GEOLOGY AND GROUND WATER AND GROUND–WATER QUALITY

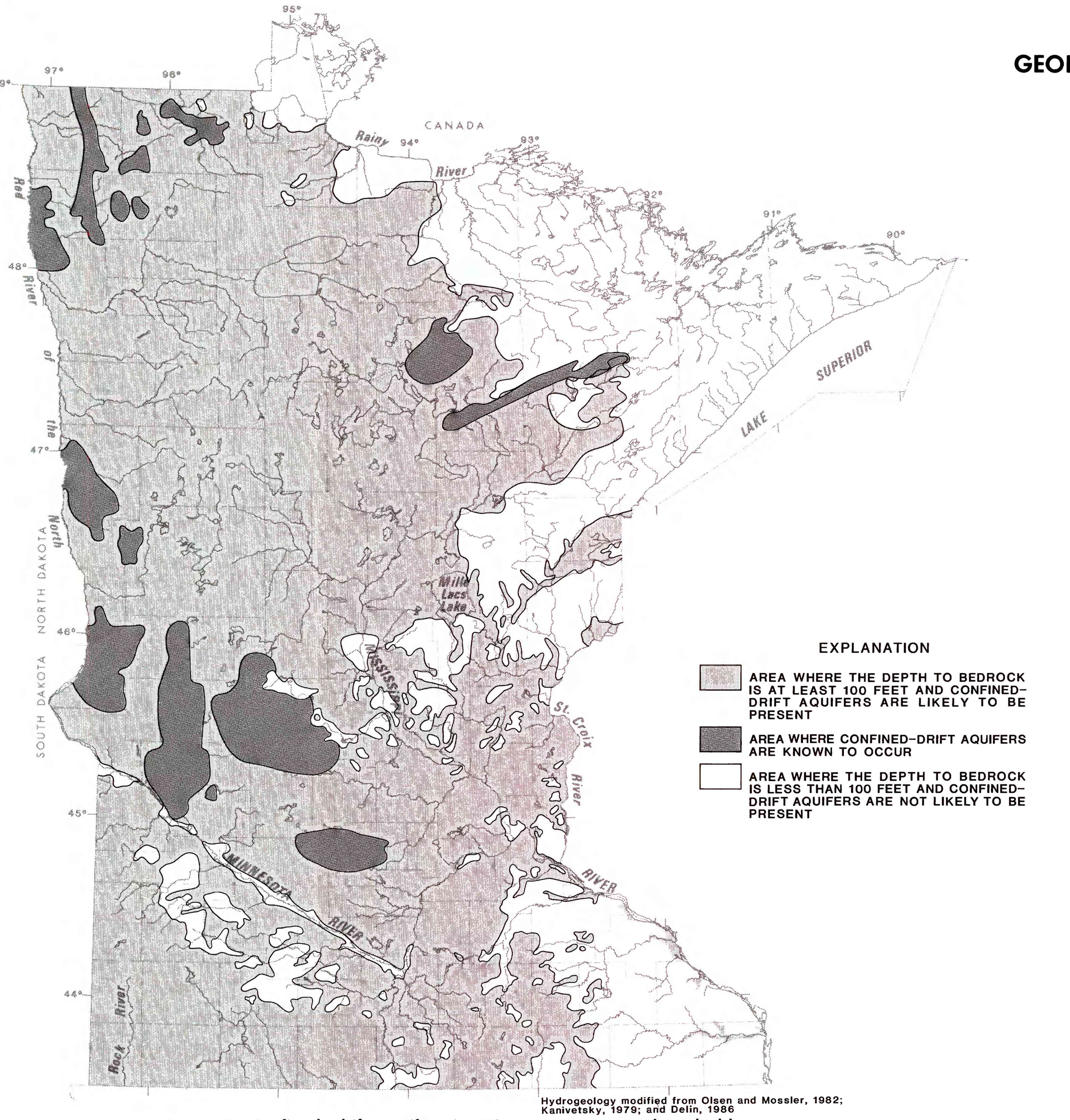

Figure 2.--Confined–drift aquifers in Minnesota––areas of probable occurrence based on drift thickness and results from previous studies

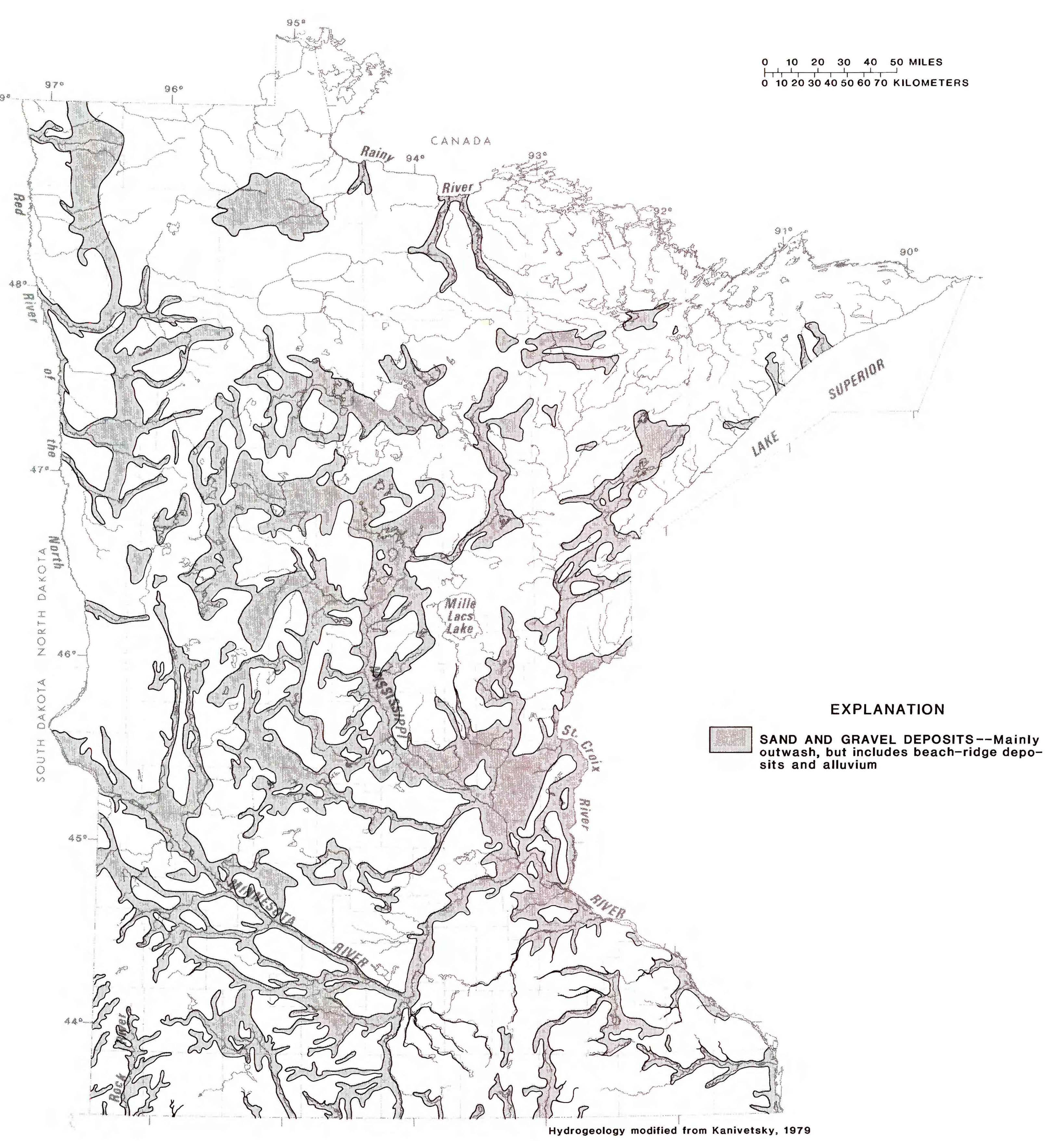

Figure 1.--Unconfined–drift aquifers in Minnesota

ABSTRACT

Water in Minnesota's glacial-drift aquifers generally is of acceptable quality for most uses, including household supply, industrial use, and irrigation. The aquifers generally contain calcium magnesium bicarbonate-type waters, but other types are present also.

Calcium magnesium sulfate-type waters are common in the confined-drift aquifers in the southwestern and northwestern parts of the State. The elevated concentrations of sulfate, which exceed limits recommended for drinking water by the U.S. Environmental Protection Agency (USEPA), result mainly from solution of sulfate-bearing minerals in rocks of Cretaceous age that have been reworked in deep glacial drift.

Sodium and chloride-type waters are common in drift aquifers in northwestern Minnesota owing to the inflow of saline water from bedrock aquifers of Cretaceous age in North Dakota. Cation exchange with clay minerals in the drift also is a source of sodium to these waters, particularly in the confined-drift aquifers. Some of the water from these aquifers are unsuitable for irrigation because of elevated concentrations of sodium, and some are unsuitable for drinking because of elevated concentrations of chloride.

Concentrations of nitrite plus nitrate (as N) locally exceed the U.S. Environmental Protection Agency (USEPA) recommended limits for drinking water in central and northwestern Minnesota. Shallow, unconfined-drift aquifers are particularly susceptible to nitrate contamination from land surface. Confined-drift aquifers are much less susceptible because overlying till deposits retard downward movement of contaminants to the deeper aquifers. Nitrate contamination, which may cause methemoglobinemia in infants, is one of the more serious water-quality concerns in Minnesota. Iron and manganese concentrations commonly exceed USEPA's recommendations for drinking water throughout the State, but these constituents affect aesthetic properties of water rather than health.

INTRODUCTION

Background

The U.S. Geological Survey began a study in 1980 of the quality of water in the principal aquifers of Minnesota. The U.S. Environmental Protection Agency funded the study as part of the Underground Injection Control Program, which deals with disposal of liquid wastes beneath land surface. The initial report of the study identified 14 aquifers in the State and provided general information about their geologic, hydrologic, and water-quality characteristics (Adolphson and others, 1981, p. 10-17). This report is one in a series that describes individual aquifers in more detail.

Purpose and Scope

The report, which contains three plates with text and illustrations, describes the hydrogeology and water quality of glacial-drift aquifers in Minnesota. The text provides an overview of glacial geologic events that formed these aquifers. It also summarizes the hydrogeologic characteristics of these aquifers, and distinguishes unconfined-drift aquifers from confined-drift aquifers on the basis of their hydrogeologic features. Water quality is evaluated in each of the two kinds of glacial-drift aquifers, using analyses of samples from approximately 460 shallow-drift wells that represent unconfined-drift aquifers, and from 350 deep-drift wells that represent confined-drift aquifers. The water-quality data were used to determine major water types, variations in the concentrations of major ions and dissolved solids, and compliance with U.S. Environmental Protection Agency recommendations for drinking water.

Previous Investigations

Numerous interpretive and data reports have been published that provide information about the quality of water in the glacial-drift aquifers in Minnesota. A series of Hydrologic Atlases, published by the U.S. Geological Survey, describes the water resources of the 39 principal watersheds established by the Minnesota Department of Natural Resources. Most of the atlases include basic water-quality information about glacial-drift aquifers because they are important sources of water. A multidisciplinary investigation of water resources in the Red River of the North drainage basin in northwestern Minnesota provides an evaluation of ground-water quality in that region (Maclay and others, 1972, p. 61-68). In addition, the U.S. Geological Survey has conducted many studies, limited in scope to several counties, of glacial-drift aquifers, particularly the shallow, unconfined aquifers. Most of these studies completed since the 1970's contain water-quality information, such as the dominant water type, concentrations of various chemical constituents, and, problems caused by contamination (Adolphson, 1983; Anderson, 1986; Delin, 1986; Helgesen, 1977; Lindholm, 1980; Miller, 1982; Myette, 1984a; Myette, 1984b; Myette, 1986; Soukup, 1980; Wolf, 1976; Wolf, 1981). Other studies of glacial-drift aquifers were completed in the 1950's and 1960's. The reports produced from these studies, which are not cited here, are available in the U.S. Geological Survey District Office in St. Paul, Minnesota. Winter (1974), in a report about ground-water quality in Minnesota, discusses water types in the glacial-drift aquifers in various parts of the State. His report provides an overview of geochemical processes that affect the concentrations of major ions in the drift aquifers. The Minnesota Pollution Control Agency has published three basic-data reports that contain information about glacial-drift aquifers. Two of the reports, published in 1981 and 1985, respectively, are compilations of analytical data (Sabel, 1985a; Trippler and Clark, 1981). They contain summaries of the chemical, physical, and biological properties of ground water from each of the major aquifers. The third report, published in 1984, provides the basic data, listed by individual analysis, collected since the program started in 1978 (Sabel, 1985b).

HYDROGEOLOGY CHARACTERISTICS

Four continental glaciations advanced and retreated across Minnesota during the Pleistocene Epoch, which spanned a period of time that lasted from about two million years ago to about 10,000 years ago. The most recent episode of glaciation--the Wisconsin glaciation of the Pleistocene--occurred about 12,000 years ago. Wisconsin glaciation determined most of the present topography of Minnesota except, possibly, in southeastern Minnesota where conclusive evidence of this most recent glaciation has never been discovered (Sims and Morey, 1972, p. 518).

Glacial deposits in Minnesota consist of two basic types: (1) stratified sand and gravel that forms mainly outwash and, to a lesser extent, ice-contact deposits and glaciofluvial sediments along river valleys, and (2) unstratified and unsorted clay, sand, gravel, and boulders that form till. Most of the glacial deposits consist of till.

Glacial deposits in Minnesota have a varied lithology and complex stratigraphy. Multiple glaciations originated from different areas at different times, and each one deposited materials with a unique mineral composition. Ice lobes that advanced across the State from the northwest deposited gray, calcareous materials that contain fragments of limestone and shale. Ice lobes that advanced across the State from the northeast deposited reddish, noncalcareous materials. The ice lobes from the two source areas overlapped in many parts of the State and, in the overlap areas, mixed to form deposits of highly variable composition.

Coarse sand and gravel deposits that readily yield water to wells comprise the glacial-drift aquifers. These aquifers consist primarily of outwash, but they also include ice-contact deposits, alluvium, and beach-ridge deposits. The aquifers commonly are classified as unconfined or confined, depending on the hydraulic head conditions in the aquifer. Ground water in unconfined-drift aquifers is open to the atmosphere, and the water levels in these aquifers represent the water table. Ground water in confined-drift aquifers, on the other hand, is confined at greater than atmospheric pressure by a low-permeability layer such as clay or till. Water levels in wells completed in these aquifers will rise above the upper surfaces of these aquifers, a condition commonly referred to as artesian.

Unconfined-drift aquifers can be identified on the basis of the composition of surficial materials, regional landforms, and vegetation patterns. The areal extent of surficial deposits of stratified sand and gravel generally represents the areal extent of unconfined-drift aquifers. These deposits have been mapped in Minnesota and are shown in figure 1 as unconfined-drift aquifers.

Confined-drift aquifers are more difficult to locate. Surficial expressions provide few if any clues about the location of these aquifers, which commonly occur as separate sand and gravel lenses buried within the drift. Drilling is currently the most reliable method to determine the presence of these aquifers, although seismic and electrical resistivity geophysical methods offer some promise of being less costly alternatives.

In the absence of a map of confined-drift aquifers in Minnesota, figure 2 shows where confined-drift aquifers may be present based on thickness of the drift. The aquifers are likely to occur in nearly every part of the State, except for the northeast and southeast, where the drift is less than 100 feet thick (fig. 2). The figure also shows locations of the relatively small number of confined-drift aquifers that have been located in the subsurface during the course of previous, small scale-studies.

WATER-QUALITY CHARACTERISTICS

Methods of Analysis and Data Interpretation

The U.S. Geological Survey collected all the water-quality data interpreted in this report. The data were separated into two groups on the basis of the depth of the well sampled. Samples from wells less than or equal to 50 feet deep were assumed to represent shallow-drift aquifers. Samples from wells greater than 50 feet were assumed to represent deep-drift aquifers. The data base contains analyses of samples from approximately 460 shallow-drift wells and analyses of samples from 350 deep-drift wells. The cations and anions in each of the analyses in the data base balance within 10 percent.

The reason for the separation of the analyses into the two classes is to elucidate variations in water quality with depth, and to enable a qualitative assessment to be made of differences in water quality between the unconfined- and confined-drift aquifers. Analyses in the shallow-drift group are indicative of water quality in unconfined-drift aquifers, and analyses in the deep-drift group are indicative of water quality in confined-drift aquifers. Separation of the analyses based on depth of the sampling wells was the easiest and quickest means to organize the data into groups that represent the two aquifers.

Methods of Representing Data

Tables 1 and 2 summarize the data for the shallow- and deep-drift analyses, respectively. The 5th and 95th percentiles and the median values are listed for selected constituents. The 5th and 95th percentiles are those values in a group that are greater than 5 percent and greater than 95 percent of all the values in that group, respectively.

The relative concentrations of major ions, expressed in milliequivalents per liter, determine the water-quality type. For instance, in calcium magnesium bicarbonate-type waters, at least half the total cations are calcium and magnesium, and at least half the total anions are bicarbonate. Water-quality diagrams shown in figure 3 represent the proportions of major ions, expressed in milliequivalents per liter, of waters in the shallow-drift and deep-drift groups, respectively, for the entire State and for selected areas of the State. Diagrams of this kind ordinarily are prepared on the basis of concentrations for an individual analysis; however, the diagrams in figure 3 are based on median concentrations from multiple analyses.

The distribution of data points is shown in terms of quartiles for the major ions and dissolved solids for shallow- and deep-drift analyses in figures 4-17. These figures show the location of each sampling site in terms of the following three categories: (1) the concentration of the constituent is greater than the 75th percentile, which places the value in the upper quartile, (2) the concentration is less than the 75th percentile and greater than the 25th percentile, which places the value in one of the middle quartiles, or (3) the concentration is less than the 25th percentile, which places the value in the lower quartile.

Suitability for drinking is a primary concern about the quality of water in the glacial-drift aquifers, because they are used widely in rural and suburban areas for domestic supplies. Standards for drinking water established by the U.S. Environmental Protection Agency (USEPA) provide a convenient means to evaluate water-quality data (U.S. Environmental Protection Agency, 1976, 1977). Table 3 lists some common constituents that occur naturally in fresh waters and the recommended limiting concentrations in drinking water. Table 3 also provides brief descriptions of the value of the constituents for some uses and the water-quality problems that occur when the constituents exceed the recommended limits. The table also includes the number of analyses in which the concentration of the constituent exceeded the recommended limit, and the percentage that this number is of the total number of analyses. The locations of wells in both shallow- and deep-drift groups where samples contained nitrite plus nitrate, sulfate, iron, manganese, and chloride, in concentrations that exceeded the recommended limits, are shown in figures 18 through 27.

Table 1.--Summary of water-quality analyses for samples collected from shallow-drift wells

[Values in milligrams per liter except as indicated. N, number of samples; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L, micrograms per liter]

Constituent or property	N	5th Percentile	95th Percentile	Median
Specific conductance, µS/cm	478	178	835	542
Calcium, dissolved, (Ca)	999	24	140	77
Magnesium, dissolved, (Mg)	467	5.3	74	21
Sodium, dissolved, (Na)	486	1.8	54	4.3
Bicarbonate, as HCO_3	194	87	580	310
Alkalinity, as $CaCO_3$	142	36	290	200
Sulfate, dissolved, (SO_4)	760	2.0	210	18
Chloride, dissolved, (Cl)	1,276	1.2	58	11
Fluoride, dissolved, (F)	434	0.1	0.4	0.1
Silica, dissolved, (SiO_2)	452	9.2	28	19
Solids, dissolved, as residue on evaporation at 180 C	378	115	1,180	317
Nitrite plus nitrate, dissolved, as N	1,152	0.03	25	20
Boron, dissolved, (B) µg/L	332	<10	220	20
Iron, dissolved, (Fe) µg/L	946	<10	9,000	190
Manganese, dissolved, (Mn) µg/L	445	1	800	70

Table 2.--Summary of water-quality analyses for samples collected from deep-drift wells

[Values in milligrams per liter except as indicated. N, number of samples; µS/cm, microsiemens per centimeter at 25° Celsius; µg/L. micrograms per liter]

Constituent or property	N	5th Percentile	95th Percentile	Median
Specific conductance, µS/cm	39	301	941	621
Calcium, dissolved, (Ca)	558	26	380	80
Magnesium, dissolved, (Mg)	521	10.1	120	33
Sodium, dissolved, (Na)	495	2.8	240	26
Bicarbonate, as HCO_3	496	190	560	350
Alkalinity, as $CaCO_3$	29	132	474	322
Sulfate, dissolved, (SO_4)	561	1.8	1,000	61
Chloride, dissolved, (Cl)	561	0.8	130	4.5
Fluoride, dissolved, (F)	487	0.1	0.7	0.3
Silica, dissolved, (SiO_2)	418	12	30	24
Solids, dissolved, as residue on evaporation at 180 C	534	224	2,120	484
Nitrite plus nitrate, dissolved, as N	69	<.1	20	0.06
Boron, dissolved, (B) µg/L	400	<10	789	<10
Iron, dissolved, (Fe) µg/L	399	20	8,700	1,100
Manganese, dissolved, (Mn) µg/L	370	<100	970	140

Table 3.--Recommended limits, significance, and exceedance of limits, for common water-quality properties and constituents analyzed in samples from shallow- and deep-drift wells

[Values in milligrams or grams per liter]

			Sites that exceed standards			
			Shallow drift		Deep drift	
Property or constituent	Limit for public supply	Significance	Number	Percent of total	Number	Percent of total
Specific conductance		An indirect measure of the total concentration of ions in the water.				
Calcium		Principal cation in most of Minnesota's waters. Major cause of hardness.				
Magnesium		Second-most abundant cation in Minnesota's waters. A cause of hardness.				
Sodium		Principal cation in ground water from parts of western Minnesota. Sodium-type waters undesirable for irrigation.				
Alkalinity		Capacity for neutralizing acid. Attributed mostly to bicarbonate ion.				
Bicarbonate		Principal anion in most of Minnesota's waters.				
Chloride	250 mg/L[a]	Principal anion in some of the groundwater of western Minnestota, particularly the Paleozoic bedrock in the northwestern corner. Contributes to salinity and can cause salty taste.	12	3.3	20	4.3
Sulfate	250 mg/L[a]	Principal anion in groundwater from Cretaceous deposits, particularly those in the southwestern part of the State. Can cause a laxative effect on people.	21	5.8	128	28.0
Potassium		Widely distributed cation in ground water; essential for nutrition.				
Dissolved solids		Total concentration of dissolved substances. Fresh waters generally contain less than 1,000 mg/l. Normally, the lower the dissolved-solids concentration, the better the quality of the water for all uses.				
Silica		Essential plant nutrient.				
Nitrite + nitrate	10 mg/L (as N)[b]	May cause methymoglobinemia in infants. Indicates pollution from animal wastes or fertilizer.	71	19.8	14	3.0
Boron		Essential plant micronutrient.				
Iron	300 µg/L[a]	Can cause stains on laundry and fixtures and unpleasant tastes in beverages. Widely distributed.	56	15.6	75	16.4
Manganese	50 µg/L[a]	Causes stains and affects taste.	60	16.7	65	14.2

a Secondary drinking-water standards established by U.S. Environmental Protection Agency (1977)
b Primary drinking-water standards established by U.S. Environmental Protection Agency (1976).

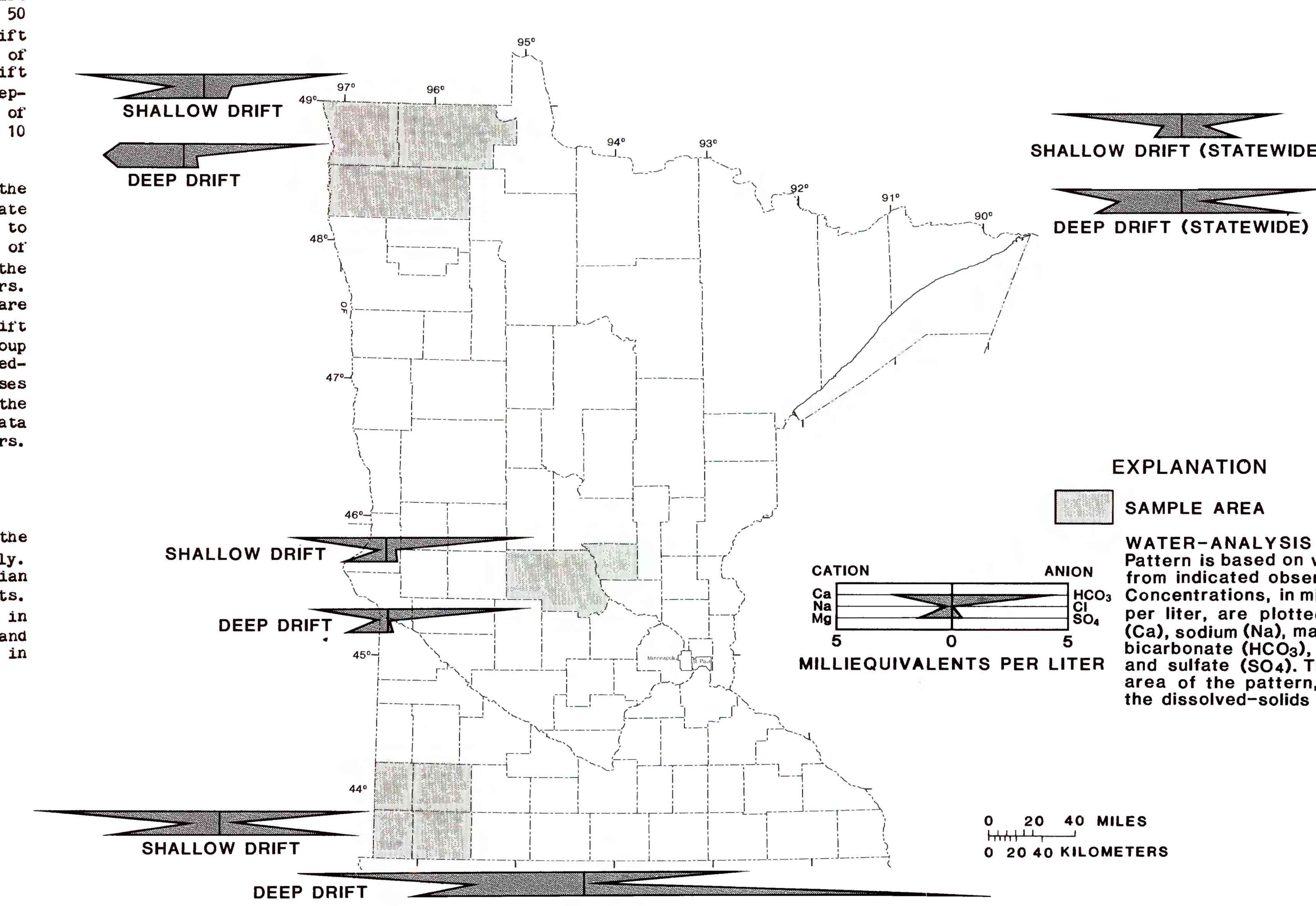

Figure 3.--Water–quality diagrams representative of water from glacial–drift aquifers in Minnesota and selected parts of Minnesota

HYDROGEOLOGIC AND WATER–QUALITY CHARACTERISTICS OF GLACIAL–DRIFT AQUIFERS IN MINNESOTA

BY
J. F. RUHL, 1987

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