GROUND-WATER QUALITY

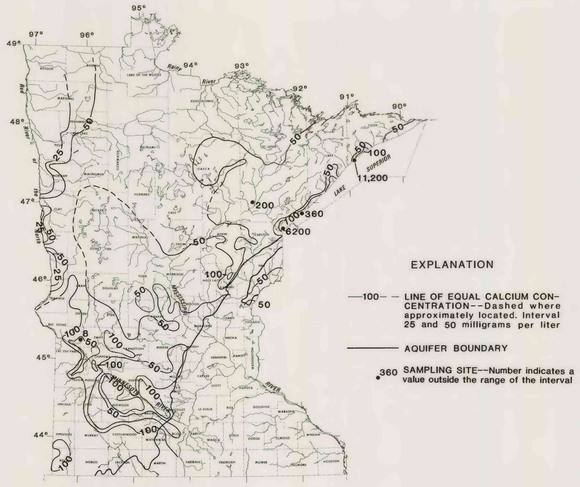

Figure 7.--Concentration of calcium

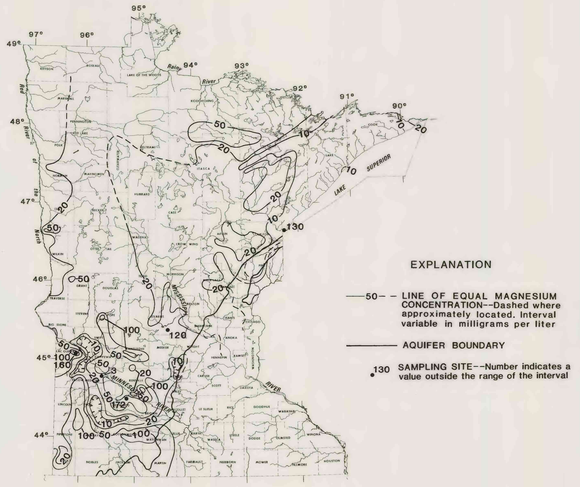

Figure 8.--Concentration of magnesium

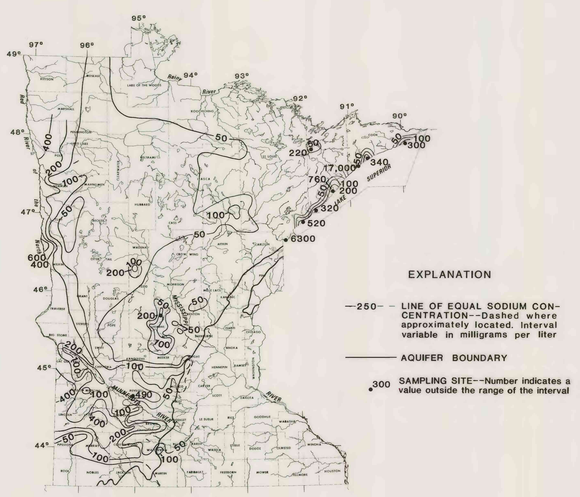

Figure 9.--Concentration of sodium

WATER QUALITY

General

Water in crystalline-rock aquifers of Archean and Proterozoic age is characterized by several different and mixed water types. The distribution of water types is summarized in table 3.

Table 3.--Distribution of water types in crystalline-rock aquifers of Archean and Proterozoic age, 1960-81, by percent

[Water type is based on a water sample having at least 60 percent of the dominant cations and at least 60 percent of the dominant anion. A mixed water type either has no predominant cation or no predominant anion. A dash indicates no water samples of that water type.]

Aquifer	Number of Samples	Water type, by percent						
		Calcium magnesium bicarbonate	Calcium magnesium sulfate	Calcium magnesium chloride	Sodium bicarbonate	Sodium sulfate	Sodium chloride	Mixed
North Shore Volcanic	21	24	---	5	19	---	19	33
Sioux Quartzite	25	24	48	---	---	---	---	28
Proterozoic metasedimentary	30	87	---	---	3	---	---	10
Biwabik Iron-formation	14	100	---	---	---	---	---	---
Undifferentiated Precambrian	197	51	7.5	---	7.5	2	2	30
Central Minnesota	(69)	78	3	---	3	---	---	16
Southwest Minnesota	(64)	31	19	---	5	6	2	37
Northwest Minnesota	(29)	69	4	---	7	---	10	10
Northwest Minnesota	(35)	17	---	---	23	---	---	60
All crystalline-rock aquifers	287	53	9	.3	7	1	3	26

Ground-water-quality data for this report came from (1) U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE) data base (102 analyses), (2) National Uranium Resource Evaluation Program reports prepared for the U.S. Department of Energy (224 analyses), (3) Minnesota Department of Health files (37 analyses), and (4) miscellaneous data tabulated by the Minnesota Geological Survey from various published and unpublished reports (36 analyses). Results of 399 analyses were examined for cation-anion balance and rejected if the results were more than 10 percent out of balance. Geologic data were examined also and the analyses rejected if the sample was from a multiaquifer well. A total of 287 analyses were selected for use in this report. The data represent results of chemical analyses made primarily during 1960-81.

Major Ions

Water commonly is classified by type on the basis of relative concentrations of major cations and anions. This classification provides the basis for grouping waters of similar types and for evaluating chemical mechanisms that effect changes in water quality. The distribution of chemical types of water among samples collected from the crystalline-rock aquifers of Archean and Proterozoic age is shown in table 3. Distribution of the major cation and anion concentrations are tabulated for each of the aquifers in tables 4 through 12 and the areal distribution of ion concentrations is shown in figures 7 through 12.

Calcium concentrations (fig. 7) in water from crystalline-rock aquifers of Archean and Proterozoic age are higher in central and south-central Minnesota and lower toward eastern Minnesota because of generally lower dissolved constituents. Calcium concentrations also are lower along the western edge of Minnesota because of ion exchange (calcium for sodium) in Cretaceous rocks and in Des Moines drift. The distribution of magnesium (fig. 8) is similar to that of calcium, but the concentration of magnesium generally is less than half that of calcium. Sodium concentrations (fig. 9) in water from crystalline-rock aquifers are high along the western edge of Minnesota and southwest of the Minnesota River. The sodium concentration generally decreases eastward, but several anomalously high concentrations of sodium chloride were found in water samples from the North Shore Volcanic aquifer near Lake Superior. Bicarbonate concentrations (fig. 10) in crystalline-rock aquifers of Archean and Proterozoic age generally are less than 200 mg/L in northeastern Minnesota, and range from 200 to 400 mg/L in most of Minnesota. In southwestern Minnesota, 9 of 64 samples from crystalline-rock aquifers contained more than 600 mg/L of bicarbonate. Sulfate concentrations (fig. 11) in water from crystalline-rock aquifers generally are less than 10 mg/L in eastern Minnesota, increase to more than 100 mg/L along the western edge of Minnesota, and exceed 1,000 mg/L in parts of southwestern Minnesota. Chloride concentrations (fig. 12) in water from crystalline-rock aquifers generally are less than 10 mg/L, except for the North Shore volcanics aquifer and the differentiated Precambrian aquifers in northwestern and southwestern Minnesota.

Table 4.--Summary of chemical analyses of water samples from the North Shore Volcanic aquifer, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	21	910	45	3.2	11,000
Magnesium, dissolved	20	20	9.8	0.0	130
Sodium, dissolved	21	1,200	56	3.9	17,000
Potassium, dissolved	18	16	1.3	.3	260
Bicarbonate	20	180	150	16	430
Sulfate, dissolved	21	42	14	1.6	210
Chloride, dissolved	21	3,400	47	1.0	48,000
Dissolved solids, calculated sum of determined constituents	21	5,700	351	91	79,300

Aquifers

North Shore Volcanic Aquifer

Water in the North Shore Volcanic aquifer generally contains low concentrations of dissolved solids. The median dissolved-solids concentration is 351 mg/L for 21 samples (table 4). However, 6 samples had concentrations greater than 1,000 mg/L. Along the north shore of Lake Superior dissolved-solids concentrations range from 91 to 74,300 mg/L; the mean concentration of 16 samples is 7,390 mg/L and the median is 413 mg/L. In east-central Minnesota, along the upper St. Croix River, five samples had dissolved-solids concentrations ranging from 135 to 367 mg/L, with a mean of 281 mg/L. Dominant ions in the saline water generally are sodium and chloride (table 4). Calcium replaces sodium in areas of calcium-rich rocks. In dilute water samples, the water type tends toward calcium magnesium bicarbonate. Four of the five samples from the North Shore volcanics aquifer in east-central Minnesota were calcium bicarbonate water type. The highly variable water quality is a result of the numerous individual flow systems in the rocks as well as differences in the solubility of minerals composing the bedrock (Olcott and others, 1978). Mixed water types are predominant on the basis of 21 samples, as shown in table 3.

Sioux Quartzite Aquifer

Dissolved-solids concentrations in water from the Sioux Quartzite aquifer range from 237 to 2,300 mg/L (table 5). The best quality water (dissolved solids less than 500 mg/L) is obtained where the quartzite crops out or underlies less than 200 feet of drift. The dissolved-solids concentrations locally exceed 2,000 mg/L where the aquifer receives highly mineralized recharge from overlying Cretaceous rocks. The aquifer is susceptible to local contamination from the land surface, particularly where the drift is thin or missing.

Table 5.--Summary of chemical analyses of water samples from Sioux Quartzite aquifer, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	25	190	200	4.6	420
Magnesium, dissolved	25	60	63	1.9	120
Sodium, dissolved	25	91	47	11	520
Potassium, dissolved	23	5.7	5.5	1.0	11
Bicarbonate	25	390	400	190	540
Sulfate, dissolved	25	580	560	29	1,500
Chloride, dissolved	17	22	5.5	1.0	180
Dissolved solids, calculated sum of determined constituents	25	1,150	1,230	237	2,300

The chemical properties of water in the aquifer are similar to those in water from overlying glacial aquifers. Calcium and bicarbonate are the dominant ions in the Rock River watershed (Anderson and others, 1976b) and sulfate is the dominant anion in the Des Moines River watershed (Anderson and others, 1976a). Calcium sulfate type water is most common in the Sioux Quartzite aquifer, based on 25 analyses (table 3).

Proterozoic Metasedimentary Aquifer

Water in the Proterozoic metasedimentary aquifer generally contains low concentrations of dissolved solids. The median dissolved-solids concentration for 30 water samples is 251 mg/L, and only one of the values exceeds 500 mg/L (table 6). Eighty-seven percent of the water samples from this aquifer are calcium magnesium bicarbonate type (table 3). The water contains much less iron, manganese, dissolved solids, and hardness than water from most other crystalline-rock aquifers.

Table 6.--Summary of chemical analyses of water samples from Proterozoic metasedimentary aquifer, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	30	49	45	8.8	200
Magnesium, dissolved	30	22	20	2.2	100
Sodium, dissolved	30	36	12	3.7	560
Potassium, dissolved	28	2.5	2.0	0.5	9.5
Bicarbonate	30	250	260	89	380
Sulfate, dissolved	12	8.4	5.0	.4	56
Chloride, dissolved	30	60	10	1.0	1,500
Dissolved solids, calculated sum of determined constituents	30	310	251	126	2,420

Biwabik Iron-formation Aquifer

Water in the Biwabik Iron-formation aquifer contains low concentrations of dissolved solids. Median dissolved-solids concentration of 14 samples is 219 mg/L and the maximum concentration is 388 mg/L (table 7). All the water samples are calcium magnesium bicarbonate type (table 3). About half of the samples can be classified as hard water (120 to 180 mg/L hardness as $CaCO_3$) and the other half as very hard water (more than 180 mg/L hardness as $CaCO_3$). Iron concentrations in most of the water samples exceed 0.3 mg/L, which the U.S. Environmental Protection Agency (1979) lists as a maximum level in secondary standards for drinking water.

Table 7.--Summary of chemical analyses of water samples from Biwabik Iron-formation aquifer, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	14	47	43	24	76
Magnesium, dissolved	14	20	18	9.5	36
Sodium, dissolved	14	7.1	4.3	3.1	12
Potassium, dissolved	13	2.0	1.7	1.0	3.5
Bicarbonate	14	220	200	170	330
Sulfate, dissolved	14	28	12	2.0	88
Chloride, dissolved	14	4.2	2.0	1.0	10
Dissolved solids, calculated sum of determined constituents	14	230	219	157	388

Undifferentiated Precambrian Aquifers

Dissolved-solids concentrations in water from the undifferentiated Precambrian aquifers range from low to high, as indicated in table 8. The aquifers are characterized by different water types in different parts of Minnesota (table 3). Because of these differences, the aquifers are discussed in reference to the areas of the State in which they occur.

Table 8.--Summary of chemical analyses of water samples from undifferentiated Precambrian aquifers in Minnesota, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	197	73	68	2.7	340
Magnesium, dissolved	197	30	25	0	170
Sodium, dissolved	197	91	63	2.0	760
Potassium, dissolved	178	5.2	4.0	.3	40
Bicarbonate	197	357	333	37	980
Sulfate, dissolved	189	178	122	2.0	1,400
Chloride, dissolved	163	47	14	.5	1,400
Dissolved solids, calculated sum of determined constituents	197	605	506	96	2,450

Central Minnesota

Water in the undifferentiated Precambrian aquifers in central Minnesota, located in the upper Mississippi River basin, generally contains low concentrations of dissolved solids. The range in dissolved-solids concentrations is from 145 to 2,130 mg/L, but the median value is only 289 mg/L (table 9) based on water samples from 69 wells. The water is a calcium magnesium bicarbonate type in 78 percent of the water samples (table 3). Only a few samples contain elevated concentrations of sodium or sulfate.

Table 9.--Summary of chemical analyses of water samples from undifferentiated Precambrian aquifers in central Minnesota, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	69	59	52	9.0	310
Magnesium, dissolved	69	23	20	6.5	120
Sodium, dissolved	69	36	15	2.0	350
Potassium, dissolved	65	3.3	2.3	1.0	21
Bicarbonate	69	310	280	130	590
Sulfate, dissolved	61	62	14	2.0	1,400
Chloride, dissolved	68	19	10	.5	260
Dissolved solids, calculated sum of determined constituents	69	362	289	145	2,130

Southwestern Minnesota

Water in the undifferentiated Precambrian aquifers in the Des Moines, Rock, and upper Minnesota River basins in southwestern Minnesota contains medium to high dissolved-solids concentrations, which generally is similar to the quality of water from other aquifers in the area. The range in dissolved-solids concentrations is from 244 to 1,980 mg/L and the median concentration is 843 mg/L (table 10). Only 7 of 64 water samples had dissolved-solids concentrations less than 500 mg/L. Dissolved-solids concentrations generally increase with depth in the aquifer. In a few places, both dissolved solids and sulfate decrease with depth, possibly as a result of soluble minerals leaching from overlying Cretaceous rocks into the Precambrian aquifer. More than a third of the 64 water samples from this aquifer were a mixed water type, nearly a third were calcium magnesium bicarbonate type, and the remaining third included mostly a calcium magnesium sulfate type (table 3).

Table 10.--Summary of chemical analyses of water samples from undifferentiated Precambrian aquifers in southwestern Minnesota, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	64	110	98	3.0	340
Magnesium, dissolved	64	49	41	1.5	170
Sodium, dissolved	64	120	93	3.1	490
Potassium, dissolved	61	6.2	6.0	.3	18
Bicarbonate	64	440	420	84	980
Sulfate, dissolved	64	360	300	5.0	1,200
Chloride, dissolved	31	49	13	1.0	540
Dissolved solids, calculated sum of determined constituents	64	915	843	244	1,980

Northeastern Minnesota

Water in the undifferentiated Precambrian aquifers in the Lake Superior and Rainy River basins in northeastern Minnesota generally contains low concentrations of dissolved solids. The median dissolved-solids concentration is 237 mg/L, and the range is 96 to 2,450 mg/L (table 11). Only 5 of the 29 samples had dissolved-solids concentrations greater than 500 mg/L. The dissolved-solids concentration is low (less than 200 mg/L) in a long narrow area just north of the Biwabik Iron-formation. Water in undifferentiated Precambrian aquifers in northeastern Minnesota is mainly a calcium magnesium bicarbonate type (table 3), but sodium bicarbonate and sodium chloride type waters are present locally.

Table 11.--Summary of chemical analyses of water samples from undifferentiated Precambrian aquifers in northeastern Minnesota, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	29	54	41	2.7	190
Magnesium, dissolved	29	18	10	0.0	92
Sodium, dissolved	29	63	16	3.9	760
Potassium, dissolved	24	2.6	1.8	.3	5.6
Bicarbonate	29	232	185	37	610
Sulfate, dissolved	29	44	11	2.7	700
Chloride, dissolved	29	77	2.5	0.6	1,400
Dissolved solids, calculated sum of determined constituents	29	392	237	96	2,450

Northwestern Minnesota

Water in the Undifferentiated Precambrian aquifers in the Red River basin in northwestern Minnesota contains medium to high concentrations of dissolved solids and is characterized by mixed water types (table 3). Dissolved-solids concentrations range from 333 to 2,060 mg/L and the median concentration is 539 mg/L (table 12). Dissolved-solids concentrations less than 500 mg/L were found in 13 of the 35 samples and were greater than 1,000 mg/L in 7 samples.

Table 12.--Summary of chemical analyses of water samples from undifferentiated Precambrian aquifers in northwestern Minnesota, 1960-81

[Concentrations in milligrams per liter]

Constituent	Number of samples	Mean	Median	Minimum	Maximum
Calcium, dissolved	35	47	42	4.0	120
Magnesium, dissolved	35	21	20	1.8	64
Sodium, dissolved	35	170	140	3.4	700
Potassium, dissolved	28	9.7	5.3	2.4	40
Bicarbonate	35	400	400	270	660
Sulfate, dissolved	35	160	75	12	810
Chloride, dissolved	35	75	32	10	380
Dissolved solids, calculated sum of determined constituents	35	695	539	333	2,060

Dissolved-solids concentrations as high as 2,060 mg/L in the undifferentiated Precambrian aquifers along the western border of Minnesota reflect the influence of recharge from the overlying Cretaceous aquifer. Both Kelly (1968) and Swenson (1968) describe the eastward movement of water across North and South Dakota through the Dakota sandstone of Cretaceous age and the associated increase in dissolved solids. Calcium concentrations are often lower than sodium concentrations in the aquifer along the western edge of Minnesota. This correlates with areas where Cretaceous shale and the Des Moines drift are thick and overlie the Precambrian aquifers. Ion exchange in the clays is a source of sodium in water that recharges Precambrian aquifers in northwest Minnesota. Sodium concentration is as much as 700 mg/L near the western border of Minnesota, but it generally is less than 100 mg/L in the eastern part of the Red River basin.

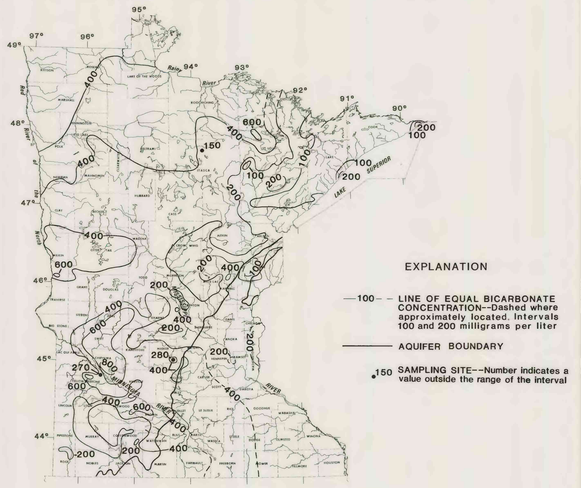

Figure 10.--Concentration of bicarbonate

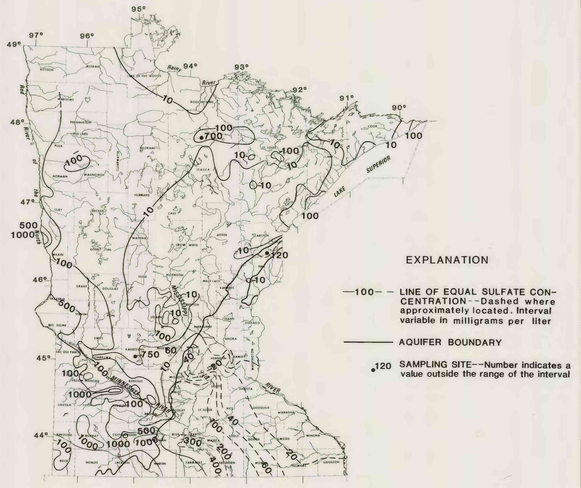

Figure 11.--Concentration of sulfate

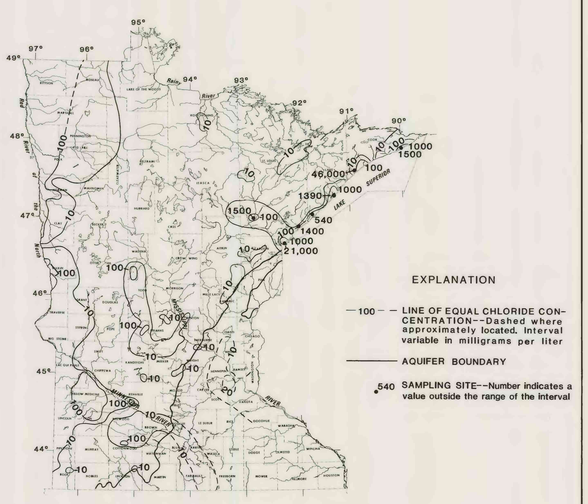

Figure 12.--Concentration of chloride

HYDROGEOLOGIC AND WATER-QUALITY CHARACTERISTICS OF CRYSTALLINE-ROCK AQUIFERS OF ARCHEAN AND PROTEROZOIC AGE, MINNESOTA

BY
H. W. ANDERSON, JR., 1986

Base from U.S. Geological Survey
State base map, 1:1,000,000, 1965