4.3
Zinc (Zn)		5 mg/L	0
Total dissolved solids		500 mg/L	11

[a/] Calculation is based only on those waters having a dissolved-solids concentration of 1,000 mg/L or less.

waters. Iron and manganese concentrations are frequently greater than secondary maximum levels; total dissolved-solids concentration exceeded the secondary maximum level in 11 percent of the waters. Concentrations of lead, and certainly those of iron and manganese, are likely to decrease if water is treated before use. However, more frequent chemical analyses of lead are desirable when evaluating the suitability of domestic water supplies, particularly in those parts of the State where lead concentrations are highest.

AREAL VARIATIONS IN WATER QUALITY

Geologic conditions are a principal factor determining the areal variation in quality of ground water throughout the State, although differences may also be due to varying hydrologic conditions. Examples of the areal variation of some water-quality characteristics are shown in figures 3, 4, 5, and 6. Areal patterns were determined by plotting values on maps, and noting areas of similarity. In preparing these figures, only analyses of water containing 2,000 mg/L or less of dissolved solids have been used, largely because waters containing greater than 2,000 mg/L are unlikely to be used as public or domestic supplies. Dissolved-solids concentration of water tend to be highest in the central part of the Lower Peninsula (fig. 3). Many wells in this area obtain water from bedrock deposits, which normally contain more highly mineralized water. The major dissolved substances - calcium, magnesium, sodium, sulfate, and chloride - also tend to be highest in the same area. Hardness[4] of water is highest in the southeastern part of the State and at some places in the Upper Peninsula (fig. 4.)

Areal variation of ammonia is also illustrated in figure 4. The ammonia concentration of ground water has been of major significance on at least one occasion during the past several years. Plans for a fish hatchery in southeastern Michigan were abandoned when ground water was found to contain ammonia in excess of that suitable for propagation of trout. Higher ammonia concentrations are likely in the south-central and southeastern part of the State than at other locations. As information accumulates, more precise delineations of ammonia distribution may provide one of the initial bases for judging the suitability of a ground water for fish hatchery use.

Areal variation of mercury and lead is shown in figure 5. Mercury concentrations in ground water are highest in the Upper Peninsula and in the southeastern part of the Lower Peninsula. Geologic conditions in the Upper Penninsula undoubtedly contribute to the higher mercury concentrations in that area. Lead concentrations seem to be highest in the north-central part of the Lower Peninsula, where concentrations frequently approach the maximum permitted in drinking water supplies. Figure 6 shows the areal variation of iron and copper concentrations in ground water throughout the State. Iron

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[4] The U.S. Geological Survey (Durfor and Becker, 1964) has classified the hardness of water as follows: 0 to 60 mg/L, soft; 61 to 120 mg/L, moderately hard; 121 to 180 mg/L, hard; and 181 mg/L or greater, very hard. Using this classification, and based on data obtained for this study, 5 percent of the ground waters are soft, 17 percent are moderately hard, 20 percent are hard, and 58 percent are very hard.

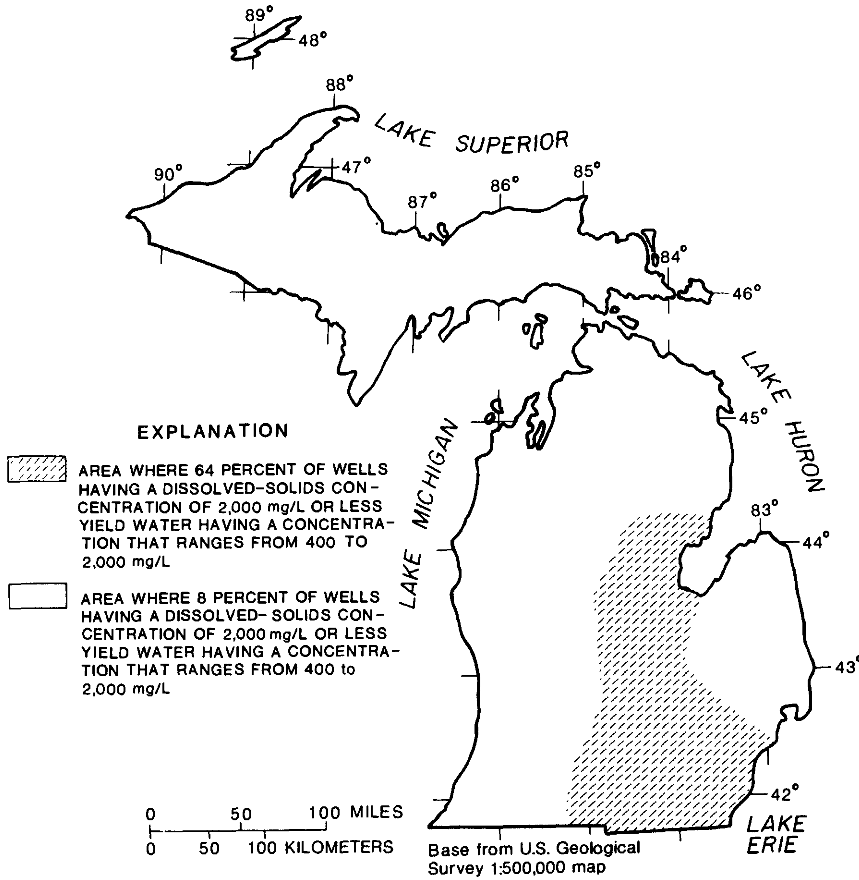

Figure 3.--Areal variation of dissolved solids in water.

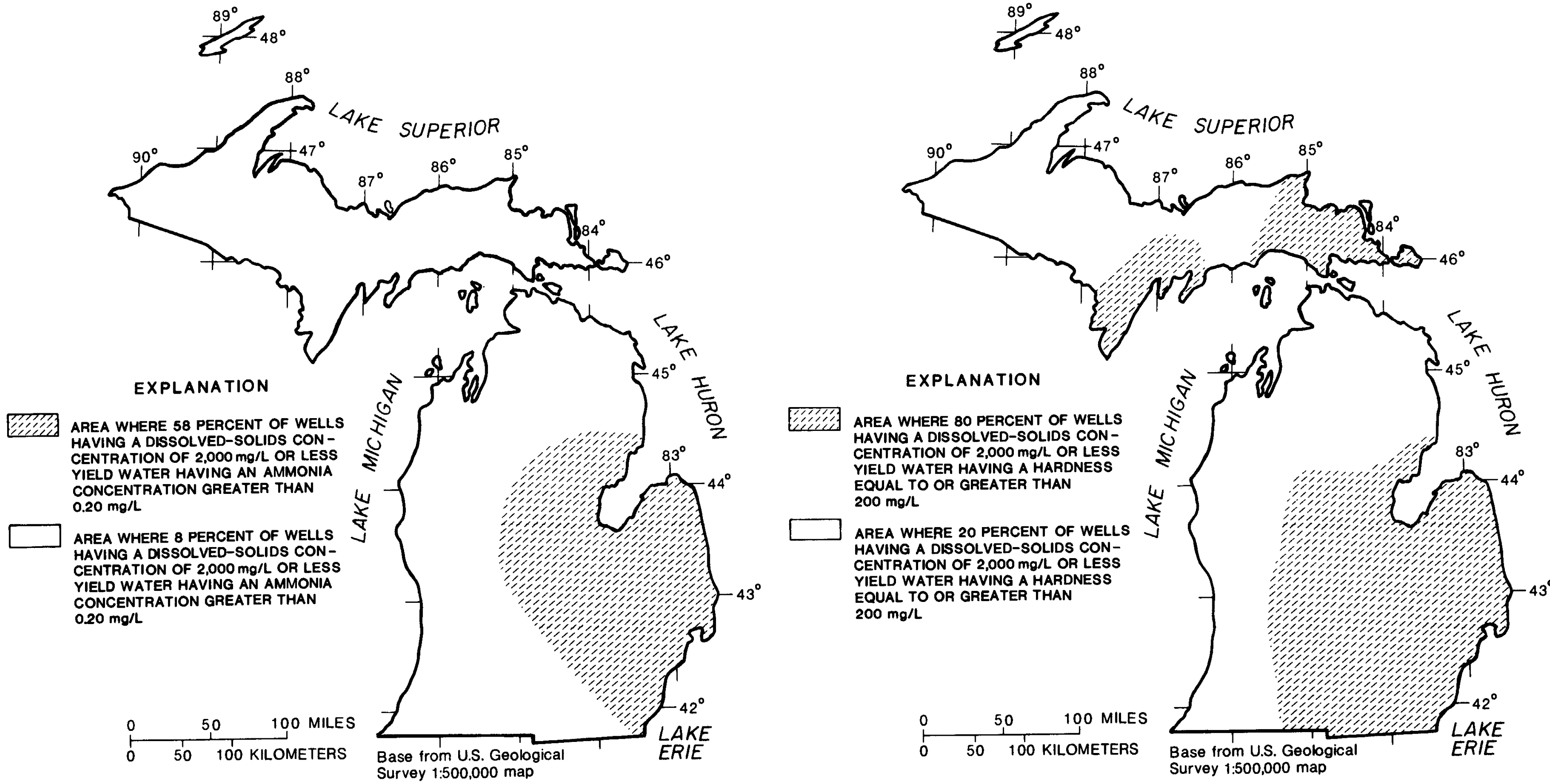

Figure 4.--Areal variation of ammonia and hardness of water.

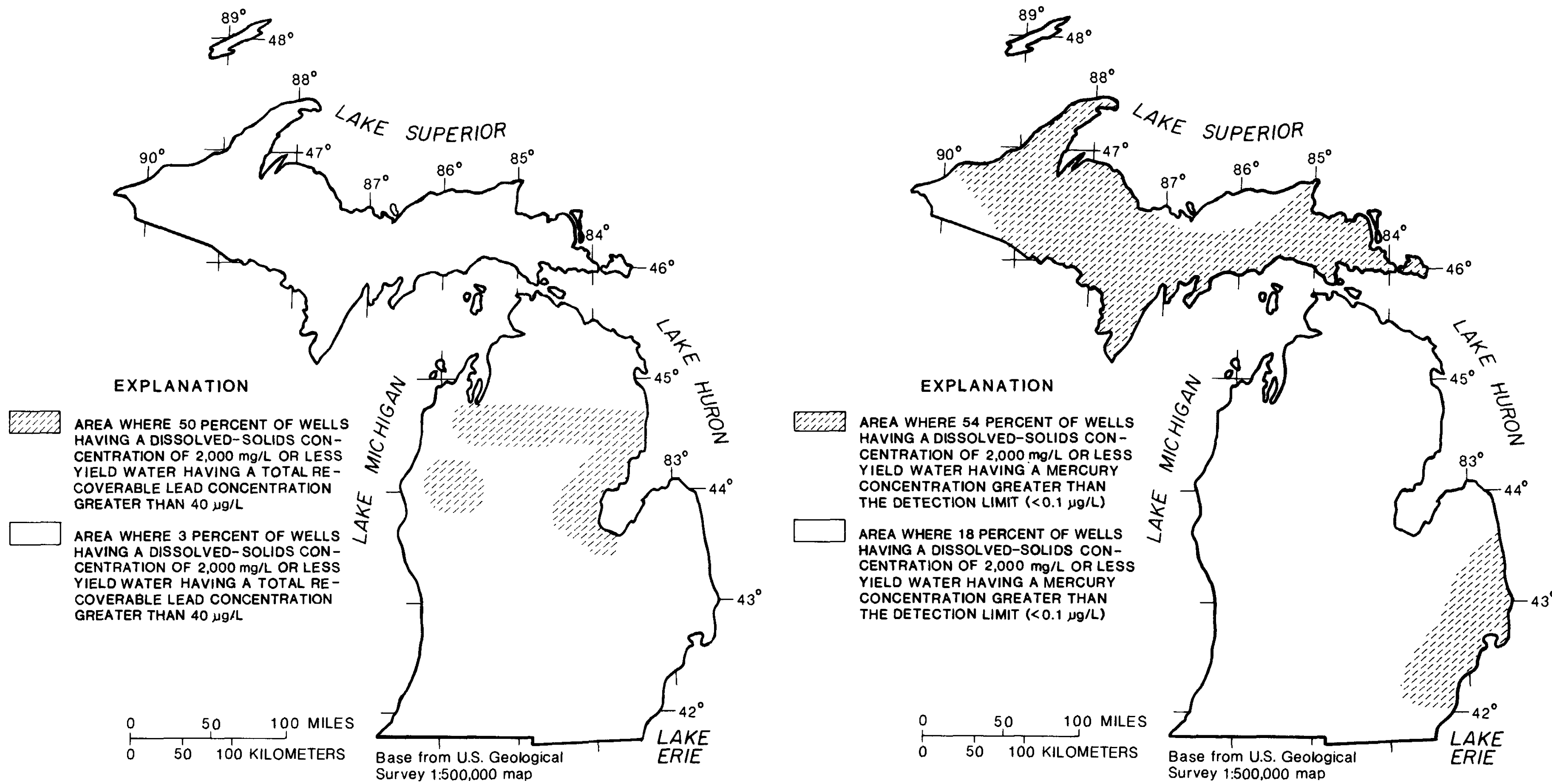

Figure 5.--Areal variation of total recoverable lead and total recoverable mercury in water.

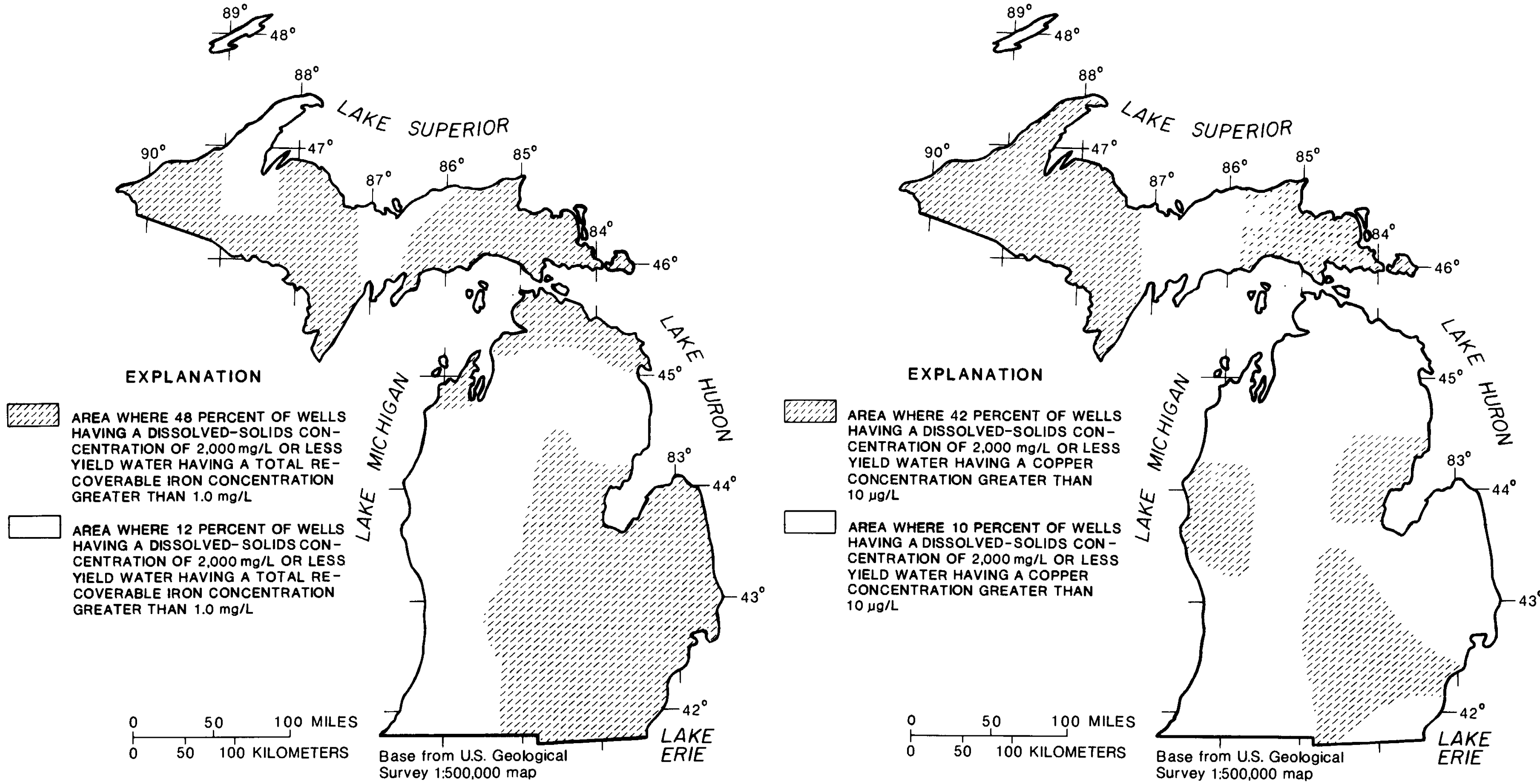

Figure 6.--Areal variation of total recoverable iron and total recoverable copper in water.

concentrations in most Michigan ground waters is higher than common in many areas of the country; copper concentrations, as might be expected because of the extensive metal deposits, is higher in the Upper Peninsula than in a large part of the Lower Peninsula.

RELATION OF WATER QUALITY TO GEOLOGIC SOURCE

Chemical analyses were made on water collected from wells tapping 8 glacial deposits (103 samples) and 37 bedrock deposits (107 samples). On the basis of lithology, 18 bedrock deposits may be classified primarily as limestone or dolomite, 9 as sandstone, 2 as limestone and sandstone, 2 as conglomerate, 2 as shale, and 1 as sandstone and shale, 2 as metamorphic (slate), and 1 as volcanic. Some of the bedrock deposits, such as the Saginaw Formation, contain sandstone, shale, limestone, and coal. The Appendix lists the median values of each chemical and physical property by geologic source. Interpretations based on the median values should be made with caution because the number of samples of water obtained from each source is different.

The average depth of wells in glacial deposits 95 ft is about a third the average depth of wells in bedrock deposits (253 ft). Although no precise correlation can be demonstrated, the mineralization of water tends to increase as depth of wells increase (fig. 7). Highly mineralized water from the Saginaw Formation, however, may occur at depths of less than 200 ft, as figure 7 indicates. The mean dissolved-solids concentration of water from glacial deposits was 266 mg/L; the mean for bedrock deposits was 2,310 mg/L (table 4). The mean for the Saginaw Formation only is 8,480 mg/L. Seventy-five percent of the maximum values given in table 1 are associated with water from bedrock deposits.

Figures 8, 9, 10, and 11 illustrate the chemical characteristics of water from each geologic source by means of bar diagrams. If sufficient analyses were available from a geologic source, waters of both high and low mineralization are illustrated.

Among glacial deposits, outwash deposits generally contain water having the highest dissolved-solids concentrations. Higher than average concentrations of some trace metals also occur in water from outwash. For example, water from one well in outwash contained 1,900 µg/L of copper, and another well contained 1,100 µg/L of manganese. Among bedrock deposits, water from the Saginaw Formation was more highly mineralized than that from other bedrock deposits. Some of the maximum concentrations of trace substances also occur in water of the Saginaw Formation. Table 4, which shows mean concentrations for selected substances in water from glacial and bedrock deposits, also shows mean concentrations computed for outwash deposits and for the Saginaw Formation.

A comparison of water from limestones and dolomites, from sandstones, and from glacial deposits identifed few distinguishing characteristics. For most substances, mean concentrations given in the Appendix do not offer sufficient evidence to form firm conclusions regarding differences in the water quality of each geologic source. Figure 12 illustrates, however, how boron and sodium are related to lithology. Highest concentrations of each occur in water in the sandstones; lowest concentrations occur in water in glacial deposits and in limestones and dolomites. Areas delineated for each deposit encompass 90 percent or more of the boron and sodium concentrations available for plotting.

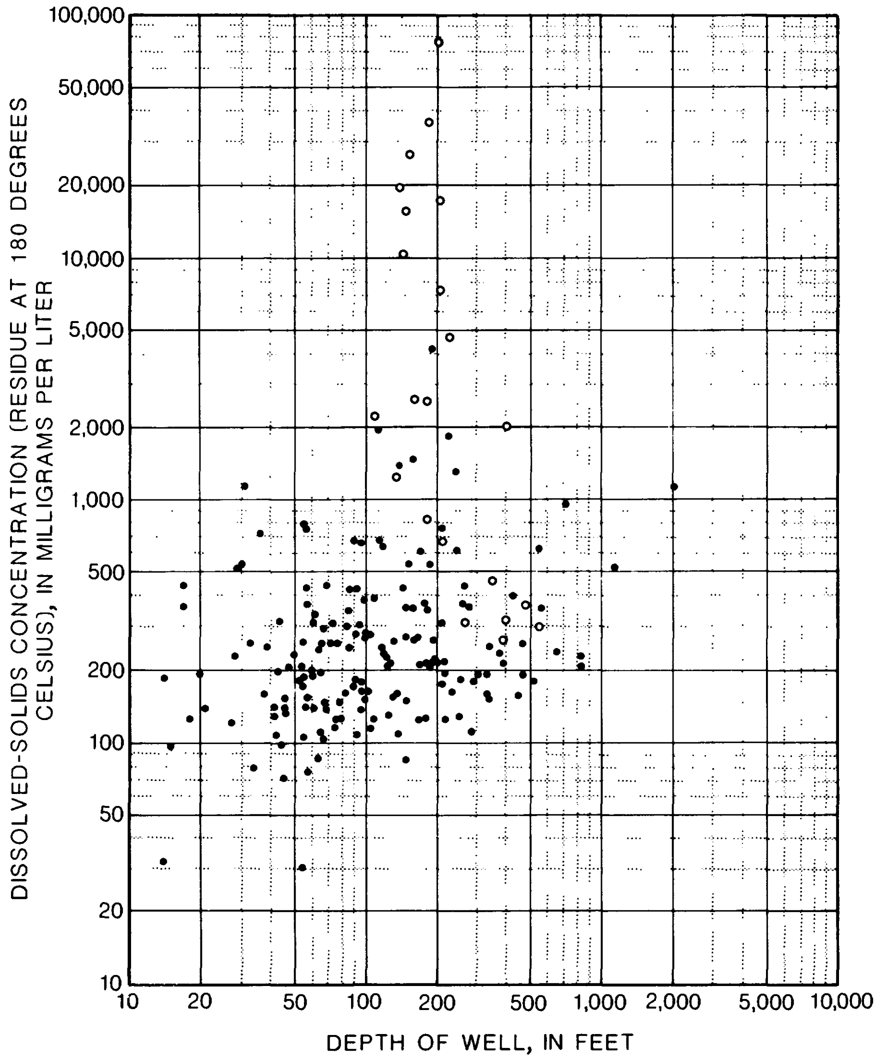

Figure 7.--Relation of depth of well to dissolved-solids concentration. (Open circles indicate Saginaw Formation.)

Table 4.--Comparison of chemical and physical characteristics of water from glacial and bedrock deposits

[mg/L is milligrams per liter. µg/L is micrograms per liter. < means less than.]

Constituent	Mean concentration			
	Glacial deposits		Bedrock deposits	
	All sources	Outwash only	All sources	Saginaw Formation only
Aluminum (µg/L)	184	149	661	2,070
Barium (µg/L)	<100	<100	121	350
Boron (µg/L)	50	89	288	700
Chloride (mg/L)	26	12	1,140	4,860
Copper (µg/L)	30	102	18	32
Hardness (mg/L)	197	241	362	780
Iron, total (µg/L)	1,340	2,780	3,280	5,040
Lithium (µg/L)	<10	<10	27	64
Manganese, total (µg/L)	68	115	82	165
Nickel (µg/L)	4.6	3.1	5.1	7.0
Nitrogen, total (mg/L)	.67	.46	.84	2.0
Potassium (mg/L)	1.3	1.2	6.2	20
Silica (mg/L)	11	11	11	9.3
Sodium (mg/L)	16	15	662	2,840
Solids (residue), dissolved (mg/L)	266	298	2,310	8,480
Strontium (µg/L)	285	384	2,130	3,220
Sulfate (mg/L)	32	68	86	146
Titanium (µg/L)	18	20	310	537
Zinc (µg/L)	225	189	1,430	5,360

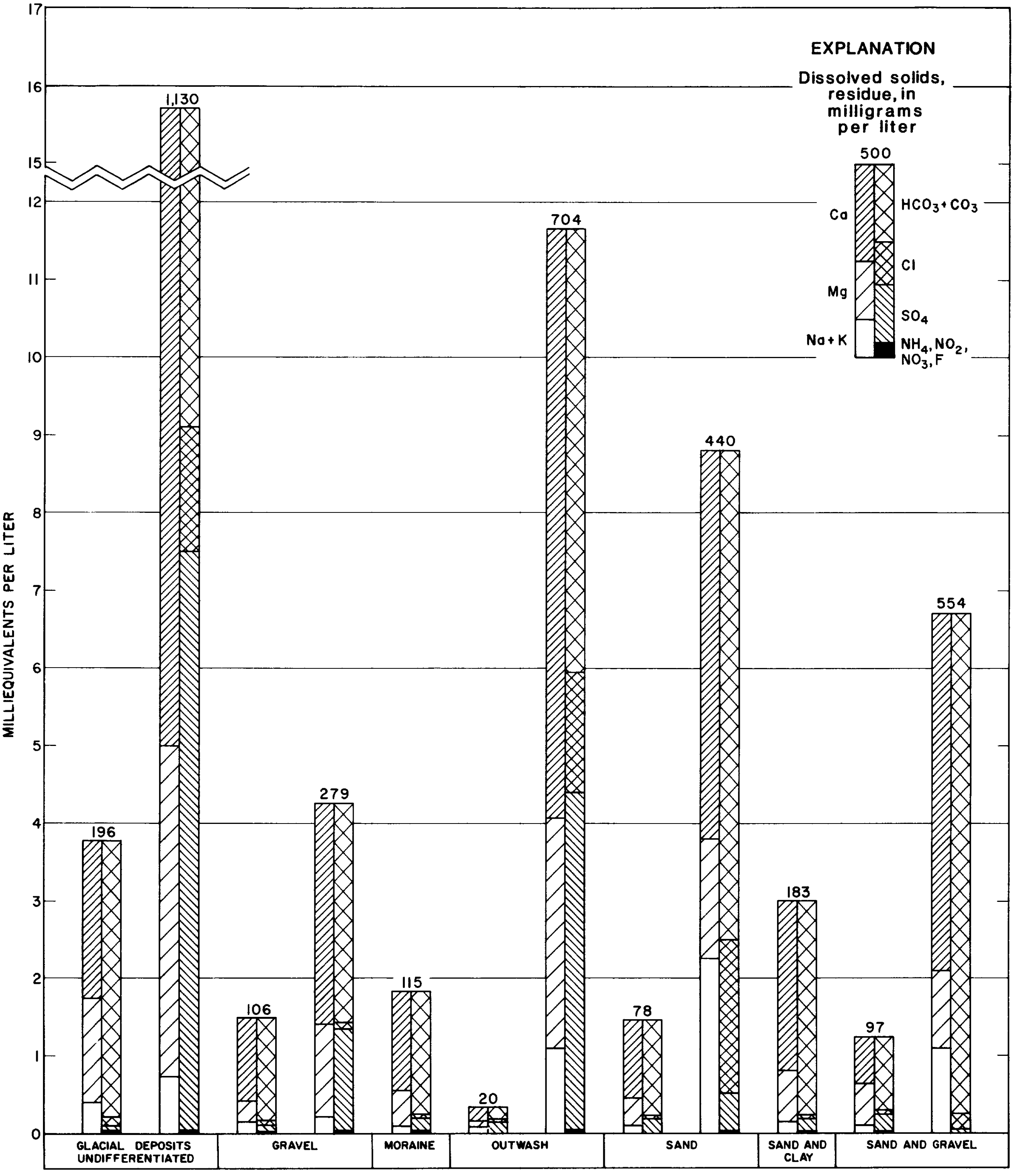

Figure 8.--Chemical characteristics of water from glacial deposits.

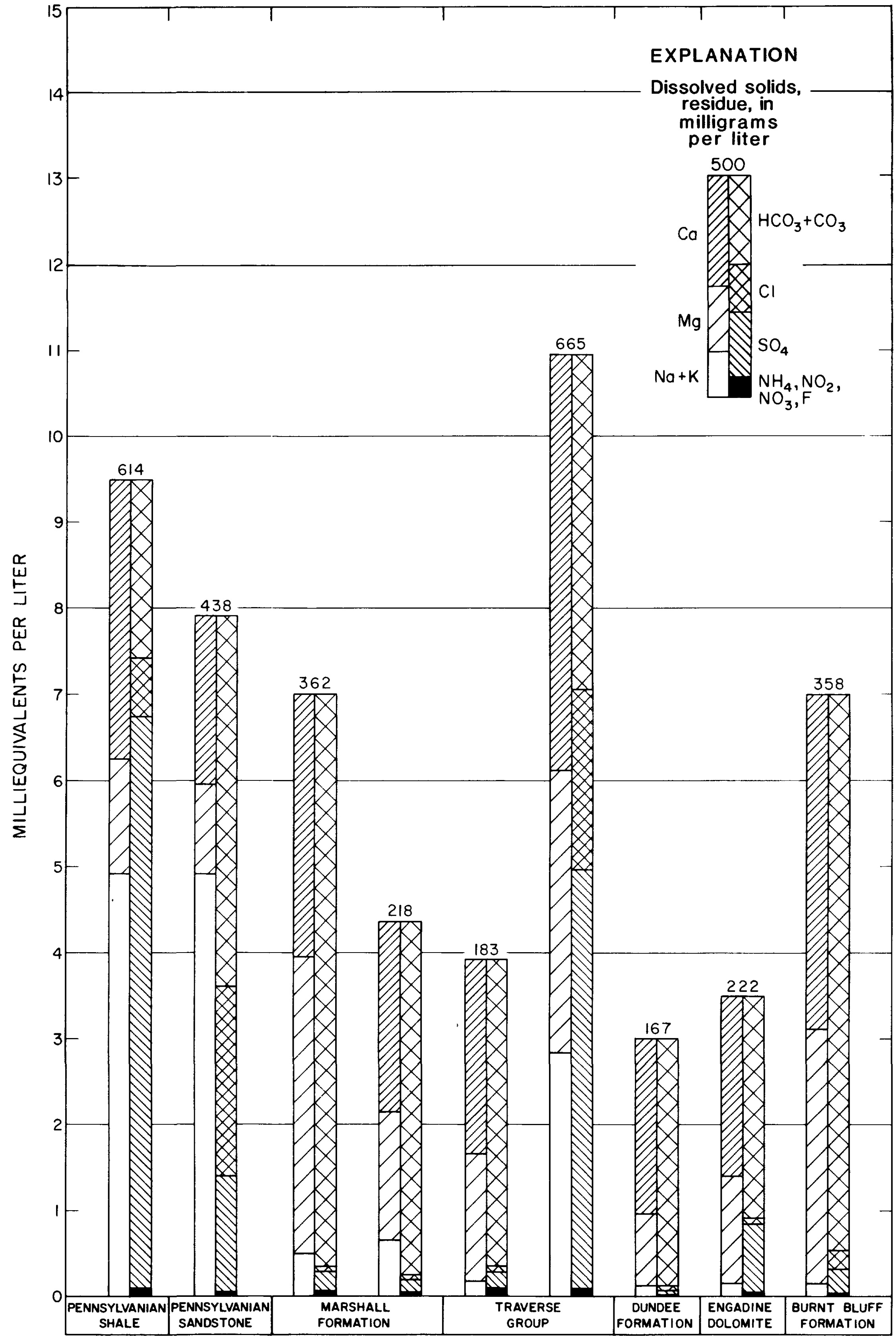

Figure 9.--Chemical characteristics of water from bedrock. (Mississippian, Devonian, and Silurian ages)

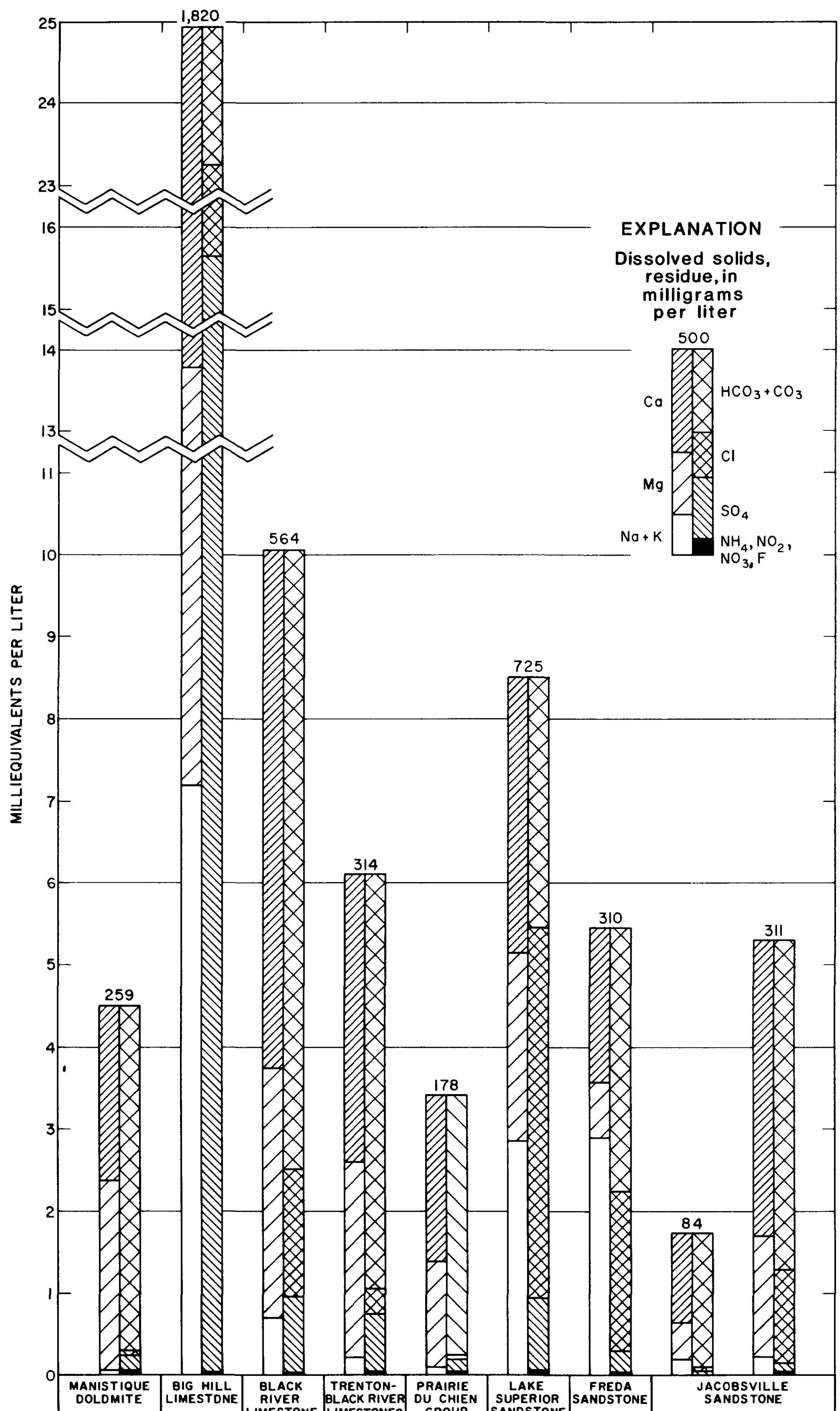

Figure 10.--Chemical characteristics of water from bedrock. (Silurian, Ordovician, Cambrian, and Precambrian ages)

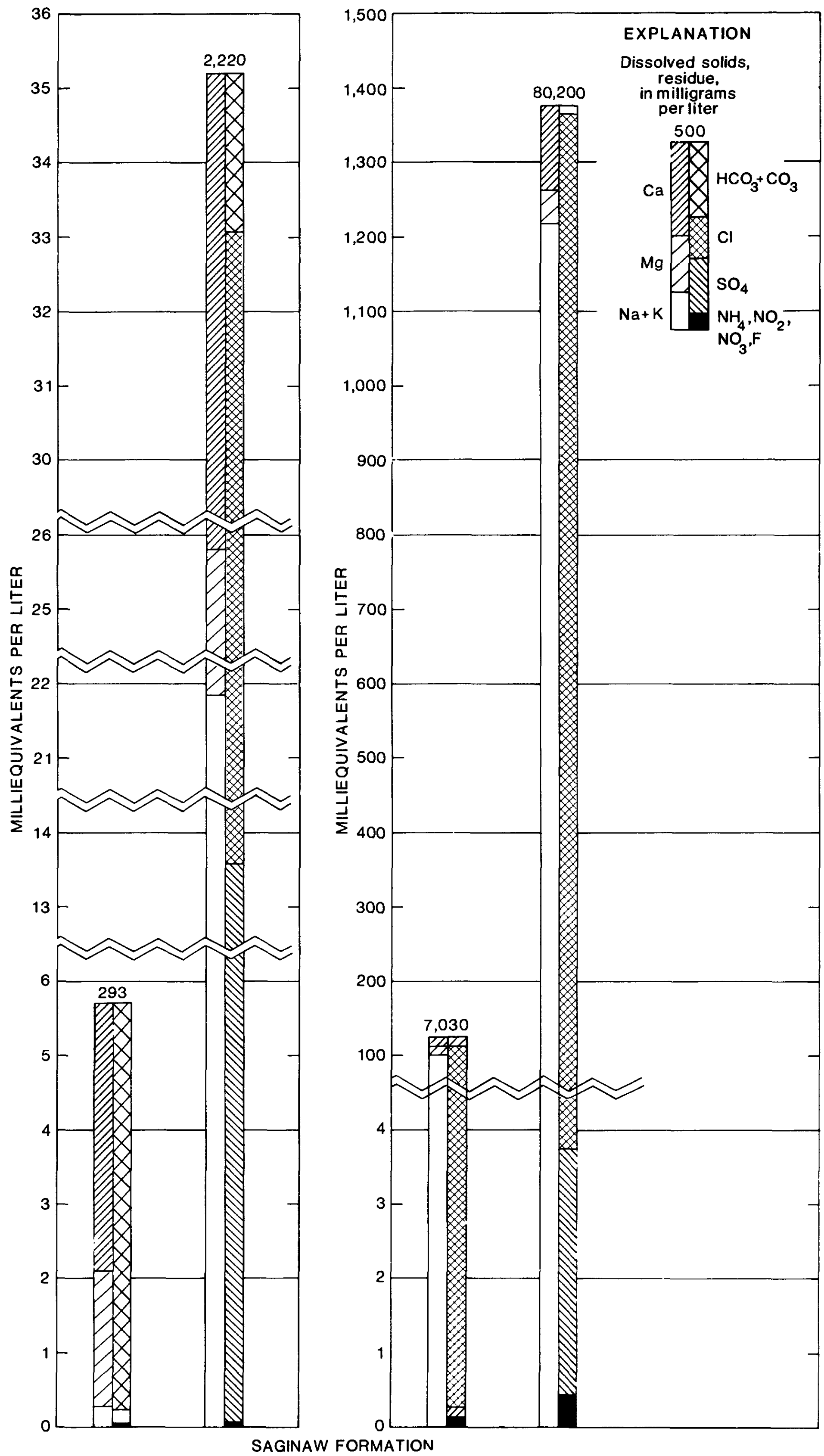

Figure 11.--Chemical characteristics of water from bedrock. (Pennsylvanian age)

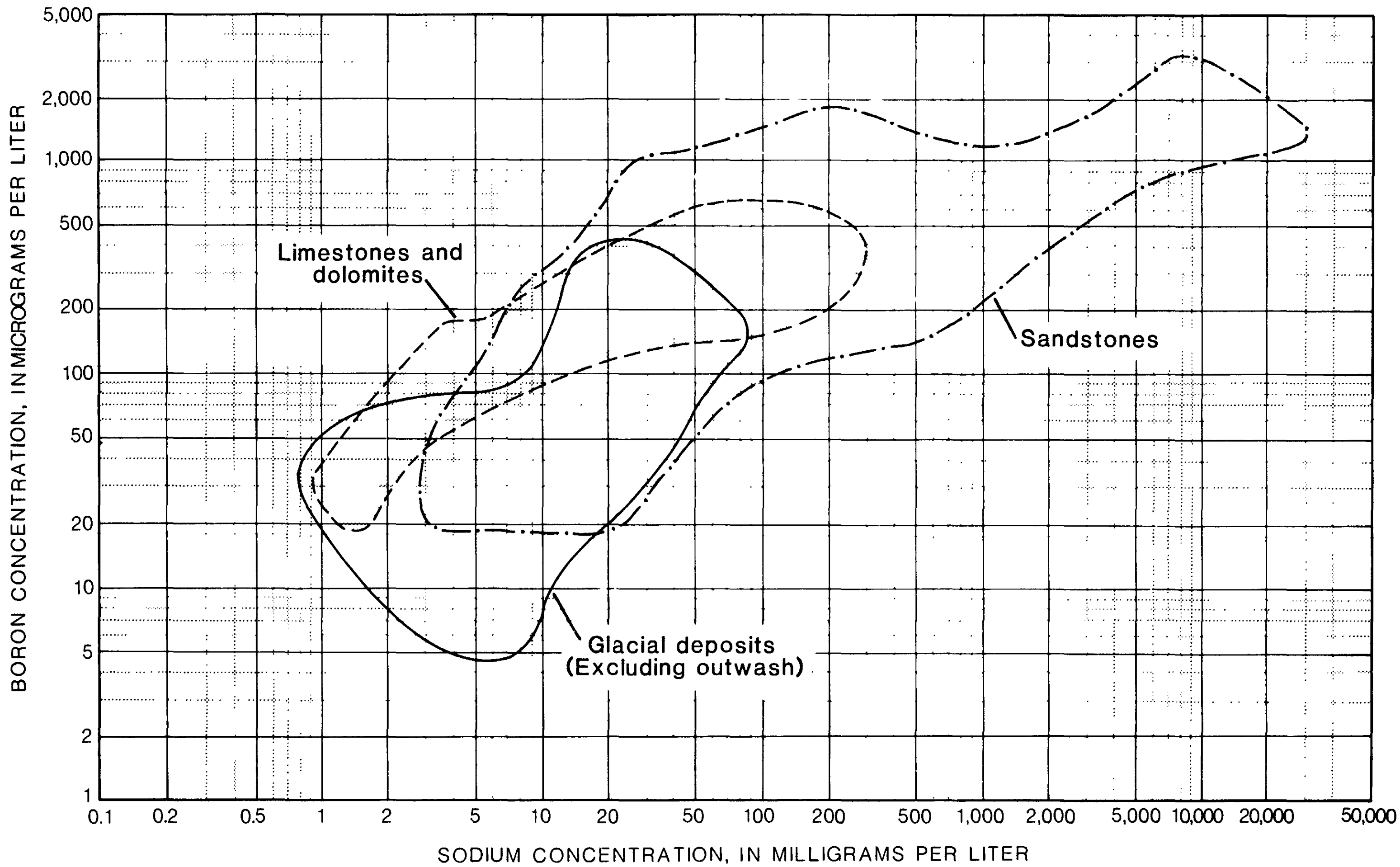

Figure 12.--Relation of boron and sodium to geologic source.

RELATION OF WATER QUALITY TO MINERAL ASSOCIATIONS

Mineral associations in geologic materials have been studied extensively. Frequently these associations are reflected in the chemical composition of water, and, for this reason, chemical analyses for trace substances serve as a prospecting tool. In the analyses of data for this report, about 40 possible relations between substances were investigated either by simple graphical correlations or by regression analysis. Because data are few and concentration ranges narrow for some substances, correlation was poor, even for some of the better known and understood associations. Extensive treatment is thus unwarranted in this report. Significant associations, involving aluminum and its relation to titanium and zirconium, are given as illustrations.

Aluminum is not commonly present in natural waters in concentrations greater than a few tenths of a milligram per liter. Its solubility is sometimes increased owing to the formation of complexes with fluoride and sulfate. Once dissolved, it rapidly hydrolyzes to aluminum hydroxide, which has a low solubility in the pH range of most natural waters. High concentrations of aluminum occur in water from several geologic sources in Michigan, and a relation between the concentration of aluminum and the composition or texture of deposits is not evident. Shale has been cited as having the highest average aluminum content among sedimentary rocks (Hem, 1972), and a well drilled in the Saginaw Formation, which is primarily sandstone and shale, did yield water having an aluminum concentration of 44,000 µg/L. Although the sample was clear when collected, much of the aluminum was probably a finely divided particulate or colloidal form. Water from the same well has a titanium concentration of 3,600 µg/L. The author is aware of only one higher concentration of titanium (5,400 µg/L), and that was found in water associated with volcanos in Kamchatka, U.S.S.R. (White and others, 1963).

A plot of titanium concentrations versus aluminum concentrations is shown in figure 13. A regression analysis of the data gave a correlation coefficient of 0.91. The relation of the two constituents seems consistent with data of Migdisov (1960) who studied the titanium/aluminum ratio of sedimentary rock samples in the U.S.S.R. Migdisov concluded, from an analysis of more than 1,900 samples, that the TiO_2/Al_2O ratio was 0.053. Expressed as a Ti/Al ratio, the value is 0.06. Figure 13 indicates that the Ti/Al ratio for Michigan ground waters ranges from about 0.1 to about 0.06. This consistency indicates that the titanium/aluminum association in Michigan ground waters is reliable and might have significance in investigating the occurrence of titanium deposits.

The relation of aluminum to zirconium in water (fig. 14) may also be of possible significance in geochemical investigations. Zirconium, like aluminum and titanium, seems to occur in concentrations higher than commonly reported. Il'ina and others (1970) found that the zirconium and titanium contents of sandstone, siltstone, and clay are related. This fact, and the apparent relation of aluminum and titanium, suggest that an aluminum-zirconium relation can be expected.

Analysis of data for this report, as well as ample geochemical literature, indicates that identification of other mineral associations may be possible as information accumulates. For example, relations between copper and titanium, manganese and iron, copper and zirconium, vanadium and iron, and boron and sodium are apparent but less definite. Further,

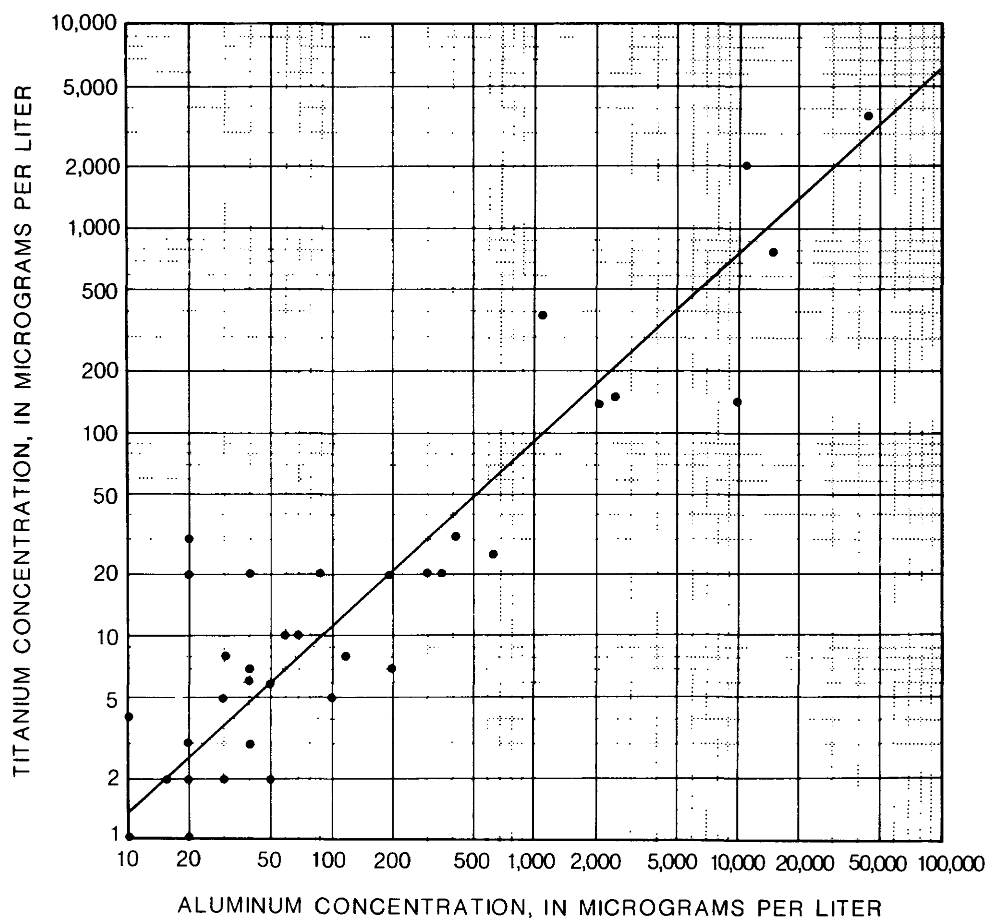

Figure 13.--Relation of titanium to aluminum in water.

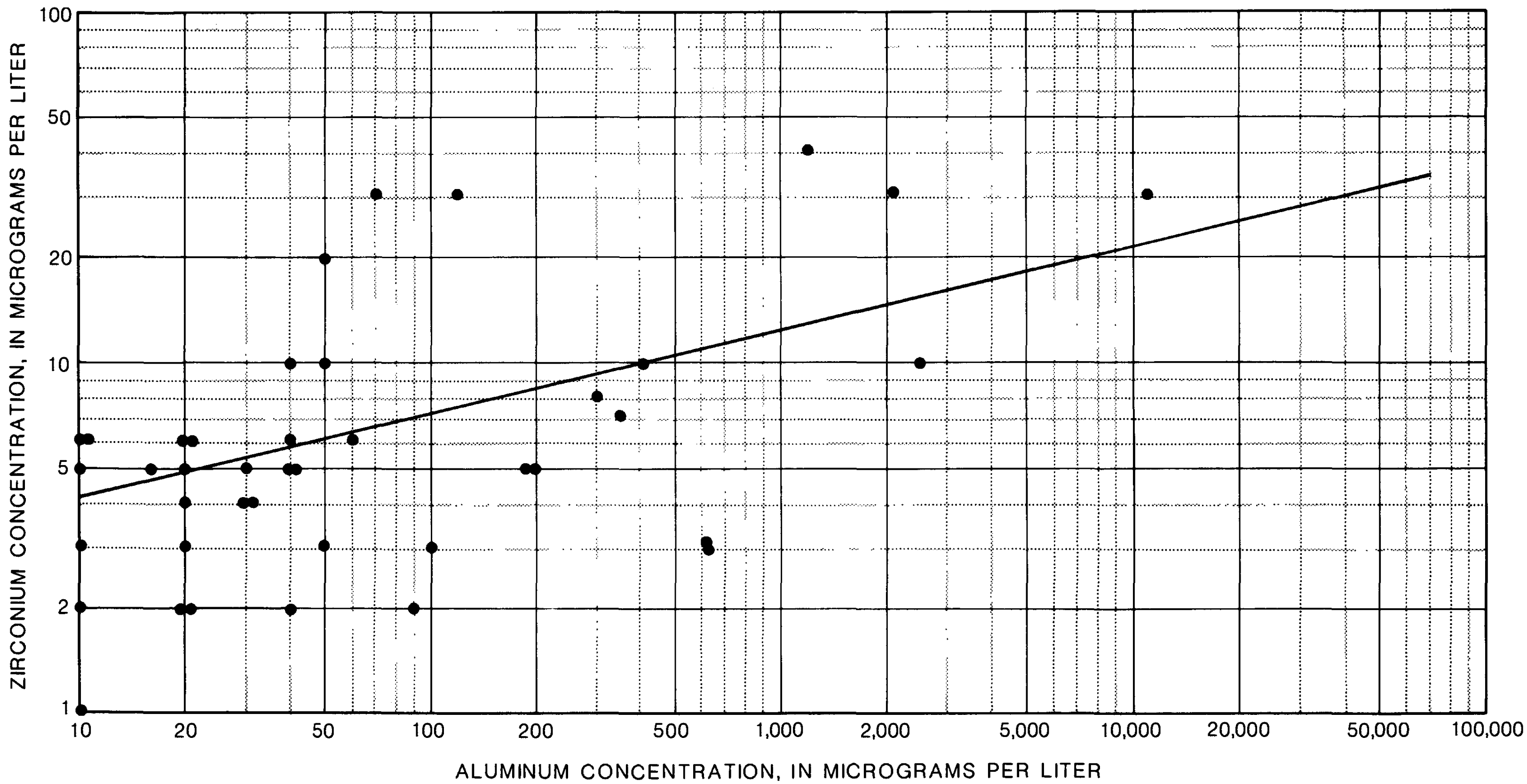

Figure 14.--Relation of zirconium to aluminum in water.

relations between pH and lead concentrations and between pH and aluminum are indicated by data. Strontium, which is chemically similar to calcium and generally in close geochemical association with it, increases rapidly as calcium increases. The concentration of strontium in ground water shows a closer relation with magnesium, however. Strontium increases much more rapidly than does magnesium (fig. 15). Strontium also increases as sulfate increases.

CONCLUSIONS

Chemical and physical analyses of 299 samples collected from 1974-87 from 210 wells indicate that the quality characteristics of ground water in Michigan vary widely. Water from bedrock deposits is more highly mineralized than that of glacial deposits. Among glacial deposits, outwash yields the most highly mineralized water. Among bedrock deposits, the Saginaw Formation yields the most highly mineralized water. Calcium and bicarbonate are generally the predominant ions in waters of lower mineralization, whereas sodium, sulfate, and chloride are the predominant ions in waters of higher mineralization. About 78 percent of ground waters may be classified as hard or very hard. Iron concentrations are higher than common in many natural ground waters. Aluminum and titanium occur in unusually high concentrations, and their occurrence seems to be one of mineral association.

Frequency distributions indicate that some waters do not meet U.S. Environmental Protection Agency drinking water regulations for iron, manganese, lead, total dissolved solids, and color. Sulfate, pH, fluoride, copper, chromium, chloride, and cadmium also do not meet regulations at times. Scant data indicate that lead tends to be naturally higher in ground water in the north central part of the Lower Peninsula than in other areas. Dissolved-solids (residue) concentrations, which ranged from 20 to 76,000 mg/L statewide, are highest in the central part of the Lower Peninsula.

Too few data are available to define conclusive differences in the chemical characteristics of water from each geologic source. Median concentrations, computed for each glacial and bedrock deposit, do provide a basis for comparison.

Mineral associations, notably those of aluminum and titanium and aluminum and zirconium, are evident from the data. Further work will likely develop additional relationships that are tentative at present.

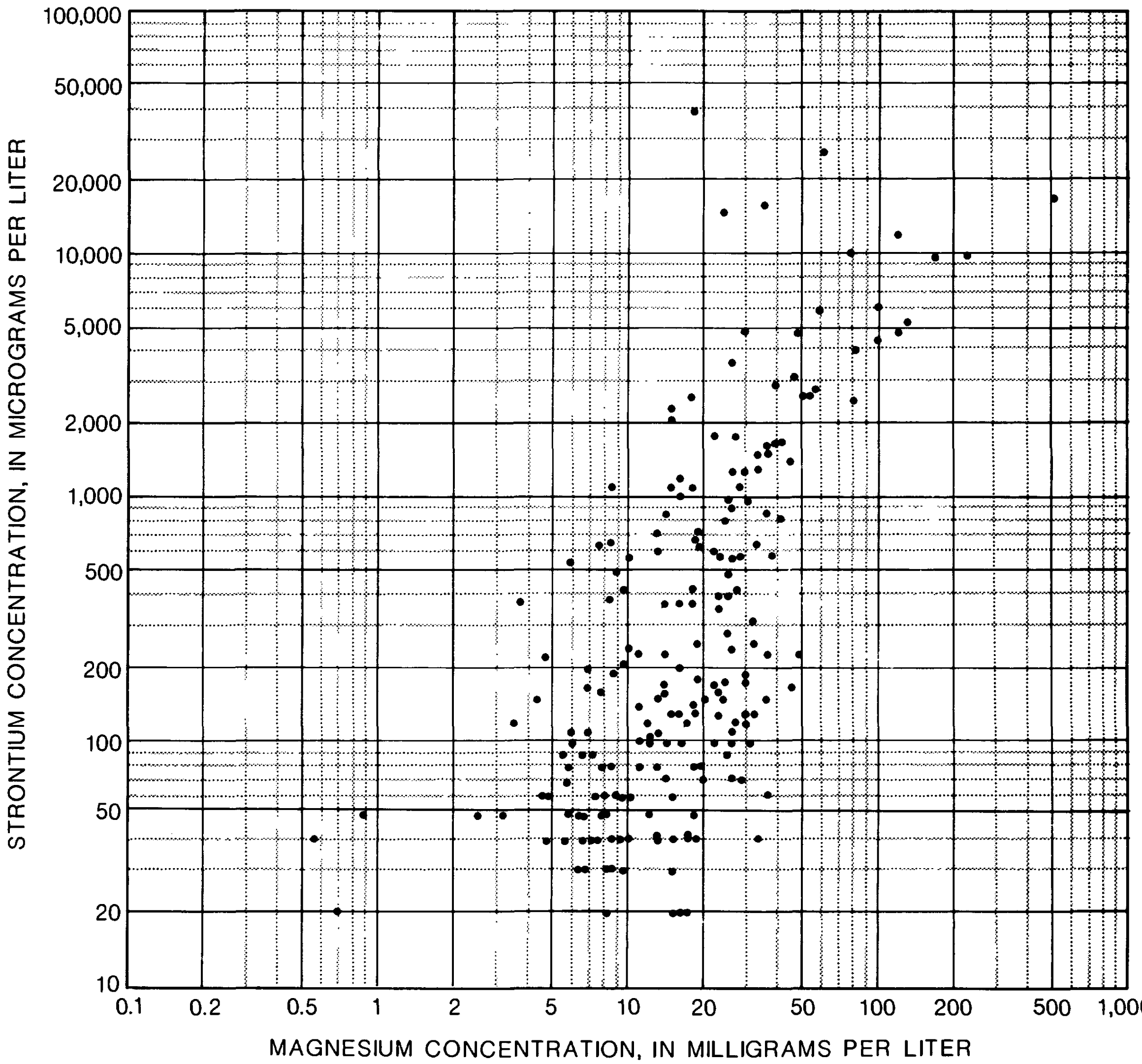

Figure 15.--Relation of strontium to magnesium in water.

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DEFINITION OF TERMS

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. It is also called a ground-water reservoir.

Bedrock. Designates consolidated rocks underlying glacial deposits.

Concentration. The weight of dissolved solids or sediment per unit volume of water expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Ground water. Water that is in the saturated zone from which wells, springs, and ground-water runoff are supplied.

Specific conductance. A measure of the ability of water to conduct an electric current, expressed in microsiemens (μS) (formerly micromhos) per centimeter at 25°C. Because the specific conductance is related to amount and type of dissolved material, it is used for approximating the dissolved-solids concentration (in milligrams per liter) to specific conductance (in microsiemens) is in the range 0.5 to 0.8.

APPENDIX

Median values of chemical and physical characteristics of water from geologic sources

[The number of samples collected from each source and used in computing tabulated medians is as follows: Glacial deposits, undifferentiated, 17; Gravel, 7; Lakebeds, 1; Moraine, 1; Outwash, 18; Sand, 45; Sand and clay, 1; Sand and gravel, 13; Paleozoic dolomite, 1; Pennsylvanian shale, 1; Pennsylvanian sandstone, 1; Saginaw Formation, 27; Michigan Formation, 1; Marshall Formation, 7; Antrim Shale, 1; Traverse Group, 3; Dundee Formation, 2; Detroit River Group, 2; Sylvania Sandstone, 1; Bass Islands Dolomite, 1; Engadine Dolomite, 2; Manistique Dolomite, 3; Burnt Bluff Formation, 3; Niagaran Series, 1; Ordovician, Upper, 1; Big Hill Limestone (Hussey, 1926), 1; Trenton Limestone, 2; Trenton-Black River Limestones, 2; Black River Limestone, 2; Mohawkian Series, 1; Hermansville Limestone (of former usage), 1; Prairie du Chien Group, 5; Prairie du Chien Group-Trempealeau Formation, 3; Lake Superior sandstone, 1; Trempealeau-Munising Formations, 5; Munising Formation, 5; Cambrian-Precambrian rocks, 1; Keweenawan Supergroup, 1; Jacobsville Sandstone, 8; Freda Sandstone, 2; Copper Harbor Conglomerate, 2; Portage Lake Volcanics, 3; Michigamme Slate, 2; Ironwood Iron-Formation, 1; and Randville Dolomite, 1. Single samples listed as median values. Median values for bismuth and germanium were calculated from reported "less than ()" values, and thus may or may not correspond to true median concentrations. < means less than. -- means no analyses made.]

Source	Alkalinity (mg/L as $CaCO_3$)	Aluminum, total recoverable (µg/L as Al)	Arsenic, total (µg/L as As)	Barium, total recoverable (µg/L as Ba)	Beryllium, total recoverable (µg/L as Be)	Bicarbonate, (mg/L as HCO_3)	Bismuth, total (µg/L as Bi)
Glacial deposits							
Glacial deposits, undifferentiated	190	40	2	<100	<10	200	<2
Gravel	150	40	1	<100	<10	190	<4
Lakebeds	110	10	1	<100	<10	--	--
Moraine	84	60	4	<100	<10	100	--
Outwash	148	35	1	<100	<10	160	
Sand	160	30	1	<100	<10	200	<20
Sand and clay	144	30	1	<100	<10	170	<4
Sand and gravel	123	30	1	<100	<10	150	--
Bedrock deposits							
Paleozoic dolomite	220	40	1	<100	<10	270	--
Pennsylvanian shale	107	60	1	<100	<10	130	--
Pennsylvanian sandstone	210	60	<1	<100	<10	260	--
Saginaw Formation	230	70	2	100	<10	380	<15
Michigan Formation	170	40	6	<50	0	280	--
Marshall Formation	168	20	2	<100	<10	225	--
Antrim Shale	330	8,400	1	100	0	400	--
Traverse Group	205	170	1	<100	<10	270	--
Dundee Formation	196	55	2	<100	<10	--	--
Detroit River Group	246	16	<1	<100	<10	250	--
Sylvania Sandstone	397	<10	<1	<100	<10	--	--
Bass Islands Dolomite	194	<10	<1	<100	<10	--	--

Median values of chemical and physical characteristics of water from geologic sources--Continued

Source	Alkalinity (mg/L as $CaCO_3$)	Aluminum, total recoverable (µg/L as Al)	Arsenic, total (µg/L as As)	Barium, total recoverable (µg/L as Ba)	Beryllium, total recoverable (µg/L as Be)	Bicarbonate, (mg/L as HCO_3)	Bismuth, total (µg/L as Bi)
Bedrock deposits--continued							
Engadine Dolomite	114	195	5	<100	<10	--	--
Manistique Dolomite	212	<10	<1	<100	<10	320	--
Burnt Bluff Formation	156	50	1	<100	<10	275	--
Niagaran Series[a/]	171	<10	<1	<100	<10	--	--
Ordovician, Upper	120	200	0	100	0	170	--
Big Hill Limestone	67	130	1	<100	<10	82	--
Trenton Limestone	223	1,100	<1	<100	<10	350	--
Trenton-Black River Limestones	240	1,240	2	<100	<10	370	--
Black River Limestone	352	21	1	100	<10	430	--
Mohawkian Series[b/]	200	20	1	200	<10	240	--
Hermansville Limestone	198	<10	<1	<100	<10	--	--
Prairie du Chien Group	127	20	<1	<100	<10	160	--
Prairie du Chien Group-Trempealeau Formation	138	<10	<1	<100	<10	--	--
Lake Superior sandstone	164	30	<1	<100	<10	200	--
Trempealeau-Munising Formations	90	30	1	100	0	71	--
Munising Formation	139	<10	1	<100	<10	195	--
Cambrian-Precambrian rocks	217	<10	2	<100	<10	--	--
Keweenawan Supergroup	125	<10	<1	<100	<10	--	--
Jacobsville Sandstone	120	25	1	<100	<10	170	--
Freda Sandstone	120	700	1	<100	<10	--	--
Copper Harbor Conglomerate	150	40	<1	<100	<10	--	--
Portage Lake Volcanics	90	30	<1	<100	<10	--	--
Michigamme Slate	96	<10	7	<100	<10	--	--
Ironwood Iron-Formation	185	<10	<1	<100	<10	--	--
Randville Dolomite	157	<10	<1	<100	<10	--	--

a/ Includes Engadine and Manistique Dolomites, and Burnt Bluff Formation

b/ Includes Trenton and Black River Limestones, and Prairie du Chien Group

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Boron, total recov-erable (µg/L as B)	Cadmium, total recov-erable (µg/L as Cd)	Calcium dis-solved (mg/L as Ca)	Carbon, organic dis-solved (mg/L as C)	Carbon dioxide, dis-solved (mg/L as CO_2)	Carbonate (mg/L as CO_3)	Chlo-ride, dis-solved (mg/L as Cl)
Glacial deposits							
Glacial deposits, undifferentiated	10	<1	57	2.8	6.2	0	4.9
Gravel	40	4	42	3.7	4.7	0	1.8
Lakebeds	<20	<1	36	3.6	--	0	1.6
Moraine	<20	2	25	1.7	1.6	0	1.1
Outwash	30	<1	53	1.6	4.4	0	4.9
Sand	<20	<2	44	2.0	4.9	0	1.5
Sand and clay	<20	2	42	.7	2.2	0	1.1
Sand and gravel	30	<1	36	2.8	3.2	0	1.5
Bedrock deposits							
Paleozoic dolomite	80	<2	57	2.1	5.3	0	1.3
Pennsylvanian shale	100	5	65	1.2	2.6	0	24
Pennsylvanian sandstone	610	6	39	7.7	5.2	0	79
Saginaw Formation	390	<1	130	2.0	28	0	180
Michigan Formation	360	0	110	1.5	44	0	440
Marshall Formation	80	<1	54	1.6	9.0	0	15
Antrim Shale	520	1	21	.8	16	0	53
Traverse Group	<20	<2	93	1.0	11	0	25
Dundee Formation	270	<1	57	7.0	--	--	10
Detroit River Group	105	<1	82	--	6.3	0	.7
Sylvania Sandstone	110	<1	200	2.3	--	--	47
Bass Islands Dolomite	130	<1	400	3.5	--	--	9.4
Engadine Dolomite	80	1	130	4.1	--	--	1.2
Manistique Dolomite	<10	<1	58	3.5	25	0	2.3
Burnt Bluff Formation	20	<1	79	2.5	24	0	6.7
Niagaran Series	130	<1	73	1.1	--	--	3.9
Ordovician, Upper	450	0	92	5.7	4.3	0	280
Big Hill Limestone	560	2	230	.6	2.1	0	270
Trenton Limestone	135	<1	54	4.8	17	0	5.4
Trenton-Black River Limestones	<20	n 3	86	2.3	23	0	17
Black River Limestone	260	<1	84	1.6	86	0	41
Mohawkian Series	80	2	43	.8	6.0	0	1.0
Hermansville Limestone	<10	<1	52	6.0	--	--	.6
Prairie du Chien Group	145	<1	34	1.8	4.6	0	0.8

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Boron, total recov- erable (µg/L as B)	Cadmium, total recov- erable (µg/L as Cd)	Calcium dis- solved (mg/L as Ca)	Carbon, organic dis- solved (mg/L as C)	Carbon dioxide, dis- solved (mg/L as CO_2)	Carbonate (mg/L as CO_3)	Chlo- ride, dis- solved (mg/L as Cl)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	220	<1	72	.7	--	--	28
Lake Superior sandstone	110	<20	68	1.6	5.0	0	160
Trempealeau-Munising Formations	30	0	27	2.9	4.5	0	4.0
Munising Formation	20	<1	39	1.1	7.2	0	2.7
Cambrian-Precambrian rocks	20	<1	44	1.5	--	--	1.3
Keweenawan Supergroup	140	<1	25	3.7	--	--	8.9
Jacobsville Sandstone	75	<1	30	2.7	9.6	0	2.8
Freda Sandstone	640	<1	28	2.2	--	--	11
Copper Harbor Conglomerate	510	<1	42	2.6	--	--	5.4
Portage Lake Volcanics	700	<1	10	1.6	--	--	5.3
Michigamme Slate	11	<1	32	1.4	--	--	8.9
Ironwood Iron-Formation	80	<1	41	1.1	--	--	8.2
Randville Dolomite	30	<1	38	2.7	--	--	.8

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Chromium, total recoverable (μg/L as Cr)	Cobalt, total recoverable (μg/L as Co)	Color (platinum-cobalt units)	Copper, total recoverable (μg/L as Cu)	Cyanide, total (mg/L as CN)	Depth of well (feet)	Fluoride, dissolved (mg/L as F)
Glacial deposits							
Glacial deposits, undifferentiated	<20	<1	1	5	0.00	72	0.10
Gravel	<20	<3	3	6	.00	65	.10
Lakebeds	10	<1	15	4	<.01	21	<.10
Moraine	<20	3	1	15	.00	103	.10
Outwash	<20	<2	3	4	.00	56	.15
Sand	<20	<2	5	4	.00	87	.10
Sand and clay	<20	2	5	5	.00	54	.10
Sand and gravel	<20	<2	10	7	.00	60	.10
Bedrock deposits							
Paleozoic dolomite	<20	2	10	7	.00	67	<.10
Pennsylvanian shale	<20	2	10	<2	.00	172	.50
Pennsylvanian sandstone	<20	<2	5	<2	.00	270	.30
Saginaw Formation	10	2	2	16	<.01	207	.30
Michigan Formation	10	0	4	3	.01	245	.80
Marshall Formation	<20	<1	4	6	<.01	180	.40
Antrim Shale	20	8	3	29	.00	90	.90
Traverse Group	<20	3	10	5	.00	91	1.4
Dundee Formation	<10	<1	72	4	<.01	122	.60
Detroit River Group	11	<1	4	4	<.01	64	1.0
Sylvania Sandstone	<10	<1	5	7	<.01	97	.70
Bass Islands Dolomite	10	<1	5	2	<.01	112	1.4
Engadine Dolomite	<10	2	32	30	<.01	96	.80
Manistique Dolomite	10	<1	3	5	<.01	102	.40
Burnt Bluff Formation	<20	1	3	6	<.01	185	.80
Niagaran Series	<10	<1	3	2	<.01	560	2.0
Ordovician, Upper	20	0	0	2	.01	120	1.8
Big Hill Limestone	<20	2	5	5	.00	225	<.10
Trenton Limestone	20	1	4	22	.00	84	.20
Trenton-Black River Limestones	<20	1	5	4	<.01	222	.10
Black River Limestone	6	2	4	4	<.01	245	.30
Mohawkian Series	30	2	15	2	.00	65	.20
Hermansville Limestone	30	<1	13	19	<.01	38	.10
Prairie du Chien Group	<20	<1	5	4	<0.01	280	0.40

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Chromium, total recoverable (µg/L as Cr)	Cobalt, total recoverable (µg/L as Co)	Color (platinum-cobalt units)	Copper, total recoverable (µg/L as Cu)	Cyanide, total (mg/L as CN)	Depth of well (feet)	Fluoride, dissolved (mg/L as F)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	10	1	3	9	<.01	665	.50
Lake Superior sandstone	<20	<1	5	4	.00	1,160	.40
Trempealeau-Munising Formations	20	0	3	4	.00	300	.10
Munising Formation	<10	4	2	8	<.01	200	.10
Cambrian-Precambrian rocks	<10	<1	5	140	<.01	122	.10
Keweenawan Supergroup	30	1	2	8	<.01	230	.10
Jacobsville Sandstone	<20	1	3	8	.00	185	.10
Freda Sandstone	11	1	3	48	<.01	88	.40
Copper Harbor Conglomerate	16	<1	5	8	<.01	230	.11
Portage Lake Volcanics	10	1	5	10	<.01	100	.60
Michigamme Slate	16	2	6	3	<.01	276	.26
Ironwood Iron-Formation	<10	<1	5	2	<.01	390	.10
Randville Dolomite	10	2	1	11	<.01	100	.20

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Gallium, total (μg/L as Ga)	Germanium, total (μg/L as Ge)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate, total (mg/L as $CaCO_3$)	Iron, dissolved (μg/L as Fe)	Iron, total recoverable (μg/L as Fe)	Lead, total recoverable (μg/L as Pb)
Glacial deposits							
Glacial deposits, undifferentiated	<1	<4	210	27	270	470	4
Gravel	<1	<4	160	15	57	350	2
Lakebeds	--	--	120	10	10	380	<1
Moraine	--	--	85	2	40	160	<2
Outwash	<6	<20	185	16	530	1,380	5
Sand	<1	<6	170	8	50	270	7
Sand and clay	--	--	140	0	40	580	6
Sand and gravel	--	--	130	7	1,200	2,000	10
Bedrock deposits							
Paleozoic dolomite	--	--	250	30	160	300	12
Pennsylvanian shale	--	--	230	120	250	320	160
Pennsylvanian sandstone	--	--	150	0	550	890	150
Saginaw Formation	<20	<20	460	210	570	1,500	8
Michigan Formation	--	--	390	220	710	780	2
Marshall Formation	--	--	250	76	270	840	5
Antrim Shale	--	--	91	0	20	7,200	10
Traverse Group	--	--	310	69	120	610	5
Dundee Formation	--	--	290	92	1,990	1,980	2
Detroit River Group	--	--	360	140	50	85	2
Sylvania Sandstone	--	--	600	200	1,800	2,300	<5
Bass Islands Dolomite	--	--	1,500	1,300	40	50	<5
Engadine Dolomite	--	--	515	400	1,290	3,200	6
Manistique Dolomite	--	--	230	9	8	90	7
Burnt Bluff Formation	--	--	350	26	210	710	1
Niagaran Series	--	--	330	160	260	610	<5
Ordovician, Upper	--	--	350	230	60	120	0
Big Hill Limestone	--	--	900	840	50	600	15
Trenton Limestone	--	--	240	16	158	1,820	<5
Trenton-Black River Limestones	--	--	330	89	660	1,040	16
Black River Limestone	--	--	330	48	39	165	2
Mohawkian Series	--	--	190	0	240	230	10
Hermansville Limestone	--	--	240	43	520	550	<5
Prairie du Chien Group	--	--	150	6	49	250	6

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Gallium, total (µg/L as Ga)	Germanium, total (µg/L as Ge)	Hardness, total (mg/L as $CaCO_3$)	Hardness, noncarbonate, total (mg/L as $CaCO_3$)	Iron, dissolved (µg/L as Fe)	Iron, total recoverable (µg/L as Fe)	Lead, total recoverable (µg/L as Pb)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	--	--	320	82	12	810	6
Lake Superior sandstone	--	--	290	130	90	70	41
Trempealeau-Munising Formations	--	--	100	11	40	240	<5
Munising Formation	--	--	170	13	27	180	<5
Cambrian-Precambrian rocks	--	--	230	17	20	1,800	11
Keweenawan Supergroup	--	--	87	0	7	<10	<5
Jacobsville Sandstone	--	--	114	0	15	130	6
Freda Sandstone	--	--	101	2	16	1,150	<5
Copper Harbor Conglomerate	--	--	127	<1	16	170	14
Portage Lake Volcanics	--	--	29	0	47	120	<5
Michigamme Slate	--	--	130	30	164	540	<5
Ironwood Iron-Formation	--	--	180	1	23	40	<5
Randville Dolomite	--	--	170	12	5	7,100	<5

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Lithium, total recov- erable (µg/L as Li)	Magne- sium, dis- solved (mg/L as Mg)	Manga- nese, dis- solved µg/L as Mn)	Manga- nese, total recov- erable (µg/L as Mn)	Mercury, total recov- erable (µg/L as Hg)	Molyb- denum, total recov- erable (µg/L as Mo	Nickel, total recov- erable (µg/L as Ni)
Glacial deposits							
Glacial deposits, undifferentiated	<10	17	37	40	<0.50	3	3
Gravel	<10	8.5	40	40	<.50	1	2
Lakebeds	<10	7.2	13	40	<.10	<1	3
Moraine	<10	5.6	<10	<10	<.50	2	10
Outwash	<10	18	20	25	<.10	4	2
Sand	<10	13	10	20	<.50	1	3
Sand and clay	<10	8.0	<10	20	<.50	1	21
Sand and gravel	<10	9.4	43	50	<.50	1	5
Bedrock deposits							
Paleozoic dolomite	20	26	<10	<10	<.50	6	8
Pennsylvanian shale	60	16	50	50	<.50	<1	3
Pennsylvanian sandstone	40	13	20	20	<.50	3	3
Saginaw Formation	30	39	60	110	<.50	2	2
Michigan Formation	30	27	10	30	<.10	5	1
Marshall Formation	<10	22	60	70	<.50	1	3
Antrim Shale	80	9.3	20	150	.10	6	15
Traverse Group	<10	18	12	20	<.50	<1	3
Dundee Formation	25	36	36	55	.21	2	2
Detroit River Group	31	38	12	20	<.30	2	2
Sylvania Sandstone	20	24	26	30	<.10	2	1
Bass Islands Dolomite	50	120	10	20	<.10	<1	2
Engadine Dolomite	26	46	86	110	.06	5	2
Manistique Dolomite	<10	18	2	<10	<.10	<1	<1
Burnt Bluff Formation	40	30	7	10	.10	1	2
Niagaran Series	20	35	8	10	<.10	3	2
Ordovician, Upper	70	30	70	50	.30	2	0
Big Hill Limestone	50	80	50	50	<.50	4	11
Trenton Limestone	10	25	14	50	.15	<.1	2
Trenton-Black River Limestones	<10	28	16	30	.15	2	7
Black River Limestone	15	30	16	25	.21	2	4
Mohawkian Series	<10	19	20	<10	<.50	1	8
Hermansville Limestone	<10	27	16	20	<.10	1	<1
Prairie du Chien Group	<10	15	7	<10	.10	1	4

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Lithium, total recov-erable (µg/L as Li)	Magne-sium, dis-solved (mg/L as Mg)	Manga-nese, dis-solved µg/L as Mn)	Manga-nese, total recov-erable (µg/L as Mn)	Mercury, total recov-erable (µg/L as Hg)	Molyb-denum, total recov-erable (µg/L as Mo	Nickel, total recov-erable (µg/L as Ni)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	30	33	17	20	.20	3	1
Lake Superior sandstone	30	29	40	40	<.50	1	4
Trempealeau-Munising Formations	<10	8.2	30	30	.10	2	1
Munising Formation	<10	18	15	20	<.10	2	1
Cambrian-Precambrian rocks	<10	30	30	30	<.10	1	2
Keweenawan Supergroup	<10	5.9	<1	<10	<.10	1	2
Jacobsville Sandstone	<10	8.0	6	6	.15	2	6
Freda Sandstone	55	7.2	2	36	.20	2	3
Copper Harbor Conglomerate	21	5.5	1	<10	<.10	2	4
Portage Lake Volcanics	<10	.9	5	<10	<.10	2	<1
Michigamme Slate	5	11	236	226	<.10	10	2
Ironwood Iron-Formation	10	18	3	<10	<.10	<1	<1
Randville Dolomite	<10	18	25	60	.10	2	3

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Nitrogen, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrate, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, organic, total (mg/L as N)	pH (units)	Phenols, total (µg/L)
Glacial deposits							
Glacial deposits, undifferentiated	0.63	0.03	0.05	<0.01	0.11	7.6	<1
Gravel	.20	.07	.01	<.01	.08	7.8	0
Lakebeds	.30	.03	.07	.03	.17	8.0	4
Moraine	.24	<.01	.21	<.01	.03	8.0	0
Outwash	.36	.04	.02	<.01	.13	7.6	1
Sand	.42	.02	.02	<.01	.14	7.9	0
Sand and clay	.45	<.01	.28	<.01	.17	8.1	0
Sand and gravel	.31	.08	.02	<.01	.10	7.8	0
Bedrock deposits							
Paleozoic dolomite	.15	.08	.00	<.01	.07	7.9	0
Pennsylvanian shale	.98	.93	.00	.01	.04	7.9	1
Pennsylvanian sandstone	.83	.67	.00	<.01	.16	7.9	0
Saginaw Formation	.80	.54	<.01	<.01	.25	7.6	2
Michigan Formation	.40	.29	.00	.00	.11	7.0	2
Marshall Formation	.24	.07	<.10	<.01	.04	7.6	1
Antrim Shale	.44	.15	.00	.00	.29	7.6	0
Traverse Group	.24	.02	<.10	<.01	.10	7.6	0
Dundee Formation	.60	.38	.05	.01	.16	7.6	3
Detroit River Group	2.6	.28	<.10	<.01	2.3	7.5	0
Sylvania Sandstone	.30	.22	<.10	<.01	.08	7.3	2
Bass Islands Dolomite	.62	.44	<.10	<.01	.16	7.1	3
Engadine Dolomite	.42	.14	<.10	<.01	.25	7.8	2
Manistique Dolomite	.50	.01	<.10	<.01	.18	7.8	3
Burnt Bluff Formation	.14	.08	<.10	<.01	.11	7.5	2
Niagaran Series	<.20	.05	<.10	<.01	<.01	7.8	1
Ordovician, Upper	.26	.19	.01	.00	.06	7.8	0
Big Hill Limestone	.75	.17	.22	<.01	.36	7.8	0
Trenton Limestone	.13	.06	<.10	<.01	.05	7.6	2
Trenton-Black River Limestones	.21	.08	.04	<.01	.07	7.5	1
Black River Limestone	.45	.13	<.10	.01	.30	7.6	2
Mohawkian Series	.32	.03	.05	<.01	.24	7.8	1
Hermansville Limestone	.72	.14	<.10	<.01	.56	7.8	3
Prairie du Chien Group	0.09	0.07	<0.10	<0.01	0.01	8.1	<1

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Nitrogen, total (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, nitrate, total (mg/L as N)	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, organic, total (mg/L as N)	pH (units)	Phenols, total (µg/L)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	.42	.05	<.10	<.01	.35	7.7	3
Lake Superior sandstone	.47	.07	.01	<.01	.39	7.8	0
Trempealeau-Munising Formations	.17	.04	<.10	.00	.07	7.7	2
Munising Formation	.05	.04	<.10	<.01	.01	8.0	1
Cambrian-Precambrian rocks	.22	.08	<.10	<.01	.12	7.9	<1
Keweenawan Supergroup	.32	.01	<.10	<.01	.29	7.7	<1
Jacobsville Sandstone	.25	<.01	.12	<.01	.12	7.6	0
Freda Sandstone	.90	<.01	.65	<.01	.25	7.2	3
Copper Harbor Conglomerate	.28	.02	.25	<.01	.01	7.4	2
Portage Lake Volcanics	.05	.03	<.10	<.01	.01	8.8	<1
Michigamme Slate	.20	.04	.15	<.01	.01	7.6	2
Ironwood Iron-Formation	.24	.03	.20	<.01	.01	7.6	<1
Randville Dolomite	.42	.02	<.10	<.01	.38	8.1	2

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Phosphorus, total (mg/L as P)	Phosphorus, ortho, total (mg/L as P)	Potassium, dissolved (mg/L as K)	Selenium, total (µg/L as Se)	Silica, dissolved (mg/L as SiO_2)	Silver, total recoverable (µg/L as Ag)	Sodium, dissolved (mg/L as Na)
Glacial deposits							
Glacial deposits, undifferentiated	0.02	0.01	1.2	<1	12	<1	9.0
Gravel	.02	<.01	1.4	<1	11	<1	3.0
Lakebeds	.05	.05	.5	<1	7.4	<1	2.5
Moraine	.01	<.01	.9	<1	15	<1	1.9
Outwash	.01	<.01	.9	<1	10	<1	4.5
Sand	.01	<.01	.7	<1	9.8	<1	2.6
Sand and clay	.01	.01	1.1	<1	19	<1	2.7
Sand and gravel	.01	<.01	.9	<1	11	<1	3.7
Bedrock deposits							
Paleozoic dolomite	<.01	<.01	1.4	<1	.9	<1	7.4
Pennsylvanian shale	.01	<.01	5.8	<1	6.2	<1	110
Pennsylvanian sandstone	<.01	<.01	4.6	<1	6.1	<2	110
Saginaw Formation	.02	<.01	6.4	<1	10	<1	400
Michigan Formation	.01	.00	3.6	0	11	0	290
Marshall Formation	<.01	<.01	2.0	<1	12	<1	19
Antrim Shale	.00	.01	2.3	0	10	0	140
Traverse Group	.01	<.01	2.1	<1	8.8	<1	3.9
Dundee Formation	<.01	<.01	1.8	<1	15	<1	24
Detroit River Group	.02	.01	2.4	<1	20	<1	20
Sylvania Sandstone	.02	<.01	1.9	<1	14	<1	23
Bass Islands Dolomite	<.01	<.01	2.6	<1	13	<1	6.0
Engadine Dolomite	.04	.21	2.0	<1	12	<1	19
Manistique Dolomite	<.01	<.01	.8	<1	6.7	<1	1.9
Burnt Bluff Formation	.01	.01	1.6	<1	6.5	<1	2.4
Niagaran Series	.02	<.01	2.5	<1	8.5	<1	8.4
Ordovician, Upper	.01	.00	14	0	8.2	0	97
Big Hill Limestone	.04	.01	9.0	<1	.6	<1	160
Trenton Limestone	.07	<.01	2.1	<1	18	<1	6.4
Trenton-Black River Limestones	<.01	<.01	2.0	<1	12	<1	6.2
Black River Limestone	.02	.02	3.8	<1	9.6	<1	14
Mohawkian Series	<.01	<.01	2.0	<1	7.8	<1	2.0
Hermansville Limestone	<.01	<.01	1.5	<1	17	<1	2.3
Prairie du Chien Group	0.01	<0.01	3.2	<1	7.4	<1	4.6

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Phos-phorus, total (mg/L as P)	Phos-phorus, ortho, total (mg/L as P)	Potas-sium, dis-solved (mg/L as K)	Selenium, total (µg/L as K)	Silica, dis-solved (mg/L as SiO_2)	Silver, total recov-erable (µg/L as Ag)	Sodium, dis-solved (mg/L as Na)
Bedrock deposits-continued							
Prairie du Chien Group-Trempealeau Formation	.01	<.01	4.1	<1	6.9	1	34
Lake Superior sandstone	<.01	<.01	5.4	<1	7.4	<1	65
Trempealeau-Munising Formations	.01	.01	2.0	0	13	0	3.6
Munising Formation	.01	<.01	2.6	<1	8.9	<1	3.2
Cambrian-Precambrian rocks	<.01	<.01	1.7	<1	20	<1	4.0
Keweenawan Supergroup	--	<.01	.5	<1	18	<1	22
Jacobsville Sandstone	.01	.01	1.8	<1	12	<1	7.0
Freda Sandstone	.08	.04	4.1	<1	18	<1	30
Copper Harbor Conglomerate	.02	<.01	.7	<1	8.4	<1	15
Portage Lake Volcanics	<.01	<.01	.1	<1	15	<1	34
Michigamme Slate	<.01	<.01	1.0	1	16	<1	3.1
Ironwood Iron-Formation	.02	.01	1.3	10	13	<1	9.8
Randville Dolomite	.03	<.01	1.3	<1	5.7	<1	1.3

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Solids, residue at 180 deg. C dis- solved (mg/L)	Solids, sum of consti- tuents, dis- solved (mg/L)	Specific conductance (microsiemens)	Stron- tium, total recov- erable (µg/L as Sr)	Sulfate dis- solved (mg/L as SO_4)	Temper- ature (deg. C)	Tin, total recov- erable (µg/L as Sn)
Glacial deposits							
Glacial deposits, undifferentiated	249	239	408	130	14	9.5	<2
Gravel	137	169	289	120	7.8	8.5	<2
Lakebeds	138	133	240	60	12	8.5	--
Moraine	115	108	167	70	8.3	7.0	--
Outwash	206	200	408	100	11	9.5	<10
Sand	182	188	324	75	11	9.0	<3
Sand and clay	183	168	280	60	7.9	7.5	--
Sand and gravel	160	160	254	90	10	9.0	--
Bedrock deposits							
Paleozoic dolomite	291	282	482	3,600	57	7.5	--
Pennsylvanian shale	614	612	880	1,000	320	9.5	--
Pennsylvanian sandstone	438	444	735	700	64	10.0	--
Saginaw Formation	1,260	1,210	1,540	1,700	40	11.0	<10
Michigan Formation	1,320	1,220	2,410	1,800	200	12.0	--
Marshall Formation	362	336	609	580	40	10.0	--
Antrim Shale	439	434	777	410	.90	8.5	--
Traverse Group	340	324	593	370	28	9.0	--
Dundee Formation	421	654	614	13,000	150	12.0	--
Detroit River Group	536	253	628	39,000	38	11.0	--
Sylvania Sandstone	670	780	920	15,000	230	13.5	--
Bass Islands Dolomite	1,970	1,870	2,190	12,000	1,200	12.0	--
Engadine Dolomite	794	743	947	5,080	460	8.0	--
Manistique Dolomite	245	238	413	100	11	8.0	--
Burnt Bluff Formation	358	338	584	180	14	9.5	--
Niagaran Series	353	376	643	16,000	140	10.5	--
Ordovician, Upper	--	667	1,140	4,900	60	13.0	--
Big Hill Limestone	1,820	1,540	2,200	2,500	750	9.0	--
Trenton Limestone	253	275	472	125	18	9.0	--
Trenton-Black River Limestones	385	332	612	170	45	9.5	--
Black River Limestone	339	402	725	725	50	10.0	--
Mohawkian Series	197	202	380	250	10	8.0	--
Hermansville Limestone	249	227	416	120	7.5	8.5	--
Prairie du Chien Group	156	167	295	370	14	7.5	--

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Solids, residue at 180 deg. C dis-solved (mg/L)	Solids, sum of consti-tuents, dis-solved (mg/L)	Specific conductance (microsiemens)	Stron-tium, total recov-erable (µg/L as Sr)	Sulfate dis-solved (mg/L as SO_4)	Temper-ature (deg. C)	Tin, total recov-erable (µg/L as Sn)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	300	296	1,080	860	55	12.0	--
Lake Superior sandstone	532	478	905	1,300	44	13.0	--
Trempealeau-Munising Formations	252	261	272	160	13	8.5	--
Munising Formation	226	243	415	120	27	13.0	--
Cambrian-Precambrian rocks	238	249	432	180	18	7.0	--
Keweenawan Supergroup	161	163	262	100	7.3	10.0	--
Jacobsville Sandstone	158	152	274	200	5.8	9.0	--
Freda Sandstone	200	183	336	400	12	8.2	--
Copper Harbor Conglomerate	176	172	306	130	5.3	7.0	--
Portage Lake Volcanics	155	153	278	50	5.5	9.0	--
Michigamme Slate	159	156	262	100	26	9.0	--
Ironwood Iron-Formation	212	209	379	140	6.3	10.0	--
Randville Dolomite	170	168	327	2,600	9.0	7.0	--

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Titanium, total (µg/L as Ti)	Tritium, total (pCi/L)	Turbidity (FTU)	Uranium, dissolved, extraction (µg/L as U)	Vanadium, total (µg/L as V)	Zinc, total recoverable (µg/L as Zn)	Zirconium, total (µg/L as Zr)
Glacial deposits							
Glacial deposits, undifferentiated	<2	<200	2.4	0.18	<10	15	<4
Gravel	14	<200	.65	.25	5	105	<4
Lakebeds	--	<200	5.5	.57	2	20	--
Moraine	--	--	--	--	--	120	--
Outwash	<10	<200	.75	.22	<1	45	<30
Sand	<20	<200	.20	.11	<10	110	<6
Sand and clay	--	--	--	--	--	210	--
Sand and gravel	--	35	15	<.03	<1	90	--
Bedrock deposits							
Paleozoic dolomite	--	--	--	--	--	240	--
Pennsylvanian shale	--	--	--	.01	--	20	--
Pennsylvanian sandstone	--	--	--	.54	--	<20	--
Saginaw Formation	<30	<200	9.2	.08	1	300	<50
Michigan Formation	--	--	7.5	.11	0	20	--
Marshall Formation	--	<200	1.2	.04	5	30	--
Antrim Shale	--	--	210	.13	0	130	--
Traverse Group	--	<200	4.6	.22	<10	30	--
Dundee Formation	--	<24	6.0	<.01	4	35	--
Detroit River Group	--	19	1.0	.06	<1	30	--
Sylvania Sandstone	--	61	8.5	.25	<1	500	--
Bass Islands Dolomite	--	<10	.2	<.01	<1	80	--
Engadine Dolomite	--	133	14	.02	5	850	--
Manistique Dolomite	--	<120	.4	--	1	40	--
Burnt Bluff Formation	--	<100	2.9	.20	<10	260	--
Niagaran Series	--	<10	3.5	.02	<1	110	--
Ordovician, Upper	--	--	1.6	.10	0	120	--
Big Hill Limestone	--	--	--	--	--	4,700	--
Trenton Limestone	--	110	29	1.0	<1	1,100	--
Trenton-Black River Limestones	--	83	1.5	2.7	<1	.95	--
Black River Limestone	--	<100	.2	.15	5	180	--
Mohawkian Series	--	--	--	--	--	100	--
Hermansville Limestone	--	<26	.7	--	2	<10	--
Prairie du Chiein Group	--	13	0.5	0.15	--	<1	20

Median values of chemical and physical characteristics of water from geologic sources--Continued

	Titanium, total (µg/L as Ti)	Tritium, total (pCi/L)	Turbidity (FTU)	Uranium, dissolved, extraction (µg/L as U)	Vanadium, total (µg/L as V)	Zinc, total recoverable (µg/L as Zn)	Zirconium, total (µg/L as Zr)
Bedrock deposits--continued							
Prairie du Chien Group-Trempealeau Formation	--	80	2.9	.22	<1	20	--
Lake Superior sandstone	--	--	--	--	--	20	--
Trempealeau-Munising Formations	--	21	.5	.10	0	60	--
Munising Formation	--	<200	.6	.10	<10	100	--
Cambrian-Precambrian rocks	--	16	1.5	.03	<1	540	--
Keweenawan Supergroup	--	77	.2	--	4	<10	--
Jacobsville Sandstone	--	26	.2	2.2	3	50	--
Freda Sandstone	--	51	22	--	8	35	--
Copper Harbor Conglomerate	--	90	2.2	2.2	17	520	--
Portage Lake Volcanics	--	<26	1.8	.72	1	50	--
Michigamme Slate	--	44	3.0	.79	1	1,990	--
Ironwood Iron-Formation	--	160	.2	.33	<1	50	--
Randville Dolomite	--	32	3.3	--	1	680	--

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