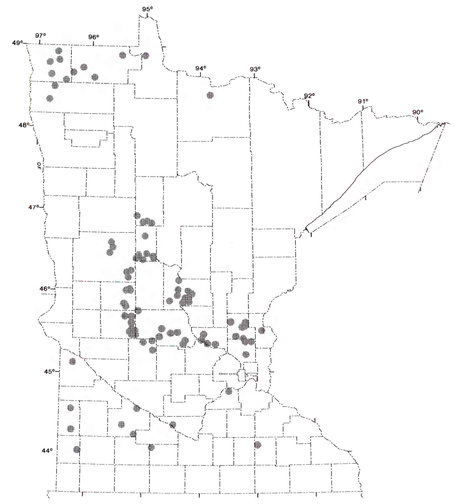

Figure 18.--Nitrite + Nitrate

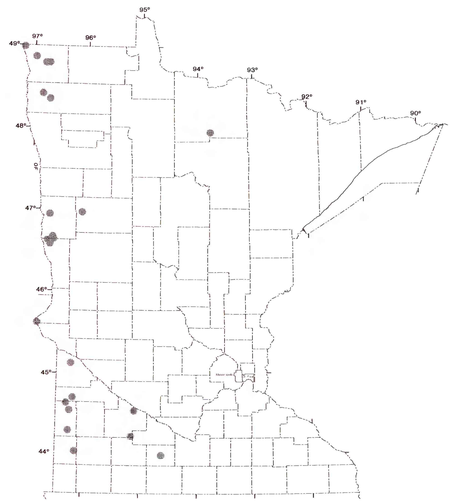

Figure 20.--Sulfate

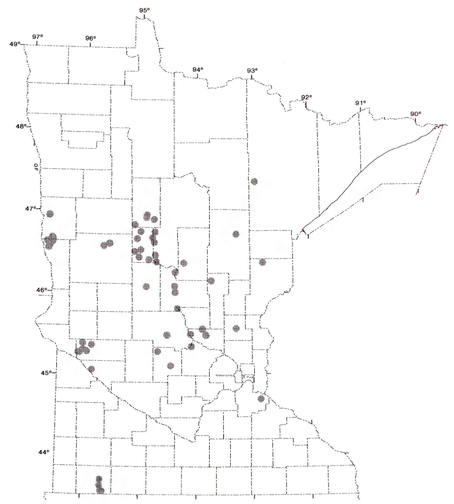

Figure 22.--Iron

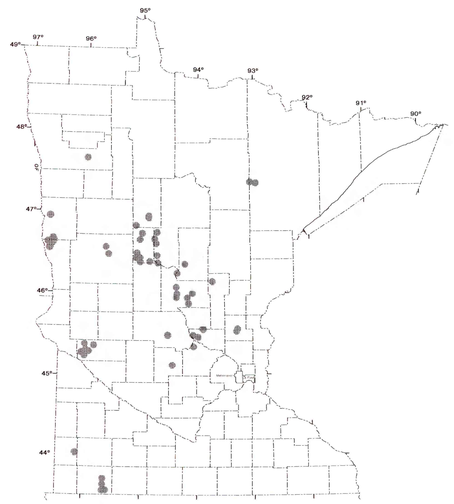

Figure 24.--Manganese

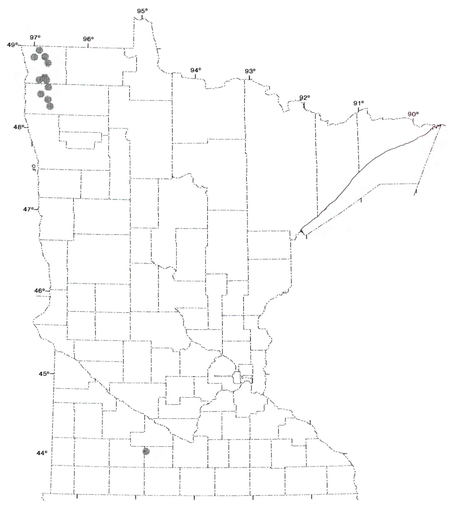

Figure 26.--Chloride

SHALLOW-DRIFT WELLS WHERE SAMPLES CONTAINED CONCENTRATIONS THAT EXCEEDED THE RECOMMENDED LIMITS

Water-Quality Types

Minnesota's glacial-drift aquifers, particularly those in the shallow drift, contain mostly calcium magnesium bicarbonate type water (Winter, 1974, p. 14; Sabel, 1985b, p. 11). The composite water-quality diagrams for the entire State in figure 3 show calcium magnesium bicarbonate waters to be the most representative type in both the shallow and deep drift. The diagrams in figure 3 also show that calcium and magnesium are the dominant cations in each of the three selected areas in the shallow-drift, and also in the central and southwestern areas in the deep-drift.

Other water types, however, occur in glacial-drift aquifers. Calcium magnesium sulfate, sodium chloride, sodium bicarbonate, and sodium sulfate type waters, are common locally in northwestern and southwestern Minnesota (Winter, 1974 p. 14-16). Figure 3 shows that sodium is the dominant cation in the deep drift in the northwest, and that sulfate is the dominant anion in the deep drift in the southwest.

The chemical composition of ground water represents the net effect of many chemical and biochemical interactions between the ground water and the geologic materials that comprise the aquifers. The mineralogic composition of the drift is one of the significant factors that determine the quality of water in glacial-drift aquifers.

Glacial drift in the northwestern and southwestern areas of the State is gray, carbonate-rich material deposited by ice lobes that advanced across the State from the northwest. The drift in the central part of the State is a mixture of the gray drift and carbonate-poor reddish drift deposited by glaciers from the northeast. Much of the drift in central, east-central, and south-central Minnesota is a mixture of the gray and red drifts.

The glacial-drift aquifers in the three selected areas represented in figure 3 comprise various kinds of glacial deposits. The aquifers in the northwest consist of (1) ice-contact deposits, channel outwash, and linear beach-ridge deposits, that are mainly in the shallow drift, and (2) lenses of glaciofluvial sand and gravel that underlie till in the deep drift. Sedimentary bedrock of Paleozoic age and scattered deposits of Cretaceous age underlie the drift in this area. The shallow- and deep-drift aquifers in the southwest consist mainly of outwash deposited in a network of long, narrow meltwater channels. The drift in this area overlies sedimentary rocks of Cretaceous age and much older igneous and metamorphic rocks of Proterozoic age. Glacial-drift aquifers in the central part of the State consist mainly of outwash in both the shallow and deep drift. These aquifers overlie crystalline bedrock of Proterozoic age, except in the eastern quarter of the area where the aquifers overlie bedrock of Paleozoic age.

Geochemical Processes that Influence Water Quality

Carbonate minerals that form part of the aquifer matrix are sources of calcium and magnesium in ground water from Minnesota's glacial-drift aquifers. Calcite, which is calcium carbonate, and dolomite, which is a mixture of calcium and magnesium carbonate, are abundant in the glacial drift from northwest sources. Carbonic acid, which is produced when atmospheric carbon dioxide dissolves in the ground water, can react with these minerals to produce calcium and magnesium cations and bicarbonate anions. The chemical equation for the solution of calcite in water is

$$CaCO_3(c) + H^+ = Ca^{+2} + HCO_3^-$$

The equation for the solution of dolomite is nearly the same; the difference is the formation of one magnesium cation and an additional bicarbonate anion.

Elevated concentrations of sodium in the glacial-drift aquifers of western Minnesota are due in part to the exchange of ions in the ground water with ions in clay and organic materials mixed into the drift from underlying rocks of Cretaceous age (Winter, 1974, p. 16). This natural softening process reduces concentrations of calcium and magnesium in the ground water and increases the concentration of sodium. Another source of sodium, particularly in northwest Minnesota, is the upward movement of saline water from underlying rocks of Paleozoic age. Sodium chloride type waters flow through the bedrock in an easterly direction from the Dakotas, and are under sufficient hydraulic head in northwest Minnesota to flow vertically upward into the overlying, hydraulically connected drift aquifers (Winter, 1974, p. 17).

Sulfate-type waters are common in the deep drift of southwest Minnesota because of the abundance of soluble, sulfur-containing minerals, such as gypsum and pyrite, that react with the ground water to form sulfate ions. Sources of these minerals are Cretaceous sediments admixed with the deep drift. Gypsum, which consists of hydrous calcium sulfate, can dissociate in water to form calcium and sulfate ions as follows:

$$CaSO_4 \cdot 2H_2O = Ca^{+2} + SO_4^{-2} + 2H_2O \quad \text{(Hem, 1985, p. 26).}$$

Oxidation of pyrite (iron sulfide) to form sulfate ions also may occur if the ground water is in an oxidizing environment.

Suitability for Water Supply

Water from glacial-drift aquifers in Minnesota generally is of acceptable quality for most uses, such as household supply, industrial supply, and irrigation. However, high concentrations of naturally occurring constituents, and contamination by organic chemicals, pesticides, and herbicides, degrade quality of the water in some areas. These problems generally are more serious in the shallow unconfined-drift aquifers where vulnerability to contamination is greatest.

Figures 18 through 27 show sampling locations where the concentrations of constituents in samples collected from the wells exceed the standards for drinking water recommended by the U.S. Environmental Protection Agency. All the constituents, except nitrate, that are plotted in these figures affect aesthetic properties of the water, such as taste and odor.

Nitrate contamination in glacial-drift aquifers is much more of a problem in the shallow drift than in the deep-drift (figures 18 and 19). The concentration of nitrate exceeded the recommended limit in nearly 20 percent of the samples from shallow-drift wells, but in only three percent of samples from deep-drift wells (table 3). Most of the nitrate-contaminated water from wells in the shallow-drift aquifers are in the central and northwestern parts of the State, where agriculture is the dominant land use (fig. 18).

The concentration of sulfate exceeded the USEPA's recommended limits in samples from deep-drift wells throughout the southwestern and, to a lesser extent, northwestern parts of the State, and from shallow-drift wells at scattered locations along the western border of the State (figures 20 and 21). Iron and manganese concentrations exceeded the recommended limits in samples from both shallow- and deep-drift aquifers mainly in the central part of the State, and from deep-drift aquifers throughout the State (figures 22 through 25). Chloride concentrations in samples from the shallow- and deep-drift aquifers exceeded the recommended limits mainly in the northwestern part of the State (figures 26 and 27).

EXPLANATION

● WELL LOCATION WHERE THE CONCENTRATION EXCEEDS THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S RECOMMENDED LIMIT FOR DRINKING WATER

Table 3 lists common constituents in the glacial-drift aquifers of Minnesota that exceed the recommended limits for drinking water established by the USEPA. Among these constituents, nitrates (determined as nitrite plus nitrate) pose the most serious threat because elevated concentrations in drinking water may cause methemoglobinemia in infants, which can be fatal. Table 3 also includes constituents or properties that may adversely affect quality of water for uses other than drinking. For instance, high concentrations of calcium and magnesium in water contribute to hardness, which is common in water from glacial-drift aquifers throughout Minnesota. Water from glacial-drift aquifers in northwest Minnesota, where salinity commonly is high, contains elevated concentrations of dissolved-solids that limits its use for nearly all purposes (Maclay and others, 1972).

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DEEP-DRIFT WELLS WHERE SAMPLES CONTAINED CONCENTRATIONS THAT EXCEEDED THE RECOMMENDED LIMITS

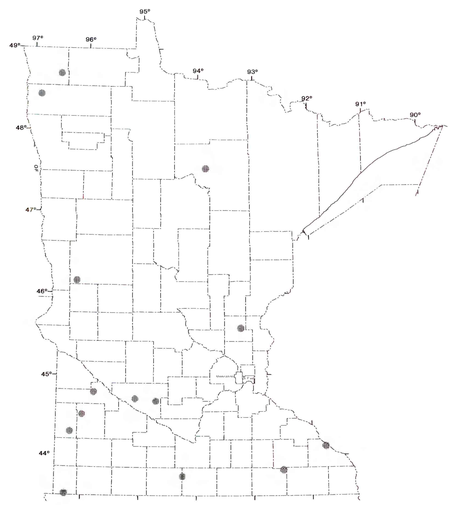

Figure 19.--Nitrite + Nitrate

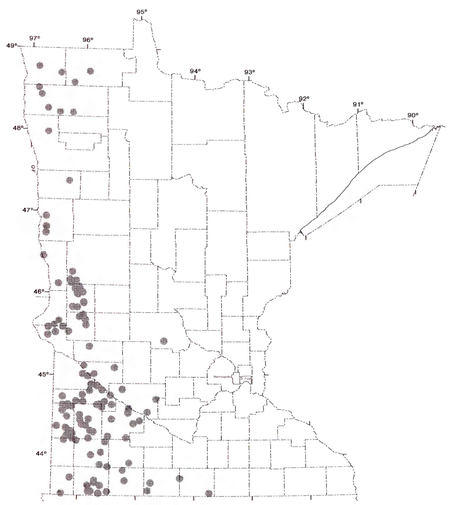

Figure 21.--Sulfate

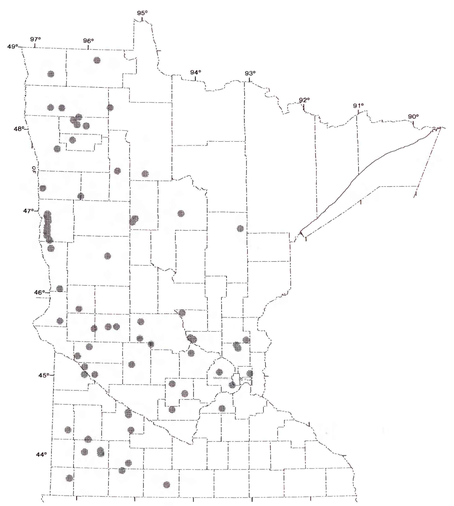

Figure 23.--Iron

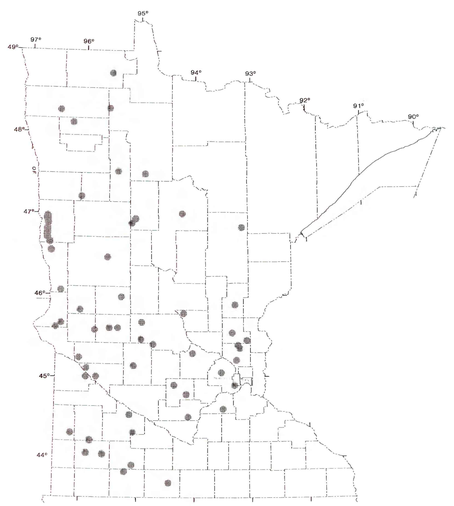

Figure 25.--Manganese

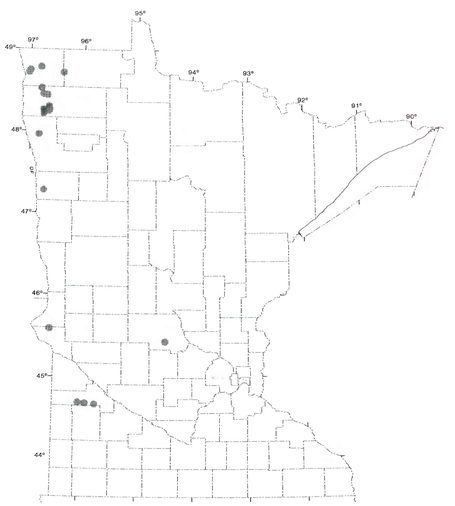

Figure 27.--Chloride

0 20 40 MILES
0 20 40 60 KILOMETERS

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

BY
J. F. RUHL, 1987

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State base map, 1:1,000,000, 1965

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