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The Chemical Composition of Lakes in the North-central United States

by

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The chemical composition of lakes in the north-central United States

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ABSTRACT

Lake waters of the north-central United States are classified into five groups, based on increasing specific conductivity and changes in ionic composition, from Wisconsin through Minnesota to North and South Dakota. The most dilute group of waters has specific conductivities less than 29 μmhos cm $^{-1}$ at 25°C; the most concentrated group has specific conductivities that range from 7,000 to 73,000 μmhos. As conductivity increases all major ions increase, but there is a shift in cation dominance from Ca^{2+} to Mg^{2+} to Na^+, and in anion dominance from HCO_3^- to SO_4^{2-}. This shift partly reflects a westward increase in climatic aridity, and partly a westward sequence of glacial drifts from noncalcareous to calcareous to calcareous with abundant sulfur-bearing minerals. Values of pH, K^+, Cl^-, F^-, B and SiO_2 also show a distinct westward increase. Concentrations of NO_3^- and Mn likewise increase from east to west, but the trend is less distinct. Concentrations of Fe vary

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widely without any trend over the range of conductivity. Color, mostly from dissolved organic matter, is controlled chiefly by lake depth except for lakes with extensive peatlands in their drainage basins.

INTRODUCTION

Investigators have treated environmental controls on the surface-water chemistry of inland waters in different ways. Some have chosen areal treatments at various geographical scales from global (Clarke, 1924: Conway, 1942: Gibbs, 1970) to regional (Clarke, 1924: Gorham, 1955; Reeder and others, 1972) to local (Mackereth, 1957; Gorham, 1957a, and 1957b; Garrels and MacKenzie, 1967). Others have examined environmental factors separately with appropriate examples chosen from different regions (Gorham, 1961), discussed individual elements one by one (Hem, 1970), or provided a strongly theoretical treatment (Stumm and Morgan, 1970). This paper examines the chemistry of surface waters of lakes in the north-central states of Wisconsin, Minnesota, North Dakota, and South Dakota, classifies them into chemical categories, and relates their concentration and composition to environmental factors.

We thank Gary Glass for providing water samples from dilute lakes in the Boundary Waters Canoe Area of Minnesota, and the analytical laboratories of the U.S. Geological Survey for analyzing most of the water samples on which we report. Ronald H. Hofstetter assisted in the analysis of Minnesota waters. George H. Harrach provided valuable assistance with computer-generated graphic plots. We are grateful for suggestions and criticisms offered by Robert Hecky, William Lewis, Daniel Livingston, John Turk, and Thomas Winter.

Description of the region

The study area is centered on 96°W, 45°N. It is about 1,000 km long from the Missouri River in the west to Lake Michigan in the east, and about 700 km wide from the Canadian border on the north to the Wisconsin border on the south. Elevations range from about 240 m ASL in eastern Wisconsin to about 550 m in north-central Wisconsin, northeastern Minnesota, and western South Dakota (Winter, 1974, and 1977: Petri and Larson, 1971).

Geology

Lakes in this region are mostly in glacial till and outwash or glacial lake sediments, although bedrock basins in crystalline igneous and metamorphic rocks are common in northeastern Minnesota and occur occasionally elsewhere.

The exposed bedrocks in northeastern Minnesota and northern Wisconsin are igneous Precambrian granite, gabbro, diabase and basalt, together with metamorphosed igneous and sedimentary rocks (Fig. 1, Winter, 1974, and 1977; Poff, 1970). Consolidated Paleozoic sandstone, dolomite, and limestone underlie much of the southern half of Wisconsin and southeastern Minnesota. Poorly consolidated Cretaceous shale is common in western Minnesota, except in the midwestern part where Precambrian granites and quartzites are at or near the land surface (Winter, 1974). Poorly consolidated Cretaceous and Tertiary shale, siltstone and sandstone predominate in the Dakotas (Sloan, 1972; Winter, 1977).

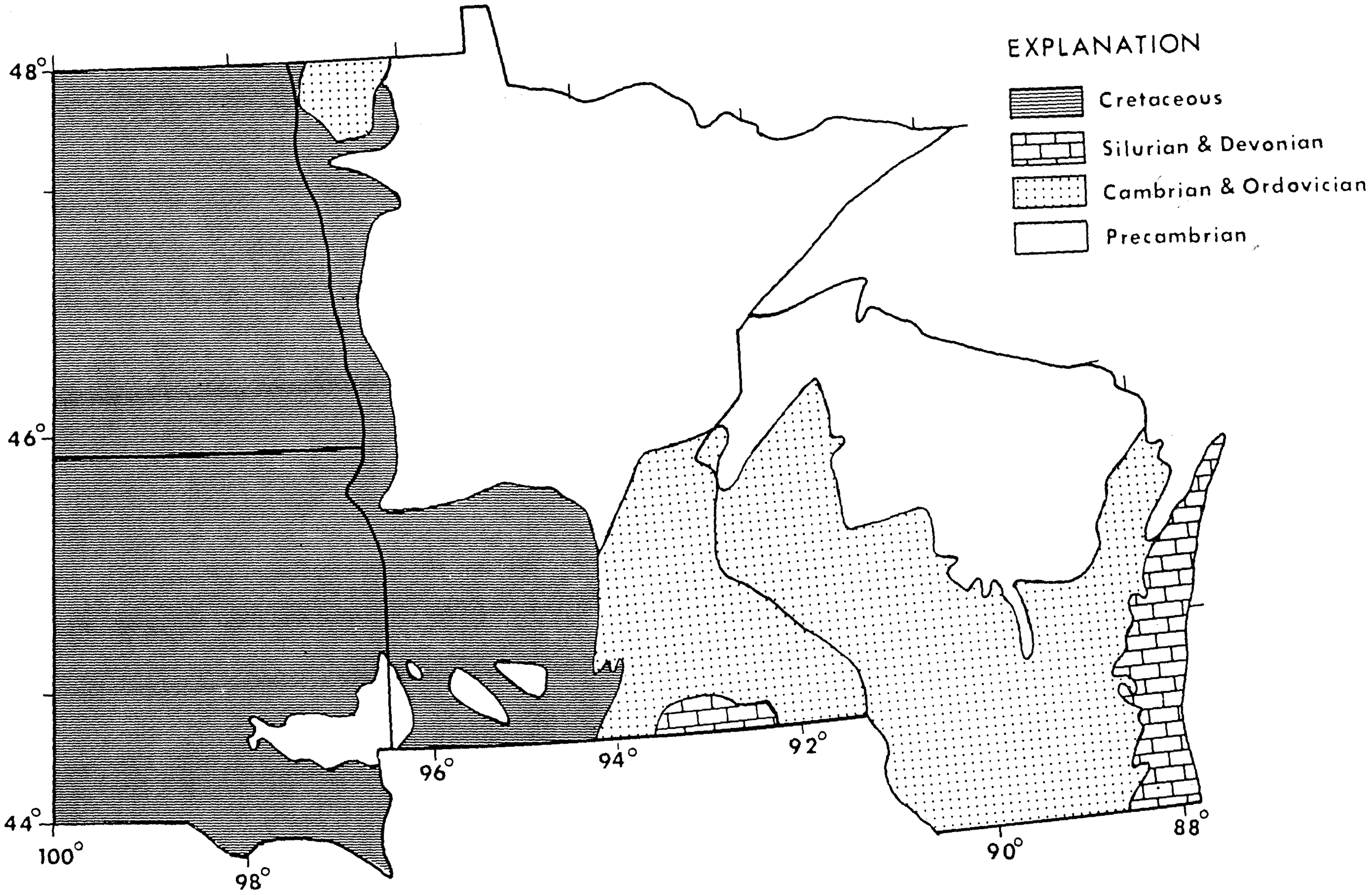

Figure 1.--Map of bedrock geology of the north-central United States. (Modified from U.S. Geological Survey, 1965b.)

Glacial drift overlies most of the bedrock, and includes ground and end moraines, outwash deposits, and glacial lake sediments. Glaciers brought calcareous gray and buff colored drift into the region from the northwest, and non-calcareous red drift from the northeast. The thickness of drift in areas of large end-moraines in northwestern Wisconsin, southwestern Minnesota and the Dakotas may be as much as 150 m (Winter, 1974, and 1977).

Groundwaters

There are several types of groundwaters based on water chemistry (Winter, 1974, and 1977). Dilute calcium-magnesium bicarbonate groundwaters with less than 250 mg $liter^{-1}$ of total dissolved solids are common in much of Wisconsin and Minnesota, whereas the groundwaters in western Minnesota and the Dakotas are of diverse other types, including calcium-magnesium sulfate, sodium bicarbonate, sodium chloride and sodium sulfate. These groundwaters may have concentrations of total dissolved solids as high as 3,000 mg $liter^{-1}$ in the Dakotas. The saline calcium-magnesium sulfate groundwaters are derived from substrates rich in gypsum and iron sulfide that were deposited by glaciers moving over Cretaceous and possibly Triassic sedimentary rocks. The sodium bicarbonate groundwaters are usually deep and products of ion exchange. Groundwaters dominated by sodium chloride are common in Cretaceous and Paleozoic bedrock aquifers in the Dakotas. Groundwaters rich in sodium and sulfate are believed to be caused by the mixing of sulfate-rich waters from glacial drift with waters rich in sodium chloride in underlying Cretaceous sedimentary rocks, or by cation exchange in clayey deposits. All of these saline groundwaters may move for long distances before surfacing to influence lake-water chemistry (Winter, 1974, and 1977).

Climate

Northeastern Minnesota and much of Wisconsin have a positive balance of precipitation over evaporation, whereas western Minnesota and the Dakotas have a distinct negative balance (Bright, 1968: Petri and Larson, 1971). The range is from 10-cm excess precipitation in northeastern Minnesota to a 50-cm deficit in the region of the Missouri River (Winter, 1976, and 1977). Mean annual temperature ranges from about 3°C in the north to 8°C in the south (Bright, 1968).

Vegetation

Northern Wisconsin and northeastern Minnesota are covered by mixed coniferous-deciduous forest. Deciduous forest predominates in southern Wisconsin, and as a band westward of the mixed forest, narrow in the northwest and broadening toward southeastern Minnesota. The Dakotas east of the Missouri River are covered by cultivated prairies, which extend narrowly into northwestern Minnesota and broadly across the southernmost part of the state. A generalized vegetation map is presented by Wright (1969).

Sources of data

In selecting data on ionic composition for this report we have excluded waters in which total cations and total anions were not within 5% of one another, except for very dilute samples (specific conductivity less than 29 μmhos cm^{-1} at 25°C) for which differences up to 10% were accepted (and only 18 of more than 50 lakes met the criteria). Most of our data for Wisconsin came from Poff (1967); the remainder (13 very dilute waters) were collected by us and analyzed by the U.S. Geological Survey. Many Minnesota samples were collected and analyzed by us, many more analyses are from Maderak (1963), some northern dilute waters were collected by Gary Glass of the U.S. Environmental Protection Agency and were analyzed by the U.S. Geological Survey, and a few analyses are from Bright (1968) and Tarapchak (1973). The data for the Dakotas are from Petri and Larson (1971), Mitten and others (1968), and the U.S. Geological Survey (1964, 1965a, 1966, 1967, 1968 and 1969). Most samples were analyzed by the standard methods of the U.S. Geological Survey (Rainwater and Thatcher, 1960; Brown and others, 1970). Our own Minnesota samples were analyzed by the techniques of Mackereth (1963).

Most of the data for Wisconsin and Minnesota lakes represent analyses of single samples collected at various times throughout the ice-free season, whereas many of the data from the Dakotas are averages of analyses of samples collected at several times during the ice-free season and over more than one year. The very considerable seasonal and annual variations of chemical composition in the western lakes are controlled by variably severe and lengthy droughts, and have been examined by Mitten and others (1968).

We have compiled measurements of specific conductivity -- closely correlated with salinity (Fig. 6) -- in 1,133 samples, and analyses of major ions -- Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, alkalinity, SO_4^{2-}, Cl^{-} -- in 217 samples. Many of the latter samples have also been analyzed for additional components, including pH, NO_3^{-}, F^{-}, B, Fe, Mn, SiO_2, and color. The results of the analyses are in Appendix I.

CHEMICAL CLASSIFICATION OF SURFACE LAKE WATERS

An examination of the data for specific conductivity, taken together with data on ionic composition and surficial geology, allows construction of a chemical classification of lake waters in the north-central United States. Figure 2 shows a frequency distribution of specific conductivity (at logarithmic intervals) in all 1,133 lakes. It is evident that the distribution contains four modal groups that overlap but can be separated at approximately 28, 141, and 7,079 μmhos. Figure 3 shows separate frequency distributions for lakes in Wisconsin, Minnesota and the Dakotas that suggest another boundary at 501 μmhos, marked by the slight overlap of Wisconsin and Dakota lakes and by a "shoulder" on the middle Minnesota group. The reality of this boundary is confirmed by the changes in ionic proportions shown in Figs. 20 and 21. Five lake groups can thus be distinguished, and will be numbered I to V in order of increasing conductivity.

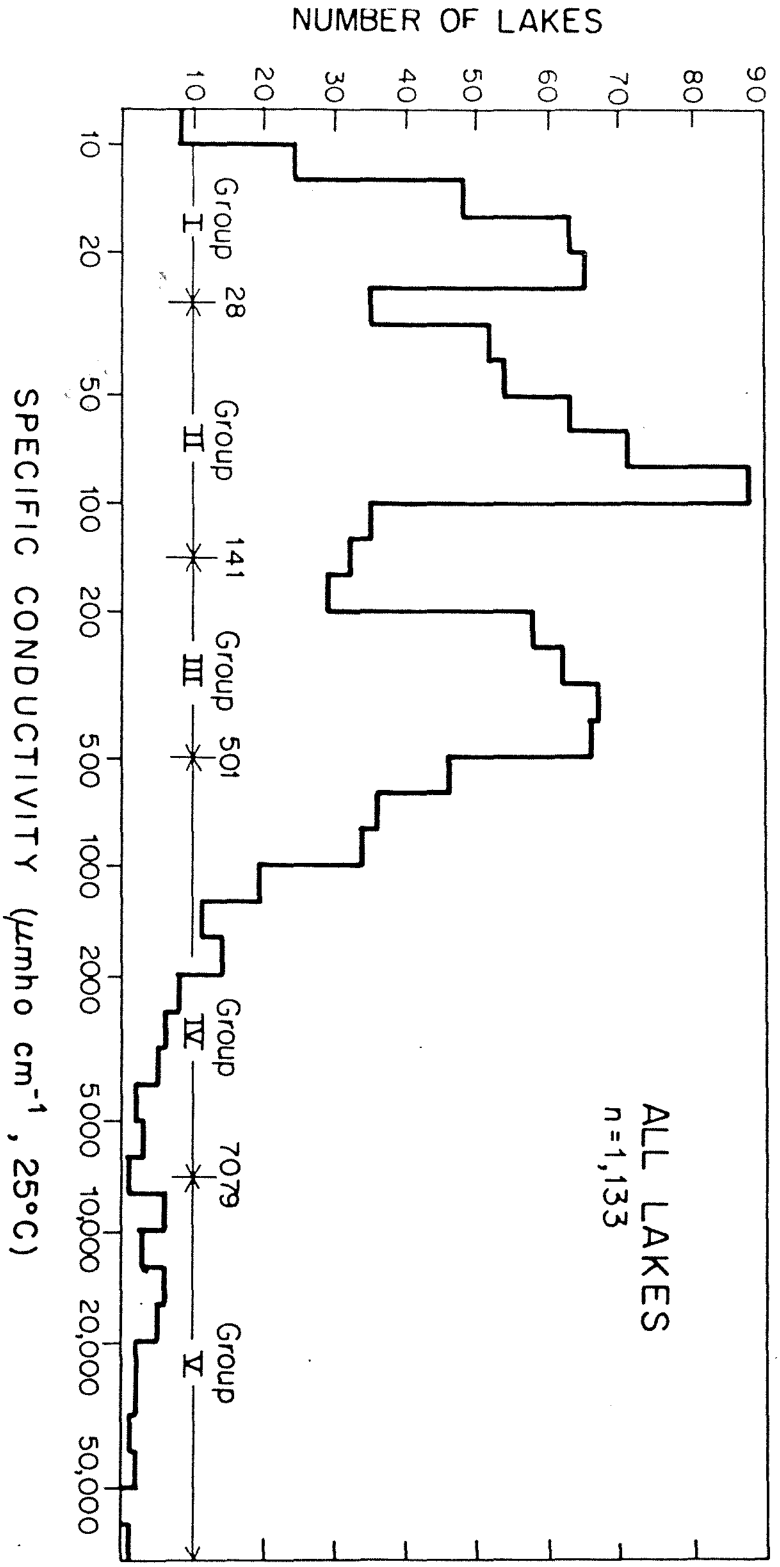

Figure 2.--Frequency distribution of specific conductivity at logarithmic intervals for 1,133 lakes.

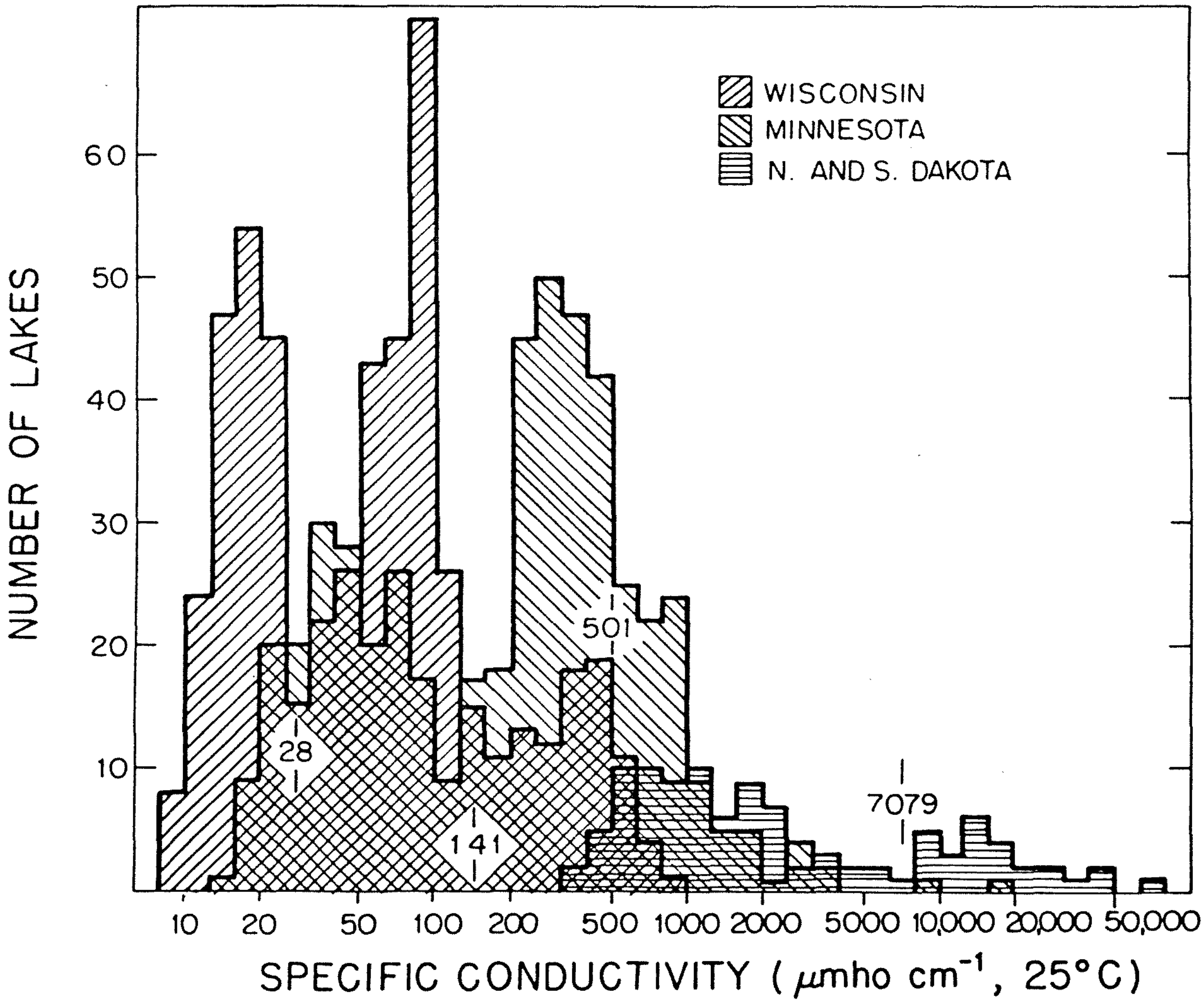

Figure 3.--Frequency distributions of specific conductivity at logarithmic intervals for 1,133 lakes in Wisconsin, Minnesota, and the Dakotas.

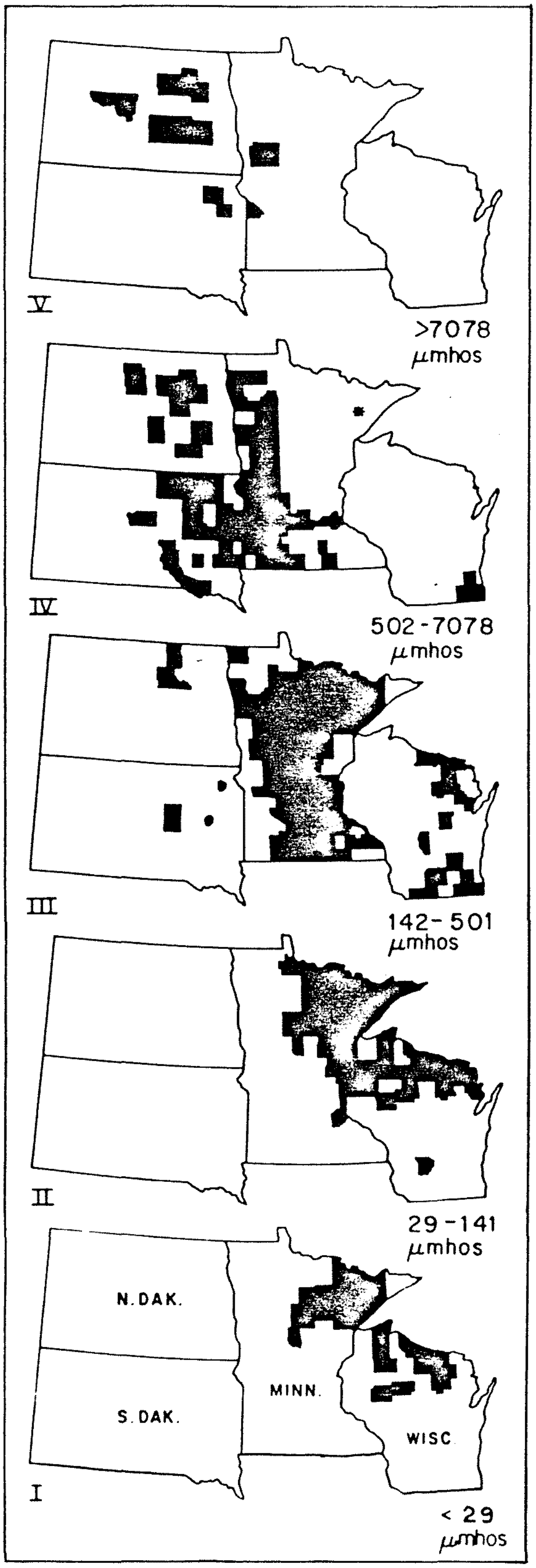

Figure 4.--The geographical distribution (by county) of lakes in the north central U.S.A., grouped (I to V) in order of increasing conductivity. Group IV asterisk in northcentral Minnesota marks Lake Manganika, partly filled by mines spoil.

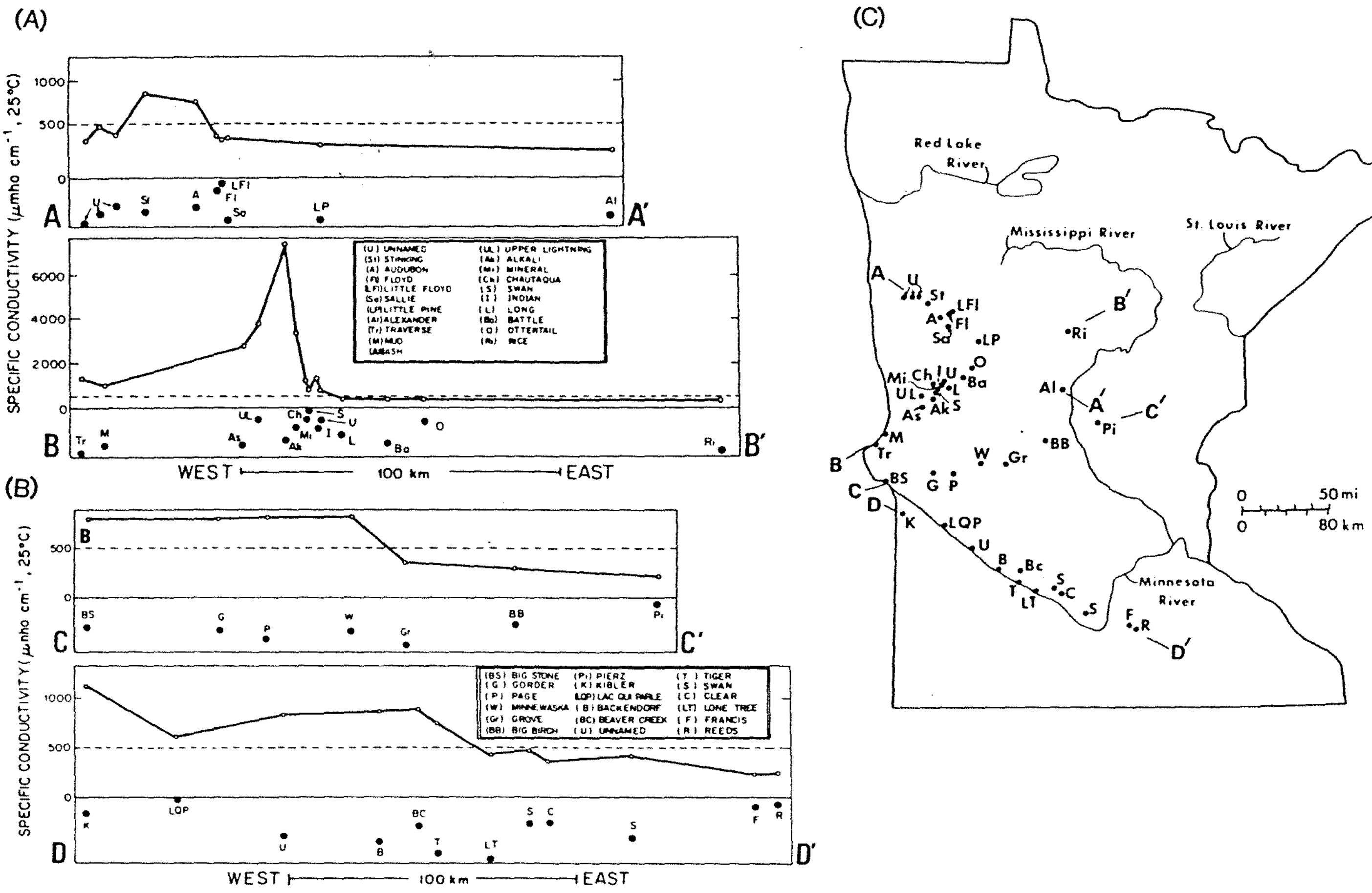

Figure 5.--Belt transects of specific conductivity in lakewaters of western Minnesota. A. Two northern transects. B. Two southern transects. C. Map locations of the four transects. The dashed lines in Fig. 5A and 5B separate lakes of group III (below) and group IV (above). The dots within the rectangles in Fig. 5A and 5B show the geographic positions of the lakes sampled within the belt transects.

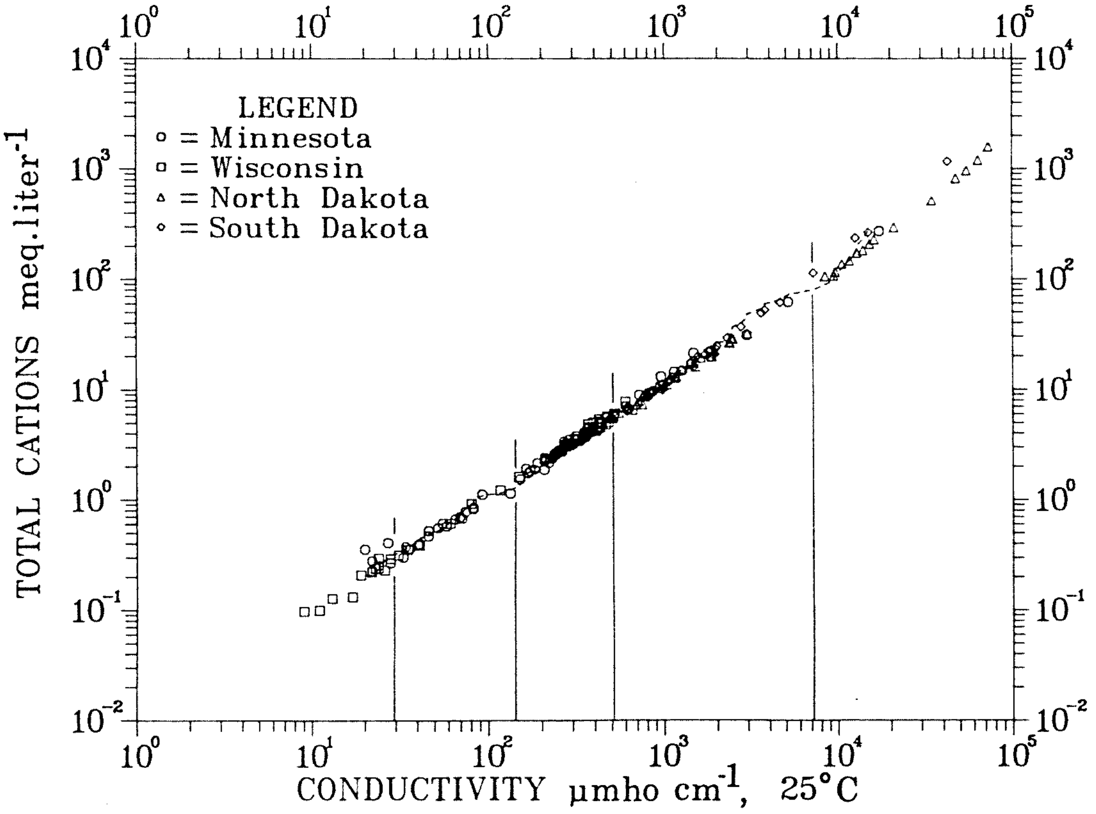

Figure 6.--The $\log_{10}$ relationship between total cations and specific conductivity. Vertical bars mark the separation of lake groups. For this and following figures, the dashed line is 21-point, weighted, moving-average of the raw data. Weighting was done according to the equation:

$$\text{average value} = \frac{\sum_{i=1}^{11} ix_i + \sum_{i=10}^{1} \sum_{j=12}^{21} ix_j}{120}.$$

The group I lakes are small, with more than half less than 20 ha and 80% less than 100 ha (Juday and Birge, 1941; Glass and Loucks, 1980). They are found on coarse, non-calcareous sand and gravel in northern Wisconsin and Minnesota (Fig. 4). Some occur in watersheds where much of the surface consists of bare, acidic igneous rock. Many have small drainage areas and no outlets, and have been designated "seepage lakes" by Juday and Birge (1933, and 1941) and "perched lakes" by Hawkinson and Verry (1975) to distinguish them from "drainage lakes" with outlets. Many others are headwater lakes. The waters of group I lakes are derived largely from rapid surface runoff and the most dilute among them are close to rain water in total ionic concentration. Table 1 provides representative analyses of both rain and extremely dilute lakewaters.

Group II lakes also occupy drainage basins in noncalcareous substrates in northern Wisconsin and Minnesota (Fig. 4), but many of the lakes are larger and have active outlets. Their drainage basins generally have deeper and more weathered soil profiles, and the waters therefore have higher contrations of dissolved solids.

Our frequency distributions (Figs. 2 and 3) are somewhat biased at low conductivity by an unusually large number of samples from northeastern Wisconsin. However, within that area alone the boundary between group I seepage and group II drainage lakes is clearly evident at about 28 µmhos (see Fig. 6 of Juday and Birge, 1933).

Group III lakes are on calcareous substrates predominantly in Minnesota but also to some extent in Wisconsin and the Dakotas (Fig. 4). All but the most dilute of those investigated in Minnesota are actively depositing marl in their profundal sediments (Dean and Gorham, 1976; Megard, 1968). The exceptions are a few lakes on the Anoka sand plain north of Minneapolis, where weathering profiles are deep and the surface horizons of the very sandy soils are now substanitally depleted of calcium carbonate.

Table 1.--The volume-weighted mean ionic composition of atmospheric precipitation in northeastern Minnesota, compared with the composition of the four most dilute group I lakes (in Wisconsin)

	Rain, Hovland, Minn.[1]		Mean, 4 dilute lakes, Wis.	
	meq $liter^{-1}$	meq %	meq $liter^{-1}$	meq %
H^+	0.0215[2]	22	0.00503[3]	4
Ca^{2+}	0.0200	20	0.0663	56
Mg^{2+}	0.0108	11	0.0267	22
Na^+	0.0061	6	0.0033	3
K^+	0.0033	3	0.0179	15
NH_4^+	0.0371	38	not done	--
Total cations	0.0988		0.1192	
Alkalinity	nil	0	0.0250	22
SO_4^{2-}	0.0394	46	0.0745	64
Cl^-	0.0262	30	0.0162	14
NO_3^-	0.0207	24	0.0	0
Total anions	0.0863		0.1157	

[1] Munger (1981), University of Minnesota. Chloride values are too high.

[2] pH 4.67.

[3] pH 5.30.

Group IV lakes occur chiefly in western Minnesota and the Dakotas (Fig. 4), although a few lakes in southeastern Wisconsin have conductivities above 501 µmhos. These probably represent the more saline tail of the distribution of group III lakes overlapping the distribution of group IV lakes, just as the few group III lakes in the Dakotas probably represent an overlapping dilute tail of the distribution of group IV lakes (Fig. 3). Lakes in group IV occur on calcareous substrates, but these substrates (mostly Cretaceous shales) are rich in the sulfur-bearing minerals gypsum and pyrite. As a result, sulfate increases sharply in these lake waters with increasing conductivity, and dominates strongly over bicarbonate and carbonate in the most concentrated waters.

The westward increase in climatic aridity is the main cause of the increase in conductivity between group III and group IV lakes, and also contributes to the shift of ionic dominance toward sulfate as marl is precipitated from increasingly concentrated bicarbonate waters during active photosynthesis in summer (Megard, 1968). This group boundary must also mark a change in geological substrate, or a different source of groundwater input (Winter, 1974), as can be seen in Fig. 5 which shows four belt transects of specific conductivity in lakes from east to west in western Minnesota. If the boundary between group III and group IV lakes is the result solely of a gradual climatic shift in the balance between precipitation and evaporation, a continuous westward increase of specific conductivity (and salinity) would be expected. In fact there is a sharp discontinuity between group III and group IV lakes (also observed on four other transects), which strongly suggests that a geological boundary has been crossed or a different source of groundwater tapped. The second most northerly transect appears to cross a lobe of drift marked by highly saline group IV waters, with conductivity declining again westward to that characteristic of group III waters.

Group V lakes are highly saline. Their waters are dominated by sodium and sulfate ions and show marked fluctuations in concentration with periods of drought and precipitation. The most saline lakes may precipitate hydrated sodium sulfate (mirabilite) during the winter (Mitten and others, 1968; Rawson and Moore, 1944). Sloan (1972) has noted that the most saline potholes in North Dakota occur in glacial outwash deposits at low elevation.

CONCENTRATIONS AND IONIC PROPORTIONS

The waters in groups I to V exhibit striking differences both in their ionic concentrations and in their proportions of cations and anions.

Total cations and anions

Total cations range from 0.098 meq liter^{-1} in northern Wisconsin to 1,570 meq liter^{-1} in N. Dakota; total anions range from 0.095 meq liter^{-1} to 1,580 meq liter^{-1} respectively. The logarithmic relationship between total cations (and total anions) and conductivity is approximately linear (Fig. 6), but the ratio of conductivity to ion concentration decreases from about 100:1 in the most dilute waters to an average of 54:1 in the six most concentrated waters. In the middle range of group III lakes the ratio of conductivity to ion concentration is about 89:1. The decline of the ratio with increasing conductivity is owing to lesser dissociation of the dissolved salts, which outweighs a shift of dominant anion from bicarbonate (with a low equivalent conductivity of 44 μmhos meq^{-1} liter^{-1} at 25°C) to sulfate (with a high equivalent conductivity of 74 μmho meq^{-1} liter^{-1}; Brown and others, 1970).

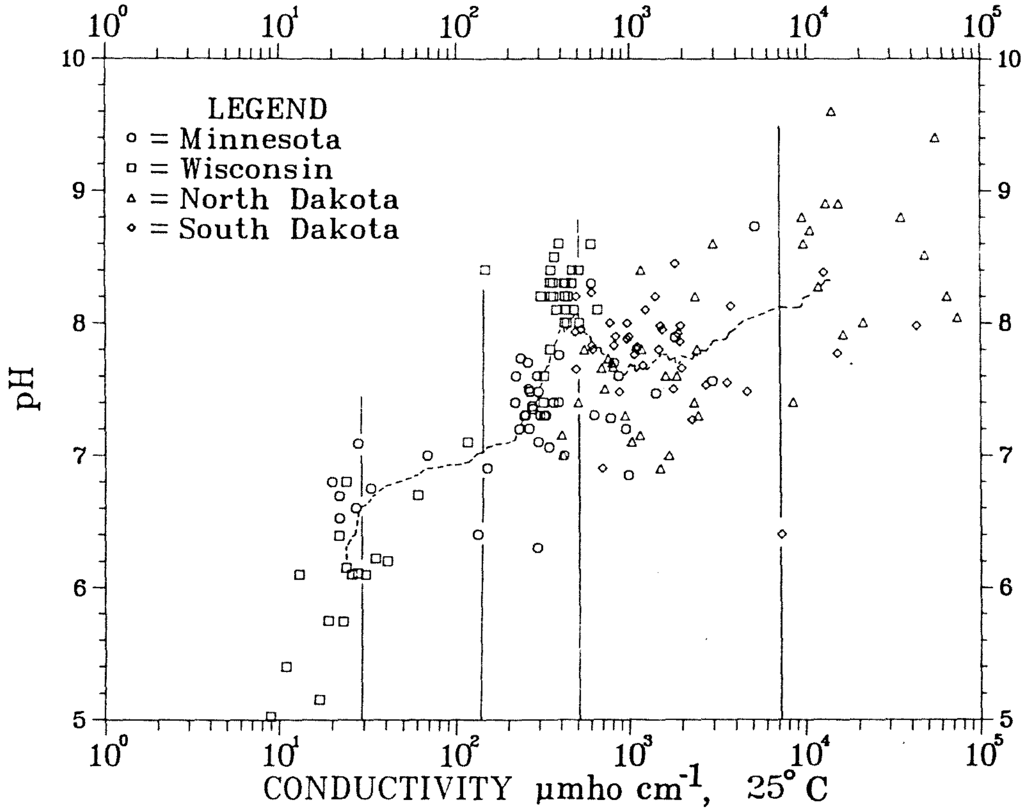

Figure 7.--The relationship between pH and $\log_{10}$ and specific conductivity.

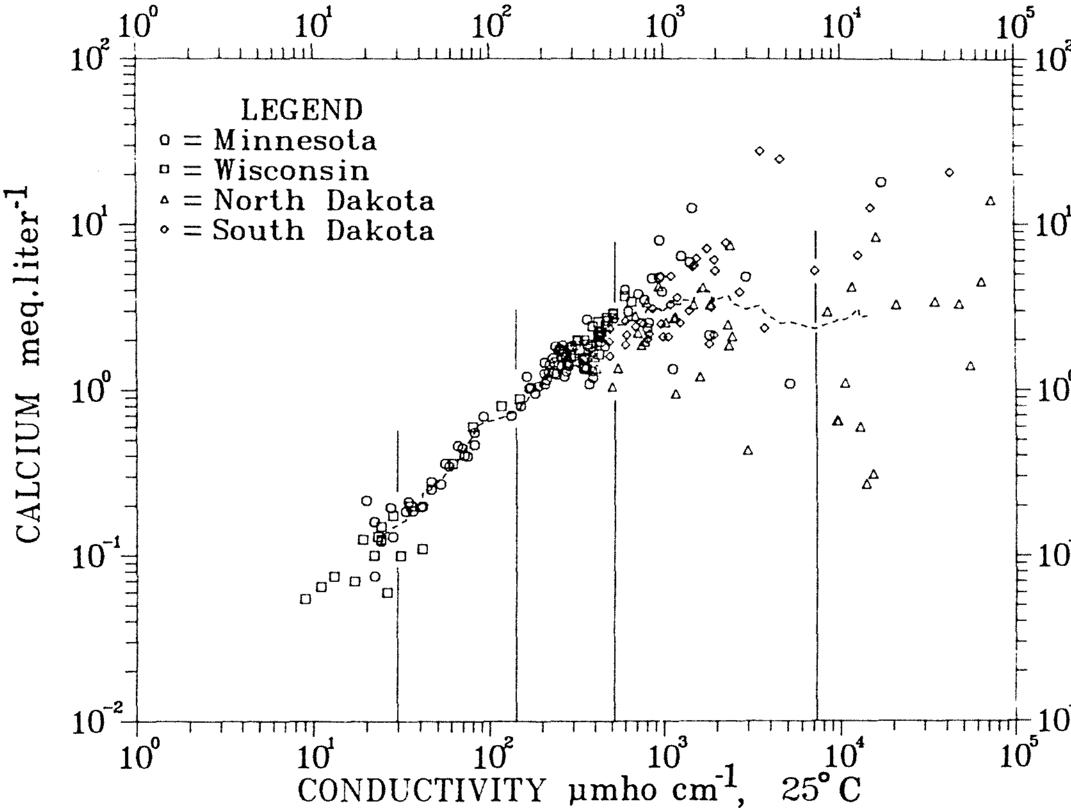

Figure 8.--The $\log_{10}$ relationship between calcium and specific conducitivty.

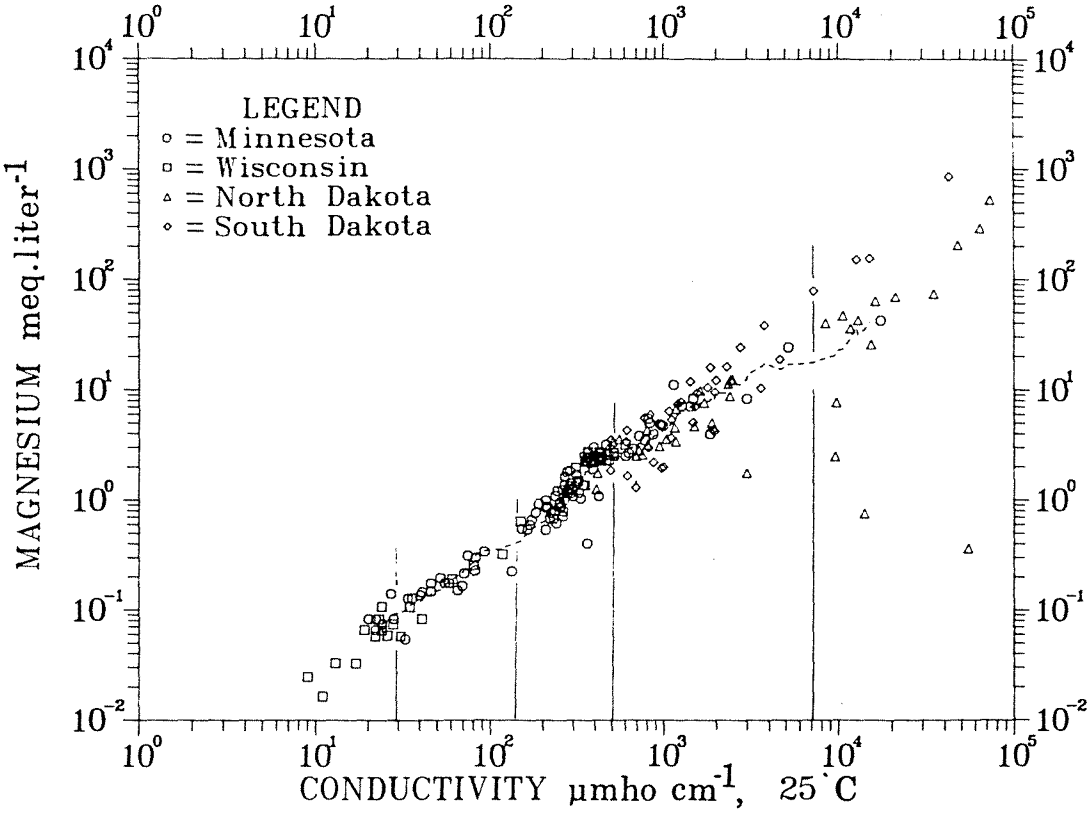

Figure 9.--The $\log_{10}$ relationship between magnesium and specific conductivity.

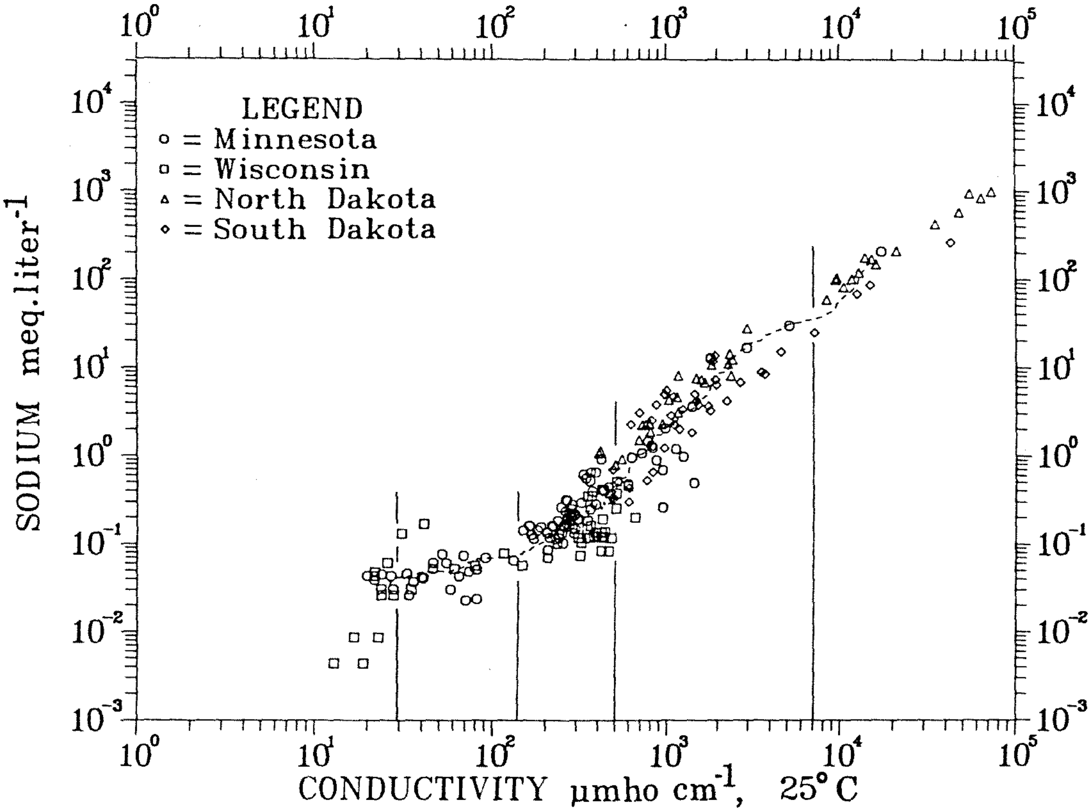

Figure 10.--The $\log_{10}$ relationship between sodium and specific conductivity.

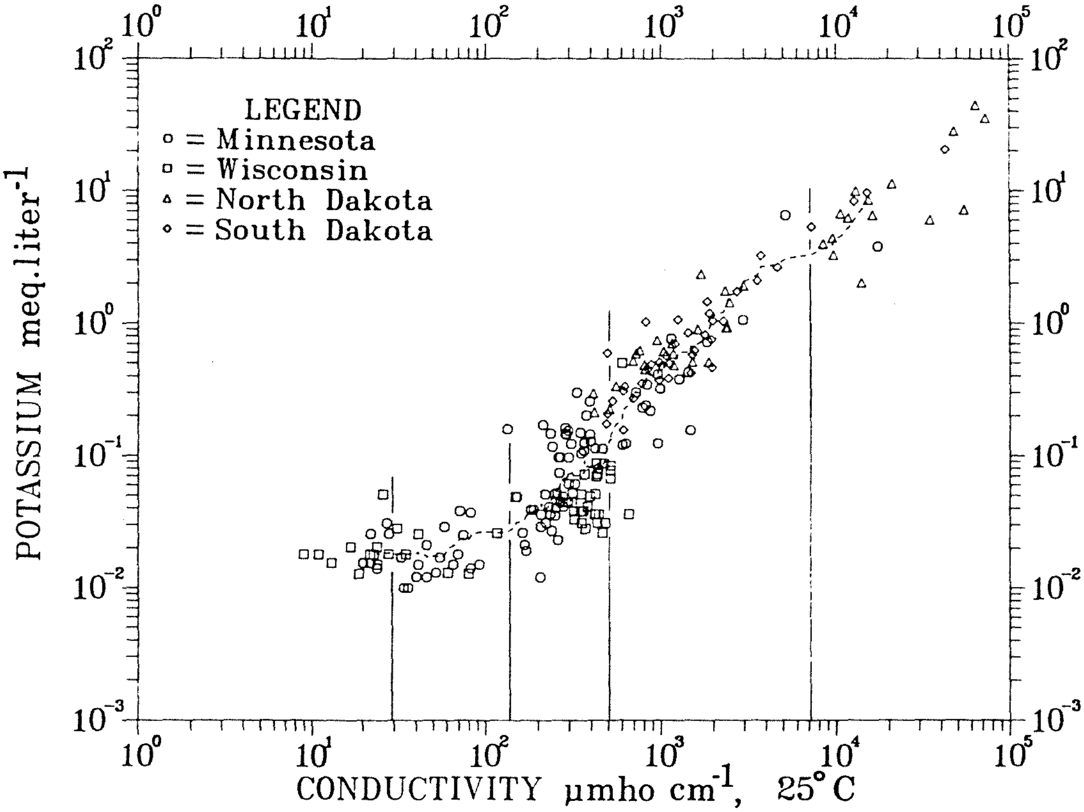

Figure 11.--The $\log_{10}$ relationship between potassium and specific conductivity.

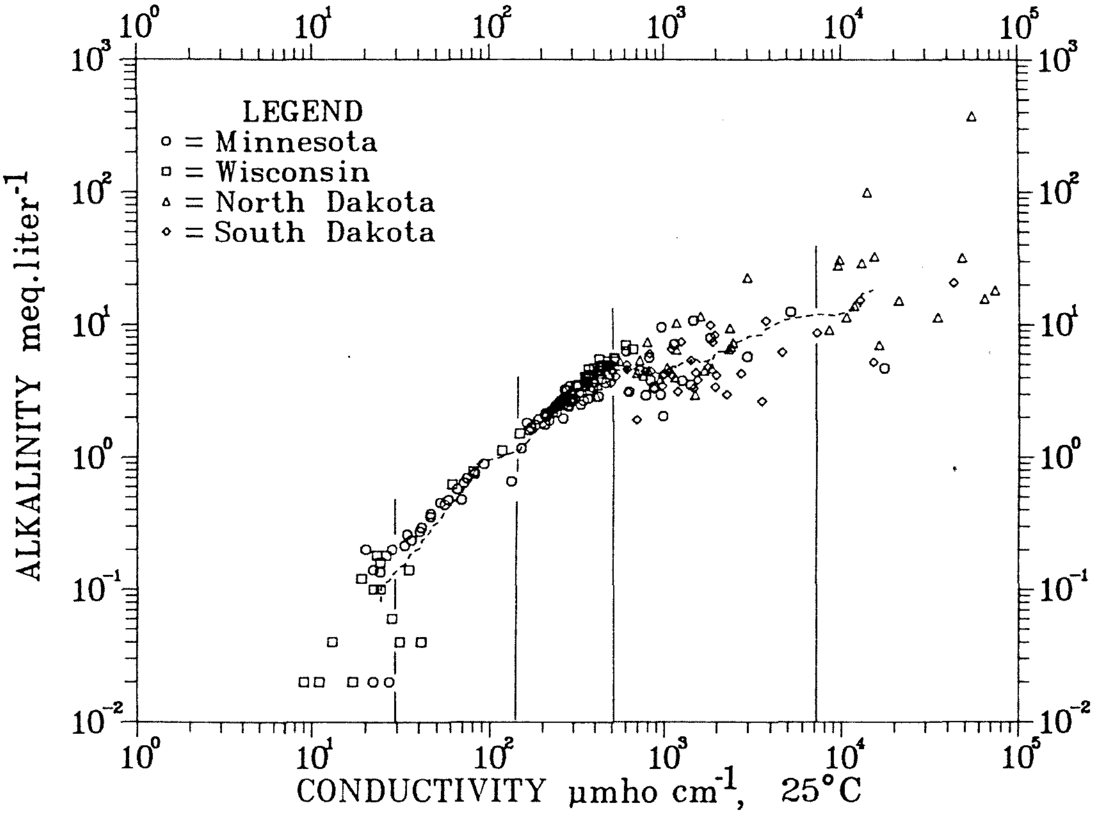

Figure 12.--The $\log_{10}$ relationship between alkalinity and specific conductivity.

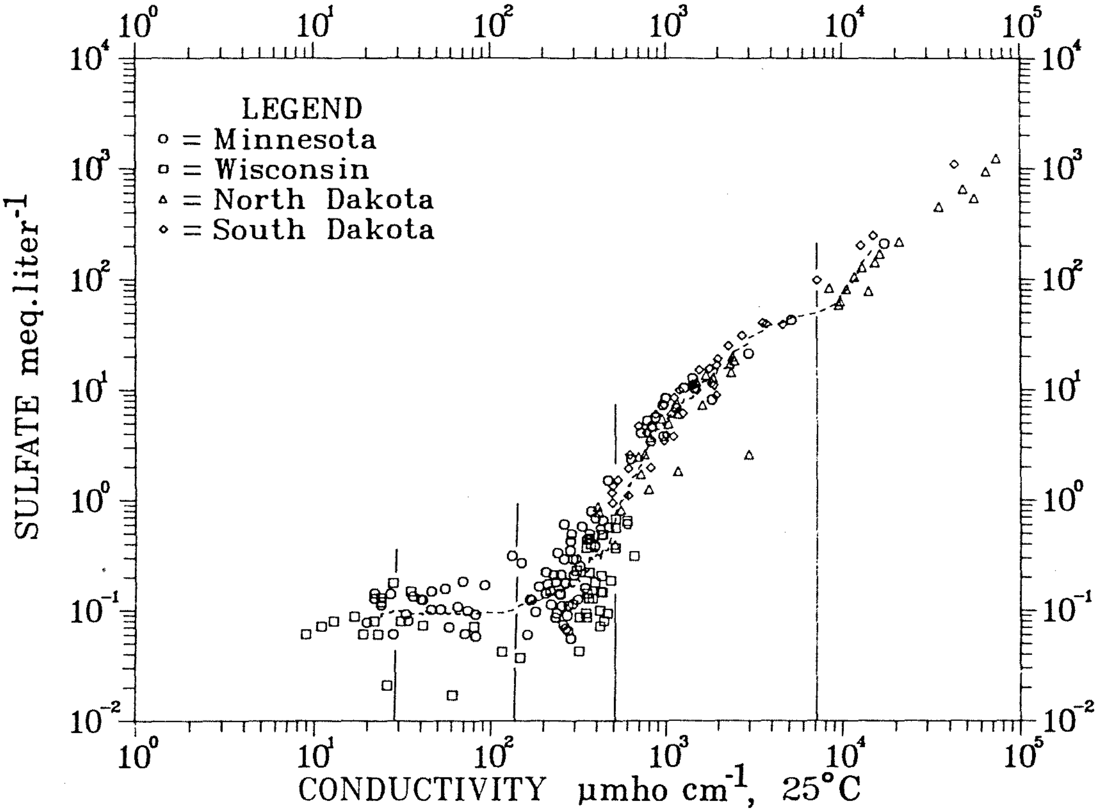

Figure 13.--The $\log_{10}$ relationship between sulfate and specific conductivity.

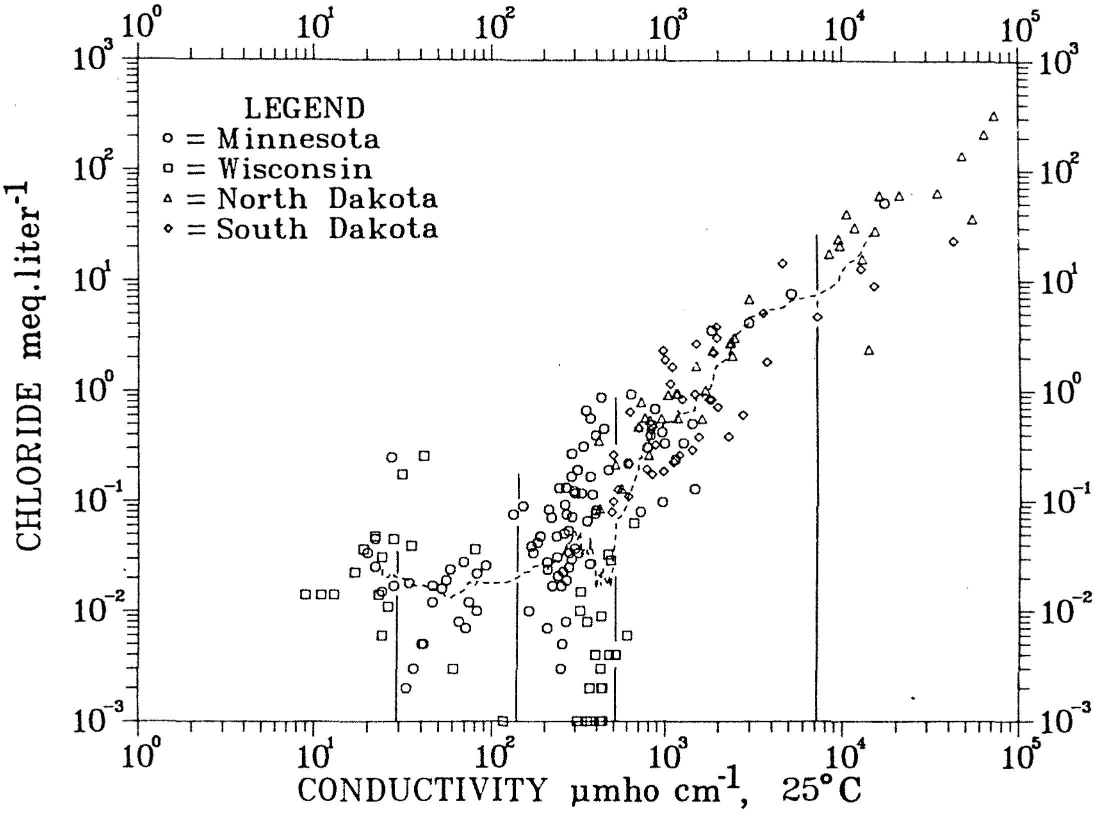

Figure 14.--The $\log_{10}$ relationship between chloride and specific conductivity.

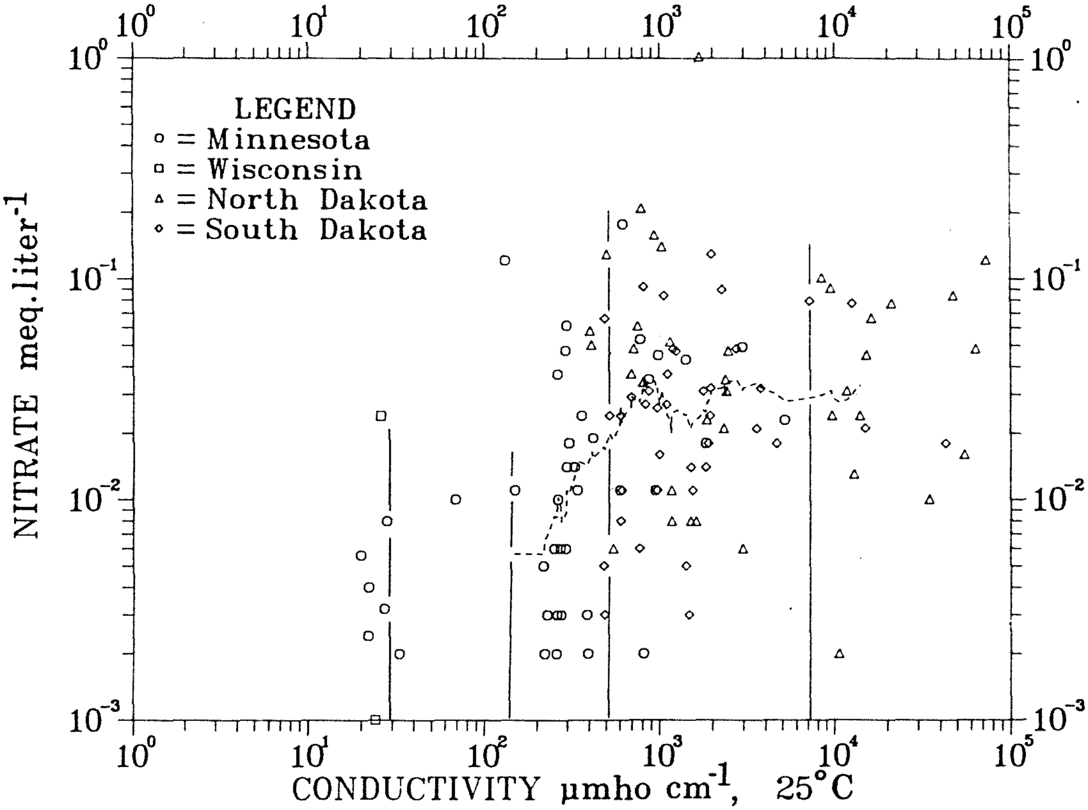

Figure 15.--The $\log_{10}$ relationship between nitrate and specific conductivity.

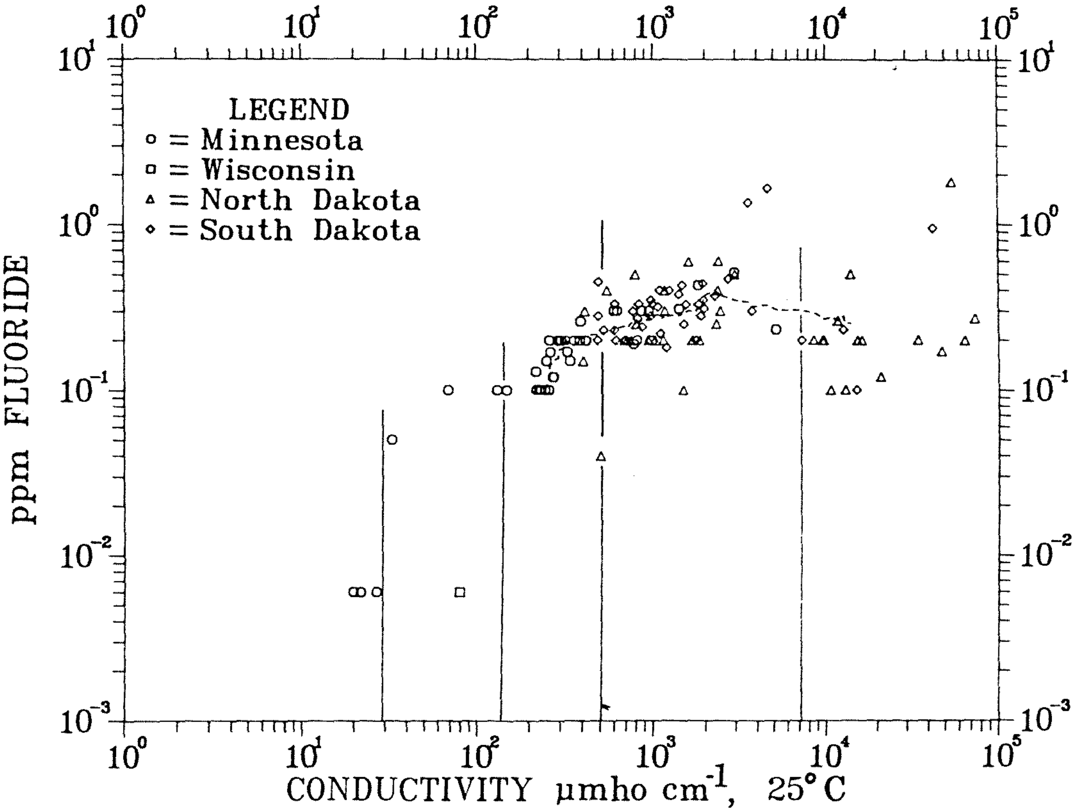

Figure 16.--The $\log_{10}$ relationship between fluoride and specific conductivity.

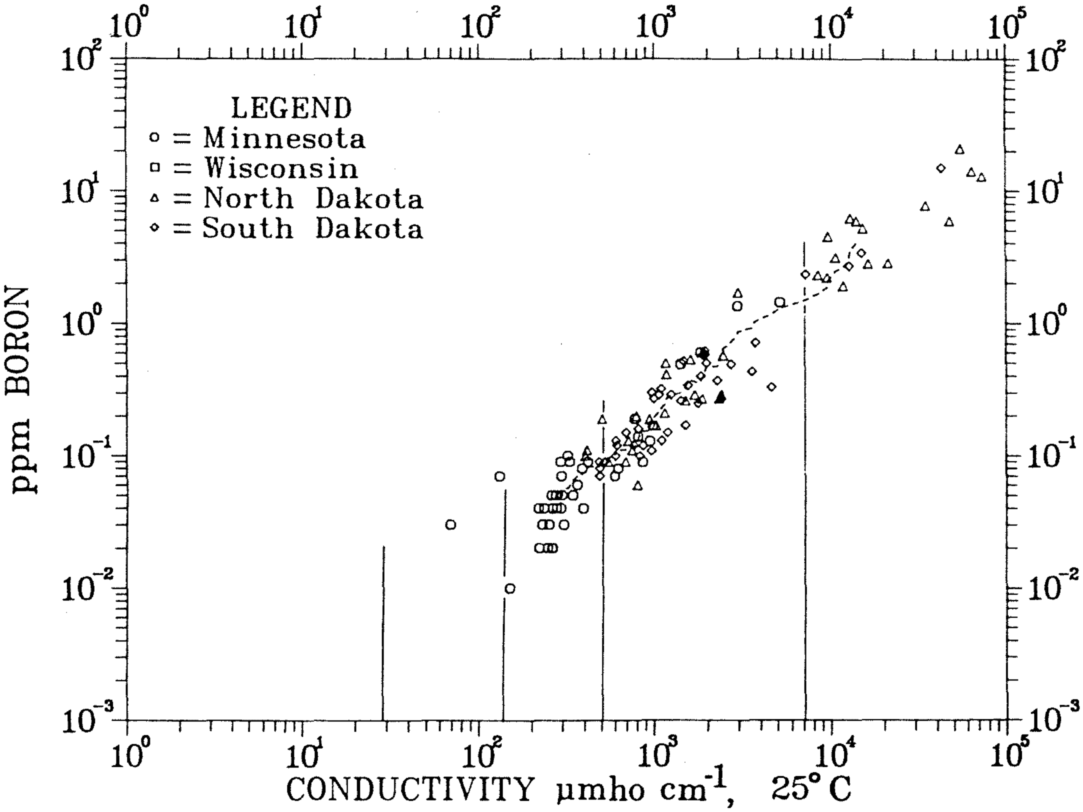

Figure 17.--The $\log_{10}$ relationship between boron and specific conductivity.

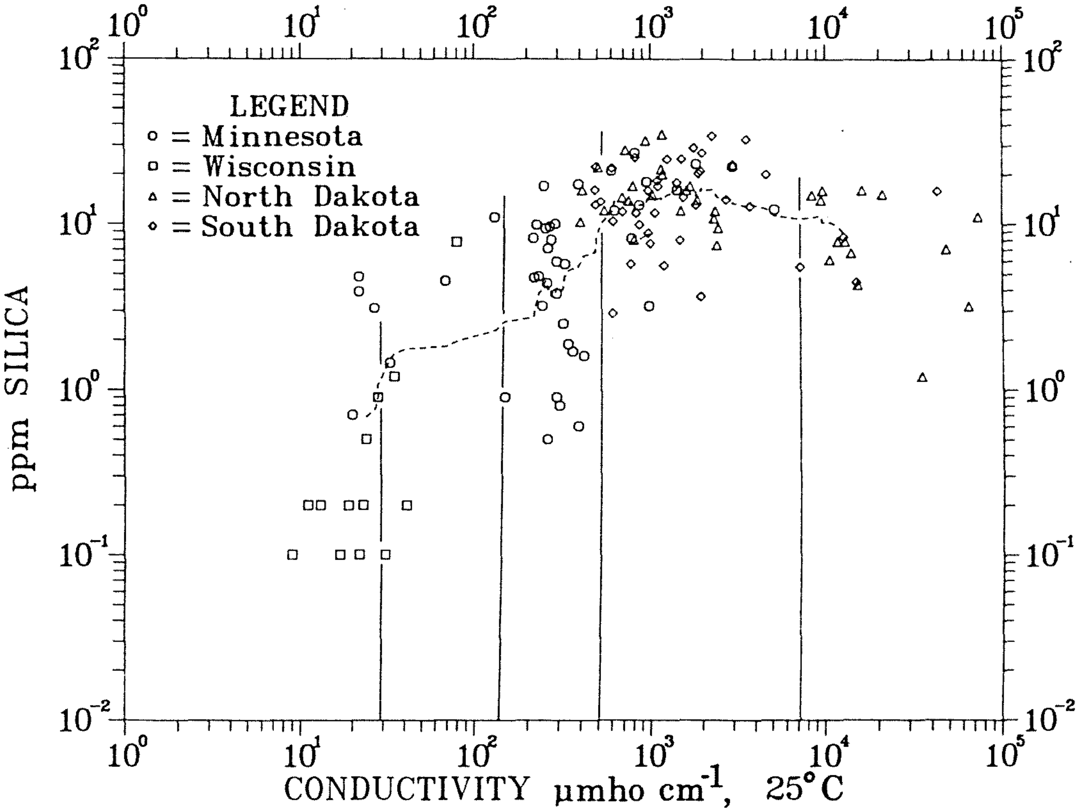

Figure 18.--The $\log_{10}$ relationship between silica and specific conductivity.

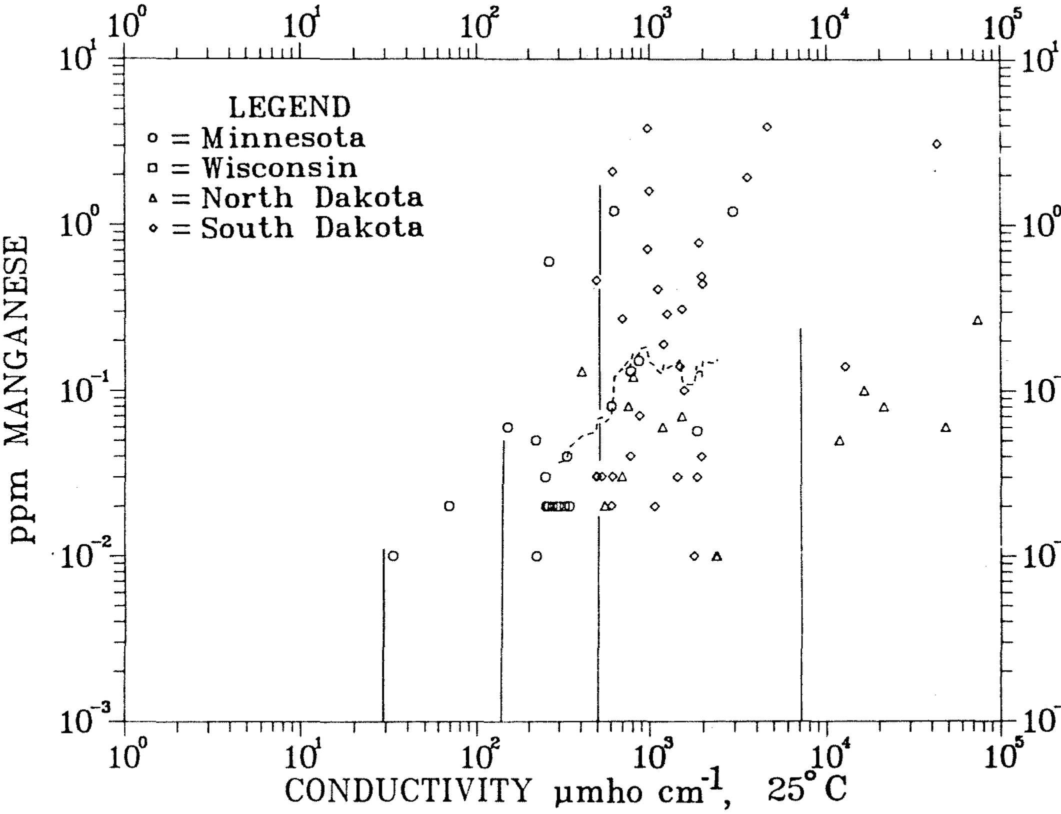

Figure 19.--The $\log_{10}$ relationship between manganese and specific conductivity.

Trends in ionic concentration

Variations in concentrations of dissolved substances relative to specific conductivity of the waters are shown in figures 7 to 19.

Values of pH (Fig. 7) increase as conductivity increases. Group I waters are distinctly acid to neutral; group II waters are faintly acid to neutral. The range of pH of lakes on the calcareous substrata in groups III to V is from slightly acid to very alkaline; the highest pH values (above 9) occur in saline group V waters.

Calcium concentration (Fig. 8) shows a close relationship to conductivity in groups I to III, rising steadily from a minimum of about 0.05 meq liter^{-1} to about 2.2 meq liter^{-1} at the group III/IV boundary. Thereafter calcium concentration shows little further increase and little relationship to conductivity, presumably because above about 2 meq liter^{-1} the waters are supersaturated with calcium ions and carbonate ions so that precipitation of marl occurs and reduces the relative importance of calcium among the dissolved ions. Dean and Gorham (1976) showed that calcium carbonate in profundal sediments of Minnesota lakes is restricted to those lakes which have a total cation concentration in the surface waters of more than 2 meq liter^{-1}, which is equivalent to a calcium ion concentration of about 1 meq liter^{-1} and a specific conductivity of about 190 µmhos.

The relationship between magnesium concentration (Fig. 9) and conductivity is somewhat similar to that of calcium concentration. However, it continues to rise with increasing conductivity from group I to group V, and only a few saline waters show evidence of marked depletion of magnesium owing to precipitation as carbonate.

The concentration of sodium (Fig. 10) is very low in the most dilute Wisconsin waters of group I. Sodium concentrations increase sharply with increasing salinity -- and presumably increased weathering soil minerals -- to the boundary with group II. Sodium increases very little within group II because the salinity increase there is dominated by the leaching of calcium and magnesium from noncalcareous soils. Throughout groups III to V the sodium concentration increases steadily with increasing conductivity reflecting the accumulation of sodium salts in arid soils.

The concentration distribution of potassium (Fig. 11) resembles that of sodium, except that the most dilute group I waters have potassium concentrations similar to those of group II. In groups III to V, potassium concentration increases steadily with increasing conductivity.

The concentration distribution of alkalinity, the sum of bicarbonate and carbonate anions (Fig. 12), is similar to that of calcium, increasing steadily with increasing conductivity to the group III/IV border, after which the rate of increase becomes much less -- and the relationship less close -- as marl is precipitated and sulfate gradually replaces bicarbonate as the dominant anion.

The concentration distribution of sulfate (Fig. 13) resembles that of the cation potassium, showing little change in concentration from the most dilute to the most concentrated waters on non-calcareous substrates (groups I and II). The concentration of sulfate in lakes with calcareous drainage basins increases steadily with increasing conductivity, the increase being most rapid in the more dilute waters of group IV.

The concentration of chloride (Fig. 14) is close to or at the limit of detection in many waters from groups I to III, and increases sharply as the lakes of group IV are reached.

Nitrate concentration (Fig. 15) shows little relationship to conductivity, but there is a tendency for low concentrations in groups I and II on noncalcareous substrates with relatively little agriculture, an increase in group III where agriculture is important, and little change across the boundary of group IV and beyond in the cultivated prairie regions.

Analyses for fluoride (Fig. 16) are few in the dilute waters of group I and II where the fluoride concentration is low. Fluoride concentrations tend to rise with increasing conductivity up to the boundary between groups III and IV and then level off in groups IV and V.

Boron (Fig. 17) is usually below detection limits in dilute waters. In groups III to V on calcareous substrates, however, the concentration of boron shows a close positive correlation with conductivity.

Silica (Fig. 18) is very low in group I lake waters, among which the most dilute consist of rain-water little altered by addition of materials from soil and rock weathering. The concentration of silica increases in groups I through III as weathering products of silicate minerals are added to lake waters. It then levels off, with a slight tendency to decline in the saline waters of group V.

Iron, with few analyses in groups I and II, shows no relationship to conductivity. The concentration of iron ranges from 0.01 to 0.7 ppm and is probably controlled by redox conditions in surrounding soils and littoral sediments, as well as the degree to which sediments are resuspended in the water column by turbulence, especially in shallow lakes. Waterlogged, peaty drainage basins may contribute substantial amounts of iron to some lakes, probably chelated by dissolved organic matter.

Manganese concentration (Fig. 19) also has little relationship to conductivity, and for the same reasons as iron. However, waters of group II (with only two samples) and III tend on average to be lower in manganese than those of groups IV and V.

Trends in ionic composition

Although most dissolved materials increase in concentration with rising conductivity, their proportions relative to one another and to total ions change radically owing to differences in mineral weathering and evaporative precipitation. This appears very clearly from an examination of their percentage contributions to total cations or total anions, as seen in Figs. 20 and 21.

Calcium (Fig. 20) on average accounts for half or more of total cations in waters of group I and II lakes on substrates mapped as non-calcareous, and also in the more dilute group III lakes on calcareous substrates. As conductivity increases and calcium carbonate precipitates, calcium decreases to less than 10% of total cations in saline group V waters.

Magnesium (Fig. 20) shows a different and less clear relationship to conductivity. On average it accounts for about 30% of total cations in group I and II waters, increases to about 50% in the more concentrated group III waters because calcium carbonate precipitation reduces the calcium concentration, and then declines again (but with great variability) to about 30% in saline group V waters as sodium becomes the dominant cation.

Sodium (Fig. 20) is variable in dilute waters, and declines in importance as calcium and magnesium are weathered from non-calcareous substrates and are added to the more concentrated group II waters. Sodium remains proportionally low in the group III lakes on calcareous substrates, and then increases rapidly once the sulfur-bearing substrates of lakes with group IV waters are reached. Sodium is clearly the dominant cation in the most saline waters of groups IV and V.

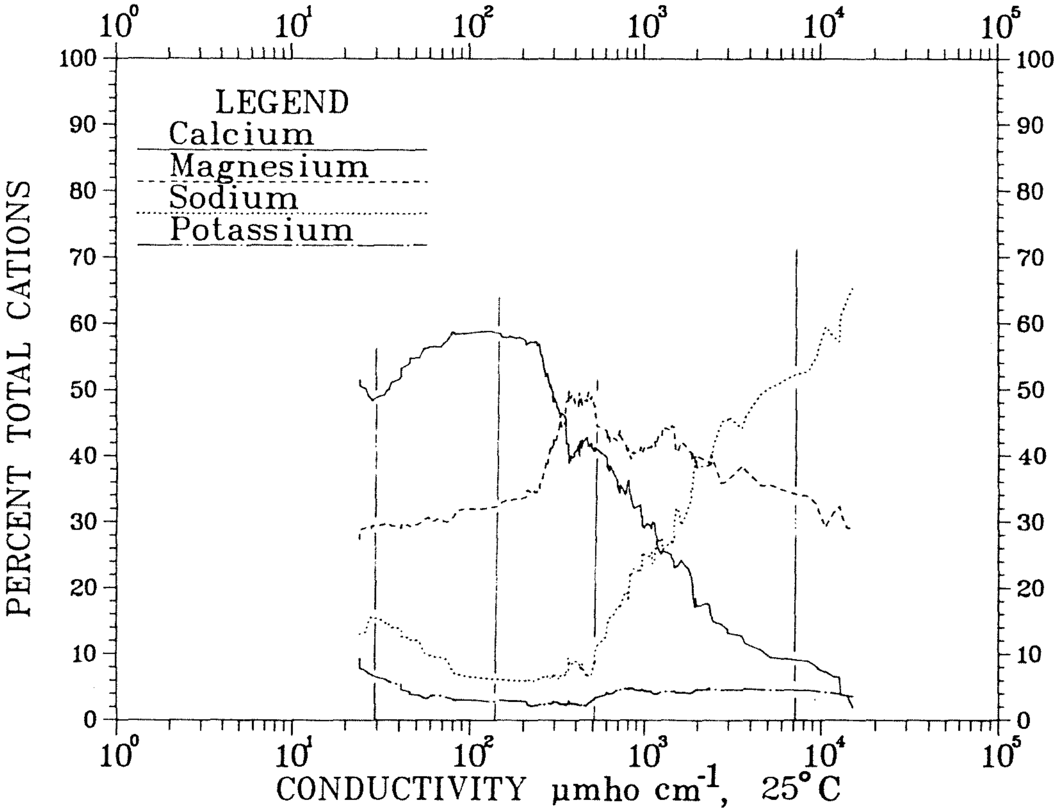

Figure 20.--The relationship of individual major cations, as a percentage of total cations, to $\log_{10}$ specific conductivity.

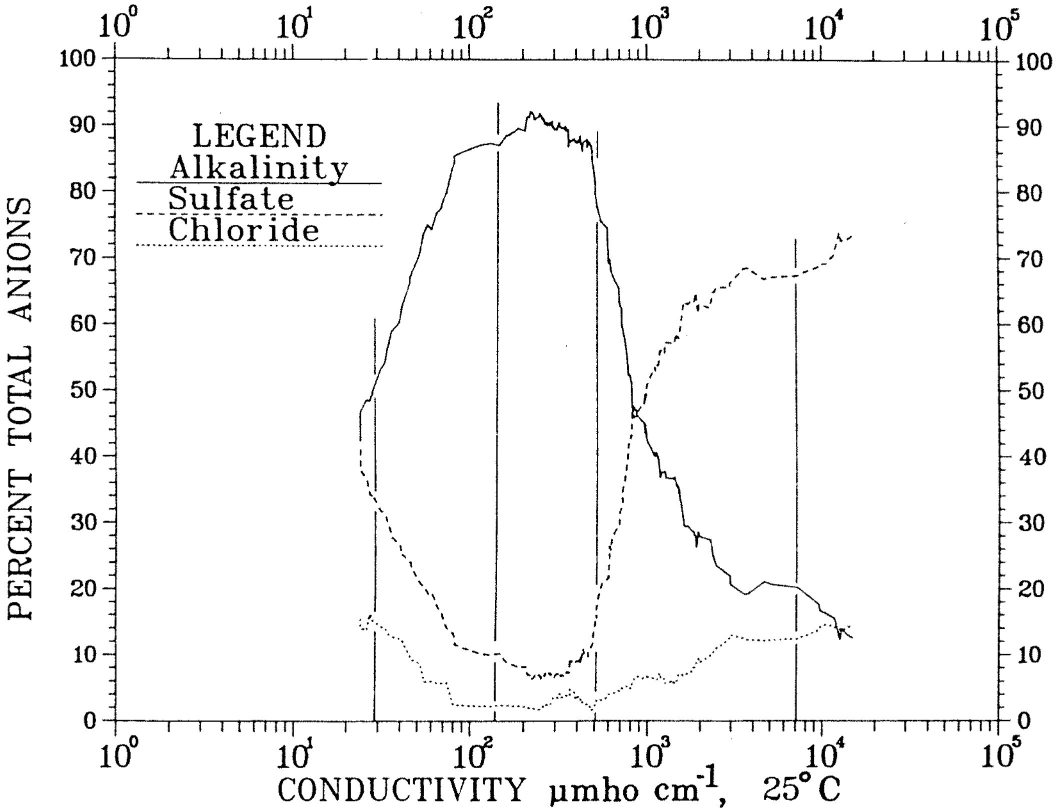

Figure 21.--The relationship of individual major anions, as a percentage of total anions, to $\log_{10}$ specific conductivity.

Potassium (Fig. 20) is the least concentrated of the major cations and is most abundant proportionally in dilute group I waters. It declines in proportion to other cations through groups II and III, increases to slightly greater proportions in group IV, and tends to decline slightly in the most saline waters of group V.

Alkalinity (Fig. 21) is extremely low in many of the very dilute waters of group I, as it is in the atmospheric precipitation from which they are derived. According to Munger (1981) precipitation (wet deposition only) is distinctly acid in northern Minnesota, with a mean volume-weighted pH of 4.67 at Hovland. At Itasca State Park in northwestern Minnesota the mean pH is 5.00; at the Tewaukon Wildlife Refuge in southeastern North Dakota the mean pH is 5.27. However, as rainwaters accumulate ions through dissolution of non-calcareous soil minerals, they are enriched in bicarbonates of calcium and magnesium and are transformed into group II waters. Group II waters are increasingly dominated by bicarbonate as they become more saline. Group III waters in lakes on calcareous substrates are strongly dominated by their alkalinity, which averages close to 90% of total anions. Group IV waters become more saline westward as they drain calcareous substrates rich in sulfur-bearing minerals, and this -- combined with the precipitation of carbonates -- results in a striking proportional decline of alkalinity in group IV waters, from about 90% of total anions near the group III/IV boundary to about 20% of total anions near the group IV/V boundary (Fig. 21). The proportional decrease in calcium and increase in magnesium, in response to precipitation of calcium carbonate, occurs within group III waters at a conductivity well below the conductivity at which alkalinity declines and sulfate increases (compare Figs. 20 and 21). As mentioned earlier, the critical empirical boundary for precipitation of calcium carbonate, based both on the presence of calcium carbonate in the sediments (Dean and Gorham, 1976) and on the water chemistry (Fig. 20) is at a specific conductivity of about 190 μmhos (about 2 meq liter^{-1} total cations). Between this empirical boundary and the boundary between group III and group IV waters, the Mg:Ca ratio increases but these two cations are clearly dominant; a major change does not occur until the group III/IV boundary when both sodium and sulfate increase markedly to become the dominant ions in the more saline group IV waters.

Sulfate as a percentage of total anions (Fig. 21) is a mirror-image of alkalinity. Sulfate accounts for more than 60% of total anions in some group I waters, and declines sharply as alkalinity increases in group II waters. In the bicarbonate waters of group III lakes on calcareous substrates, sulfate is commonly less than 10% of total anions. Group IV waters are greatly enriched by drainage from substrates with abundant sulfur-bearing minerals. In the most concentrated group IV waters, sulfate accounts for about 65% of total anions; even higher percentages are observed in the saline group V waters.

Chloride (Fig. 21) dominates three dilute waters on non-calcareous substrates, where it probably comes from road salt. In general chloride is not abundant, and it declines from about 15% of total anions in group I waters to less than 5% in group III waters. Thereafter the chloride concentration increases again to about 15% in the saline waters of group V.

Nitrate is proportionally most abundant in group I waters, and declines to very slight importance in the most saline group V lakes. Fluoride is likewise proportionally most significant in the dilute waters of group I and II lakes. It declines steadily in importance as conductivity increases. In contrast, boron does not change proportionally as conductivity increases from the group III to the group V waters; it is rarely detectable in the waters of lakes on noncalcareous substrates. Silica tends to be proportionally least abundant in both the extremely dilute group I and the strongly saline group V waters, where weathering products of silicate minerals contribute least to salinity.

Q-mode factor analysis

An independent, objective confirmation of the general aspects of the lake classification and an examination of relationships among variables were obtained by Q-mode factor analysis. The computer program used for the factor analysis was the CABFAC program of Klovan and Imbrie (1971). The $\log_{10}$ data for each of the four major cations and three major anions in 209 lakes were scaled to range from 0 to 1 so that those variables with larger means and variances would not determine the outcome of the analysis.

After varimax rotation, 93% of the variance in the scaled data could be accounted for by only two factors. A plot of varimax factor loadings from factor 1 versus conductivity was similar to the plots of proportions of calcium and alkalinity for lakes in groups I through III and the plot of proportions of Mg for lakes in groups IV and V (Figs. 20 and 21). A plot of varimax factor loadings from factor 2 versus conductivity was similar to the plot of proportions of sulfate (Fig. 21).

The factor loadings from the Q-mode analysis can be thought of as composite variables, so that the original seven variables have been reduced by the factor analysis to two factor loadings, each expressing some compositional attribute of water chemistry based on a synthesis of several measured variables. Correlation analyses among the factor loadings and the original seven measured ions show that factor 1 is mainly a measure of calcium and alkalinity with a minor contribution from magnesium. Factor 2 is mainly a measure of sodium, potassium, chloride, and sulfate.

The Q-mode factor analysis confirms in a general way the lake classification obtained from specific conductivity and the chemical characteristics of each of the five water chemistry groups. However, the Q-mode analysis recognizes only two main lake groups, one with calcium bicarbonate waters and a second with sodium, potassium, chloride, and sulfate waters; it is not capable of resolving the details of the classification we have presented. Also, the Q-mode analysis gives no indication of the details of inter-ionic associations that are particularly evident in the plots of proportions of major cations and anions (Figs. 20 and 21).

Temporal variability in concentration and composition

Lakes in the arid climate of western Minnesota and the Dakotas are particularly liable to fluctuations in concentration and composition, and the samples taken at extreme high and low water can sometimes have conductivities (and compositions) so different as to place them in different lake groups. For instance, Sully Lake near Onida, South Dakota, had a conductivity of 155 μmhos at 25°C on 7 April 1960 and 4,800 μmhos on 19 November 1959 (Petri and Larson, 1971). In late 1959 the conductivity of Sully Lake would have classified it as high group IV; in the spring of 1960 it received a great deal of dilute inflow and rose more than 3 m, which changed it to low group III. By April 1961 the water level had declined enough so that the lake crossed the conductivity boundary into group IV again and remained low in group IV until May 1964 when analyses ceased. A comparison of cations in the most concentrated and the most dilute waters of Sully Lake reveals that the concentrated waters were 16-fold richer in calcium, 45-fold richer in magnesium and 119-fold richer in sodium. Comparison of anions shows a similar trend; the more concentrated waters were 9-fold richer in alkalinity, 84-fold richer in sulfate, and 119-fold richer in chloride.

Unusual situations

Certain lakes are unusual because of natural circumstances. For instance, the group IV water of Elk Lake in Grant Co., Minnesota, has an exceptionally high ratio (>7) of magnesium to calcium, and the lake appears to be forming dolomite in its sediments as a diagenetic alteration of high-magnesium calcite (Dean and Gorham, 1976). East Stump Lake in North Dakota, because of the extreme salinity of its group V water, precipitates mirabilite (Mitten and others, 1968).

There are also regional differences between the saline group V lakes of North and South Dakota. Waters in North Dakota are generally richer in sodium and chloride, and to a lesser degree in alkalinity, than those in South Dakota. The concentrations of calcium, magnesium, and sulfate are generally higher in lakes of South Dakota. Presumably these differences reflect the influence of different types of groundwater (Winter, 1974).

Pollution may also shift a lake into a higher conductivity group. Lake Manganika in the Iron Range of northern Minnesota has group IV water rich in sulfate (Maderak, 1963), and lies far to the east of other group IV waters (Fig. 4). The reason is that a large part of the lake has been filled in with mine spoil. Some lakes such as Farquar Lake in Dakota Co., Minnesota, are strongly polluted, as indicated by a nitrate concentration of 7.5 ppm on October 1961. Big Stone Lake at Ortonville, Minnesota, also has been polluted with nitrate; nitrate levels range up to 9 ppm because of agricultural drainage. A few group III lakes in the vicinity of Minneapolis and St. Paul had, in October 1961, chloride concentrations (0.5 - 0.8 meq liter^{-1}) somewhat higher than normal for their conductivities (300 to 400 µmhos) because roads were salted in winter.

A much greater pollution threat -- acid rain -- faces group I (and to a lesser extent group II) lakes in northern Wisconsin and Minnesota. The pH of atmospheric precipitation at Hovland in northeastern Minnesota is now 4.67 (Table 1), close to the level at which damage to lakes and their fisheries has been observed in Scandinavia (Wright and Gjessing, 1976). It is possible that a slight acidification of sensitive lakes in northern Wisconsin may already have taken place. The mean pH of 18 group I lakes in Vilas and Oneida Counties, Wisconsin, during the summer of 1979 was 5.8, as compared with a mean pH of 6.1 in the late 1920s and early 1930s (Juday and others, 1935). These lakes showed no signs of human disturbance and little change in specific conductivity over 50 years, unlike five other lakes examined at the same time where the building of roads and cottages nearby has increased the conductivity considerably. Although the decline of 0.3 pH units (a doubling of hydrogen-ion concentration) is statistically significant, it is by no means conclusive because the earlier analyses were made at different seasons over several years and usually by colorimetric methods -- although these measurements agreed extremely well with measurements by quinhydrone electrode. Nevertheless, these group I waters are so low in alkalinity as to be particularly sensitive to acidification, and they should be monitored with great care in the coming years.

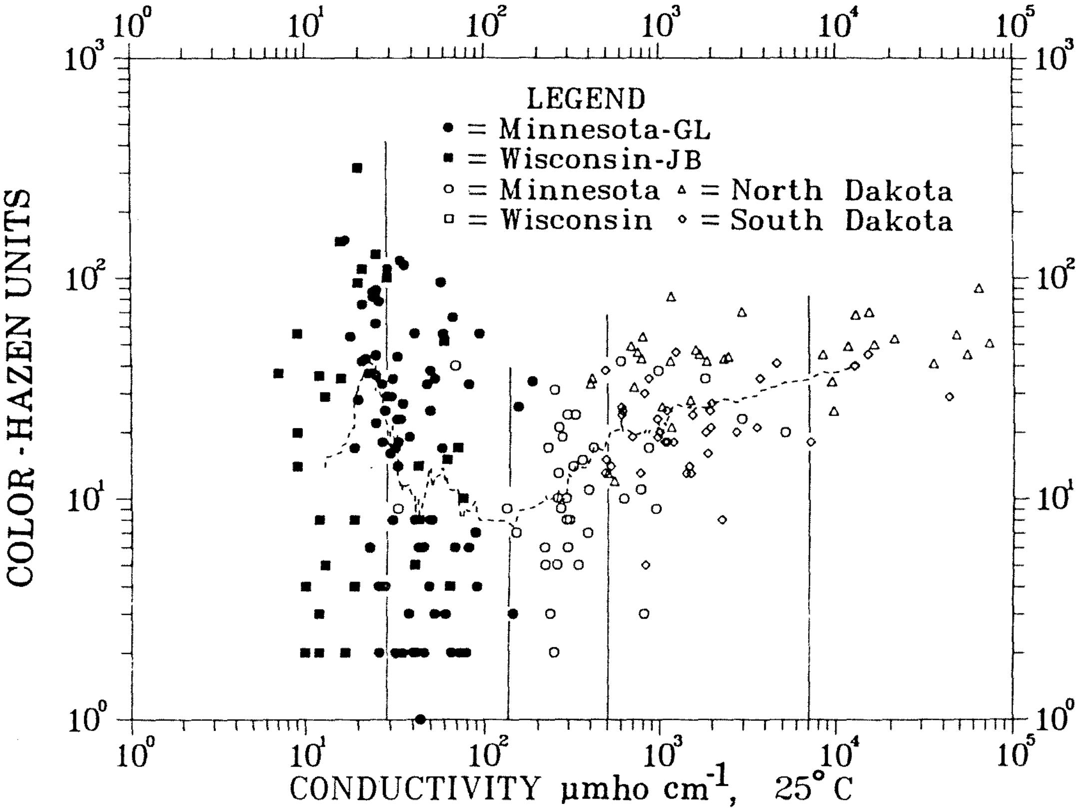

Figure 22.--The $\log_{10}$ relationship between color (Hazen platinum cobalt scale) and specific conductivity.

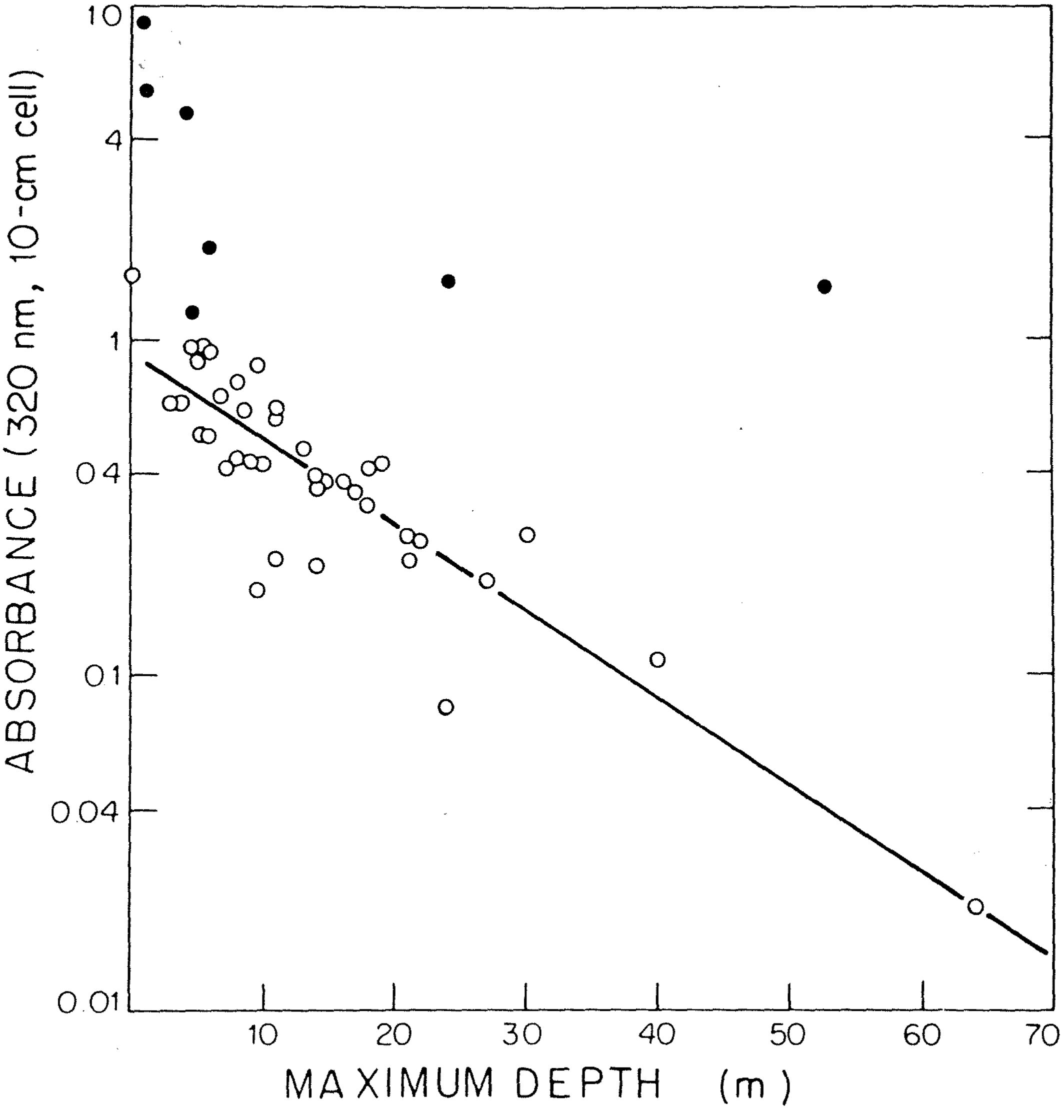

Figure 23.--The relationship of $\log_{10}$ water color (absorbance at 320 nm in a 10-cm silica cell) to maximum lake depth. Dots represent lakes with peaty drainage; circles represent lakes with normal drainage.

COLOR

Water color -- a useful measure of dissolved organic matter (Juday and Birge, 1933) -- was not measured in most of our samples of dilute waters from group I and group II lakes; however, simultaneous color and specific conductivity data are available from these and adjacent lakes in publications by Juday and Birge (1933) and Glass and Loucks (1980). These have been treated together with our data in figure 22.

Color is extremely variable in group I and II waters, ranging from 1 to 300 Hazen units. Very low values represent surface runoff over coarse, sandy and gravelly soils with thin acid humus layers, whereas high values represent drainage from acid peat deposits. Such deposits are of little significance on calcareous substrates. The most dilute group III lakes have waters with relatively little color (averaging less than 10 units) and there is a steady increase -- though not proportional to the rise in conductivity -- from these waters to those of the most saline group V lakes (greater than 50 units).

Absorbance (at 320 nm in a 10-cm silica cell) was measured in 39 of the Minnesota waters as another estimate of color and dissolved organic carbon (Gorham, 1957c; Mackereth, 1963). Most of these waters came from groups II, III, and IV with one each from groups I and V. The waters were filtered quickly through a coarse paper; filtration of 10 samples (with absorbances from 0.1 to 1.6) through 0.45 μm millipore filters removed about 5% of the color (range 1 to 11%, with no relation to amount of color).

Highly colored waters (absorbance greater than 2) were found only in lakes on peaty non-calcareous substrates. If lakes receiving peaty drainage are excluded, a very close correlation (r = -0.88) is observed between $\log_{10}$ color and maximum lake depth. The inverse relationship of color (and dissolved organic matter) to depth (Fig. 23) is probably explained by the interaction of several factors: (1) shallow lakes are more productive per unit volume than deep lakes and hence the volumetric secretion of extracellular metabolites and the release of dissolved organic matter by decomposition of dead plankton is greater in shallow lakes; (2) the ratio of sediment area to water volume is higher in shallow than in deep lakes, leading to a greater concentration of dissolved organic matter released to the overlying water by decay in the sediments, and (3) evaporative concentration per unit volume is greater in shallow than in deep lakes. Decreasing depth is probably an important factor in the increase of color (Fig. 22) from the most dilute group III lakes to the most saline group V lakes.

DISCUSSION

It is clear from our results that the chemistry of surface waters of lakes in the north-central United States -- like the chemistry of groundwaters (Winter, 1977) and of profundal lake sediments (Dean and Gorham, 1976) -- can be understood largely in terms of the interaction of climatic and geologic factors, although human influences are discernible in some lakes. Our data are in accord with -- and provide a detailed background to -- the broad generalization by Clarke (1924) that there is a pronounced shift from bicarbonate-dominated waters in the humid forests east of the Mississippi to sulfate-dominated waters that precipitate calcium carbonate in the more arid prairie regions of the west. In addition we have shown that changes in geologic substrate are also important.

Our data are broadly compatible with the model presented by Gibbs (1970) for the control of global water chemistry by atmospheric deposition, rock weathering, and the evaporation/precipitation process. He observed that the most dilute surface waters, which have ionic compositions close to rainwater, have high ratios of sodium to calcium and of chloride to bicarbonate. These ratios decline sharply toward the middle range of salinity where rock weathering is the predominant source of ions, and rise again as evaporation leads to further ion concentration and the precipitation of calcium carbonate. Generally similar relationships occur in the north-central United States (Figs. 20 and 21), but the ratio of sodium to calcium is not nearly so high as that observed by Gibbs (1970), who included a number of rivers that are strongly influenced by atmospheric deposition of sea spray. Likewise, the ratio of chloride to alkalinity never reaches the high levels observed by Gibbs (1970) at either end of the salinity range where again sea salt plays a predominant role. The distribution of the ratio of sulfate to alkalinity in the north-central United States is similar to the distribution of the ratio of chloride to alkalinity presented by Gibbs (1970); both are low in the middle range of salinity (Fig. 21).

Contrary to the view expressed by Bright (1968), water chemistry does not appear to be closely related to vegetation type. The boundary between the lakes of groups II and III generally runs east of the boundary between coniferous and deciduous forests shown by Wright (1969), whereas the boundary between groups III and IV is usually west of the forest-prairie boundary.

According to Hall (1972) the chemical composition of Minnesota lake waters approximately fits a model in which rainfall enriched by soil-derived carbon dioxide reacts with calcite, dolomite, gypsum, illite, and sodium feldspar at 5° C and 1 atmosphere total pressure. He suggested that the lake waters become saturated with respect to calcite at about 5 meq liter^{-1} total cations (equivalent to a specific conductivity of about 450 μmhos cm^{-1}) and with respect to calcite and dolomite at about 8.9 meq liter^{-1} total cations (specific conductivity of about 750 μmhos). However, this does not agree with our empirical boundary (Dean and Gorham, 1976) for carbonate precipitation at 190 μmhos (about 2 meq liter $^{-1}$ total cations). Hall also suggested that the dissolution of gypsum becomes progressively more important as salinity increases above 5 meq liter^{-1} total cations, which is consistent with Fig. 13 and Fig. 21. Our data also show (Fig. 21) that sulfate begins to dominate the anions above about 10 meq liter^{-1} total cations (specific conductivity of about 900 μmhos). Hall (1972) suggested further that isothermal evaporation of waters in the lakes of southwestern Minnesota should produce highly alkaline magnesium-calcium sulfate waters that he claimed were typical of the closed-basin lakes of the Dakotas. However, he did not account for the predominantly sodium sulfate lakes that are characteristic of the most concentrated closed-basin lake waters in those states and begin to appear as salinity increases above about 30 meq liter^{-1} (specific conductivity about 2,200 μmhos). Our data, moreover, indicate that at concentrations where sulfate begins to dominate over alkalinity (specific conductivity about 900 μmhos, Fig. 21), sodium is already a significant cation approaching calcium in concentration (Fig. 20).

According to Sloan (1972) the sodium sulfate waters of North Dakota do not require bedrock sources of saline water as sometimes suggested, but are the result of an evaporation sequence in which the waters are dominated successively by calcium bicarbonate, magnesium bicarbonate, calcium and magnesium sulfate, and sodium sulfate. Mitten and others (1968) noted that runoff from the Big Coulee at Church's Ferry into the markedly saline Devil's Lake chain in North Dakota is normally dominated by calcium, magnesium, and bicarbonate ions except during periods of low flow when sodium and sulfate ions predominate. As the dissolved salts in the runoff are concentrated by evaporation, the alkaline-earth carbonate minerals precipitate so that the waters stored in the chain of lakes come to be dominated strongly by sodium and sulfate ions, chloride increases markedly, and calcium decreases to only a few percent of total cations.

The work reported here does raise questions -- of a kind frequently encountered -- for further study by hydrogeologists, glacial geologists and soil scientists. For example, several group III lakes occur on glacial deposits mapped as noncalcareous red drift (for example, west of Mille Lacs, Minnesota (Winter, 1974). Presumably these lakes are tapping calcareous material underlying rather shallow red drift. Likewise group II lakes may occur as western outliers on deposits mapped as calcareous gray drift (for example, several lakes in Itasca State Park in northwestern Minnesota). These lakes are small and usually are found on sandy, gravelly material that has probably undergone substantial surface depletion of calcium carbonate by soil leaching. The larger lakes in the area that drain deeper weathering profiles have normal group III waters.

The boundary between group III and group IV lakes raises a very interesting hydrogeological problem. At present it is impossible to say how closely that boundary reflects mineralogical and chemical differences in the respective glacial deposits, and how far it may be influenced by regional versus local groundwater flow (Winter, 1974, and 1977).

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APPENDIX I

Specific conductivity (μmhos cm^{-1} at 25°C), concentrations of calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, nitrate, fluoride, and total cations in meq $liter^{-1}$ (epm), and concentrations of silica, iron, manganese, and boron in mg $liter^{-1}$ (ppm) in surface waters of 217 lakes in Wisconsin (W), Minnesota (M), North Dakota (N), and South Dakota (S). Values of pH are in relative pH units. Values of color are in Hazen units, and values of optical density are in absorbance at 320 nm in a 10-cm silica cell. Leaders (--) mean no analyses were made.

Lake Name	State	County	K-µmhos	epm-Ca	epm-Mg	epm-Na	epm-K	epm-alk	epm-SO4	epm-Cl	epm-T-N	epm-F	tot-cat	ppm-SiO2	ppm-Fe	ppm-Mn	ppm-B	pH	color	opt.dens
Ruth	W	Vilas	9	.055	.0246	.0	.0179	.020	.0604	.0141	.0	.0	.0975	.100	--	--	--	5.02	--	--
Weber	W	Vilas	11	.065	.0164	.0	.0179	.020	.0708	.0141	.0	.0	.0993	.200	--	--	--	5.40	--	--
Bragoner	W	Vilas	13	.075	.0328	.0043	.0153	.040	.0792	.0141	.0	.0	.1275	.200	--	--	--	6.10	--	--
Big Carr	W	Oneida	17	.070	.0328	.0087	.0205	.020	.0875	.0225	.0	.0	.1319	.100	--	--	--	5.15	--	--
Pallette	W	Vilas	19	.125	.0656	.0043	.0128	.120	.0604	.0366	.0	.0	.2077	.200	--	--	--	5.75	--	--
Emerald	M	St. Louis	20	.215	.0820	.0435	.0153	.200	.0771	.0338	.0056	.006	.3558	.700	--	--	--	6.80	--	--
Thumb	M	St. Louis	22	.075	.0820	.0435	.0256	.020	.1417	.0451	.0024	.006	.2260	3.900	--	--	--	6.52	--	--
Pauline	M	St. Louis	22	.160	.0656	.0391	.0153	.140	.1271	.0254	.0040	.006	.2800	4.800	--	--	--	6.69	--	--
Little Bass	W	Vilas	22	.100	.0574	.0478	.0179	.100	.0792	.0479	.0	.0	.2231	.100	--	--	--	6.39	--	--
Nebish	W	Vilas	23	.130	.0820	.0087	.0179	.180	.0604	.0141	.0	.0	.2386	.200	--	--	--	5.74	--	--
Big	M	St. Louis	24	.122	.0740	.0450	.0140	.135	.1110	.0150	--	--	.2550	--	--	--	--	--	--	94
Helen	W	Vilas	24	.125	.0656	.0304	.0205	.100	.1292	.0310	.0	.0	.2415	.500	--	--	--	6.15	--	--
Clear	W	Oneida	24	.150	.1070	.0260	.0150	.160	.1190	.0060	.0010	--	.2980	--	.060	--	--	6.80	--	--
Henneman	W	Chippewa	26	.060	.0580	.0610	.0510	.180	.0210	.0110	.0240	--	.2300	--	.150	--	--	6.10	--	--
Norway	M	St. Louis	27	.195	.1393	.0435	.0307	.020	.1417	.2479	.0032	.006	.4085	3.100	--	--	--	6.60	--	--
Fishmouth	M	St. Louis	28	.130	.0820	.0304	.0256	.200	.0604	.0169	.0080	.0	.2680	.900	--	--	--	7.09	--	--
Mary	W	Vilas	28	.175	.0738	.0261	.0179	.060	.1792	.0451	.0	.0	.2928	.900	--	--	--	6.11	--	--
Rahr	W	Vilas	31	.100	.0574	.1304	.0281	.040	.0792	.1746	.0	.0	.3159	.100	--	--	--	6.10	--	--
Burntside	M	St. Louis	33	.185	.0540	.0460	.0170	.214	.0920	.0020	.0020	.050	.3020	1.450	.035	.010	<0	6.75	9	--
Big	M	Carleton	34	.212	.1270	.0260	.0100	.260	.0800	.0180	--	--	.3750	--	--	--	--	--	--	29
Rose	W	Vilas	35	.200	.1066	.0304	.0179	.140	.1479	.0394	.0	.0	.3549	1.200	--	--	--	6.22	--	--
Iron	M	Cook	36	.186	.1280	.0370	.0100	.235	.1340	.0030	--	--	.3610	--	--	--	--	--	--	188
Trout	M	Cook	40	.198	.1350	.0420	.0120	.274	.1260	.0050	--	--	.3870	--	--	--	--	--	--	26
Clearwater	M	Cook	41	.200	.1440	.0410	.0150	.293	.1240	.0050	--	--	.4000	--	--	--	--	--	--	11
Midge	W	Vilas	41	.110	.0820	.1696	.0256	.040	.0729	.2563	.0	.0	.3871	.200	--	--	--	6.20	--	--
Wilson	M	Lake	46	.250	.1470	.0610	.0120	.372	.1000	.0120	--	--	.4700	--	--	--	--	--	--	36
Sandpoint	M	St. Louis	46	.278	.1730	.0520	.0210	.354	.1490	.0170	--	--	.5240	--	--	--	--	--	--	143
Kimball	M	Cook	52	.270	.1950	.0770	.0130	.449	.1010	.0160	--	--	.5550	--	--	--	--	--	--	52
Crane	M	St. Louis	55	.358	.1740	.0610	.0170	.432	.1560	.0190	--	--	.6100	--	--	--	--	--	--	149
Deming	M	Hubbard	58	.344	.1730	.0300	.0290	.470	.0700	.0240	--	--	.5760	--	--	--	--	--	--	57
Big Bass	W	Washburn	61	.359	.1890	.0520	.0130	.622	.0170	.0030	.0	--	.6130	--	.220	--	--	6.70	--	--
Basswood	M	Lake	65	.460	.1500	.0430	.0150	.572	.1070	.0080	--	--	.6680	--	--	--	--	--	--	53
Vermillion	M	St. Louis	69	.444	.1650	.0740	.0180	.476	.1830	.0280	.0100	.100	.7010	4.530	.120	.020	.030	7.00	40	--
Josephine	M	Hubbard	71	.403	.2140	.0230	.0380	.640	.0610	.0070	--	--	.6780	--	--	--	--	--	--	32
O'Leary	M	St. Louis	74	.397	.3120	.0490	.0250	.694	.0990	.0120	--	--	.7830	--	--	--	--	--	--	35
Trout	M	Cook	80	.600	.2541	.0565	.0128	.780	.0708	.0366	.0	.006	.9234	7.800	--	--	--	--	--	--
Superior	M	Cook	82	.556	.2280	.0510	.0140	.746	.0920	.0220	--	--	.8490	--	--	--	--	--	--	78
Arco	M	Hubbard	82	.468	.2960	.0240	.0370	.750	.0580	.0100	--	--	.8250	--	--	--	--	--	--	47
Perch	M	Carlton	92	.695	.3380	.0700	.0150	.888	.1680	.0260	--	--	1.1180	--	--	--	--	--	--	484
26 Lake	W	Burnett	116	.798	.3210	.0780	.0260	1.121	.0420	.0010	.0	--	1.2230	--	.300	--	--	7.10	--	--
Farquar	M	Dalota	132	.700	.2220	.0650	.1590	.656	.3120	.0760	.1210	.100	1.1460	11.000	.040	<0	.070	6.40	9	--
Wandowega	W	Walworth	148	.883	.6340	.0570	.0490	1.506	.0370	.0	.0	--	1.6230	--	.080	--	--	8.40	--	--
St. Marys	M	St. Louis	150	.798	.5430	.1440	.0490	1.164	.2700	.0900	.0110	.100	1.5340	.900	.170	.060	.010	6.90	7	--
Gladstone	M	Crow Wing	162	1.204	.5340	.1610	.0260	1.816	.0600	.0100	--	--	1.9250	--	--	--	--	--	--	18
George	M	Anoka	167	1.016	.5880	.1270	.0210	1.588	.1250	.0390	--	--	1.7520	--	--	--	--	--	--	42

Linwood	M	Anoka	171	1.032	.6520	.1150	.0190	1.658	.1220	.0340	--	--	1.8180	--	--	--	--	--	--	58
Spectacle	M	Anoka	181	.956	.7600	.1430	.0390	1.747	.0960	.0420	--	--	1.8980	--	--	--	--	--	--	38
Ham	M	Anoka	188	1.048	.9160	.1560	.0390	1.924	.1630	.0480	--	--	2.1590	--	--	--	--	--	--	68
Green	M	Isanti	206	1.084	.9840	.1340	.0290	2.069	.1410	.0280	--	--	2.2310	--	--	--	--	--	--	62
Cedar Bog	M	Isanti	206	1.250	.5320	.0850	.0120	1.758	.1410	.0070	--	--	1.8790	--	--	--	--	--	--	552
Upper Red	M	Beltrami	207	1.465	.8460	.0690	.0360	2.155	.2210	.0240	--	--	2.4160	--	--	--	--	--	--	120
Reeds	M	Waseca	211	1.148	.8680	.1170	.1710	2.028	.1720	.0840	--	--	2.3040	--	--	--	--	--	--	41
Mille Lacs	M	Aitkin	218	1.277	.6670	.1610	.0510	1.897	.1480	.0710	.0050	.130	2.1560	8.230	.050	.050	.040	7.40	6	--
Gull	M	Cass	221	1.422	.7570	.1570	.0310	2.239	.1120	.0170	.0020	.100	2.3670	4.750	.010	.010	.020	7.60	5	--
Francis	M	Lesueur	233	1.254	1.0800	.1000	.1480	2.348	.1800	.0480	--	--	2.5820	--	--	--	--	--	--	32
Pelican	M	Crow Wing	234	1.462	.7900	.1830	.0360	2.383	.0850	.0310	<0	.100	2.4710	4.830	.030	<0	.040	7.73	3	--
Nokay	M	Crow Wing	238	1.828	.6130	.1170	.0270	2.464	.0930	.0210	--	--	2.5850	--	--	--	--	--	--	47
Beaver	M	Steele	240	1.232	1.1960	.1280	.1180	2.168	.3320	.1320	--	--	2.6740	--	--	--	--	--	--	41
Alexander	M	Morrison	246	1.400	.9040	.2610	.0510	2.509	.1410	.0030	<0	.100	2.6160	3.200	.010	.030	.020	7.30	2	--
Ball Club	M	Itasca	249	1.720	.9440	.1310	.0350	2.630	.1380	.0170	--	--	2.8300	--	--	--	--	--	--	--
Round	M	Itasca	251	1.772	.8470	.1020	.0400	2.485	.2110	.0050	.0060	.150	2.7610	17.000	.030	.020	.030	7.30	31	--
Moose	M	Itasca	254	1.730	.8800	.1640	.0520	2.700	.1090	.0230	--	--	2.8260	--	--	--	--	--	--	22
Lung	M	Hubbard	258	1.397	1.2350	.1570	.0230	2.722	.0730	.0510	.0020	.100	2.8120	9.400	.050	.020	.050	7.70	5	--
Elmo	M	Washington	261	1.850	.7070	.2350	.0970	2.460	.2910	.0930	.0030	.100	2.8890	.500	.050	<0	.020	7.50	10	--
Mashkenode	M	St. Louis	262	1.550	.7890	.3180	.0740	1.968	.6030	.1330	.0370	.200	2.7310	4.400	.140	.600	.040	7.20	13	--
Pokegama	M	Pine	264	1.697	.9880	.1700	.0440	2.673	.1750	.0080	.0100	.170	2.8990	7.120	.070	<0	.020	7.48	21	--
Elk	M	Clearwater	266	1.646	1.3780	.3130	.0450	3.247	.0680	.0190	--	--	3.3820	--	--	--	--	--	--	26
Christmas	M	Hennepin	266	1.201	1.6260	.1960	.0970	2.837	.1770	.0760	--	--	3.1200	--	--	--	--	--	--	19
Leech	M	Cass	273	1.577	1.1850	.2180	.0490	2.819	.0890	.0540	.0060	.120	3.0290	9.650	.030	.020	.050	7.37	9	--
Long	M	Clearwater	274	1.291	1.7960	.1630	.0440	3.210	.0650	.0250	--	--	3.2940	--	--	--	--	--	--	8
Winnebigoshish	M	Cass	276	1.672	1.1360	.1830	.0410	2.875	.1100	.0340	.0030	.120	3.0320	8.030	.060	<0	.040	7.35	19	--
St. Olaf	M	Waseca	282	1.412	1.2440	.2180	.1620	2.470	.3500	.1680	--	--	3.0360	--	--	--	--	--	--	43
Lotus	M	Carver	283	1.461	1.3330	.2480	.1460	2.404	.4250	.2700	--	--	3.1880	--	--	--	--	--	--	63
Itasca	M	Clearwater	284	1.388	1.8200	.2780	.0440	3.454	.0550	.0300	--	--	3.5300	--	--	--	--	--	--	21
Clear	M	Lesueur	286	1.796	1.1280	.1510	.1440	2.598	.4920	.0720	--	--	3.2490	--	--	--	--	--	--	92
Prior	M	Carver	293	1.600	1.2330	.1310	.1540	2.640	.2910	.1240	.0470	.200	3.1180	.900	.030	<0	.040	6.30	10	--
Lower Red	M	Beltrami	296	1.846	1.2180	.1480	.0610	2.972	.2080	.0370	.0140	.200	3.2730	5.930	.020	.020	.050	7.48	6	--
Centerville	M	Ramsey	297	1.750	1.0690	.2180	.0970	2.706	.2080	.1180	.0610	.200	3.1340	3.800	.030	<0	.070	7.10	24	--
Medicine	M	Hennepin	305	1.600	1.3150	.1910	.1230	2.772	.2910	.1920	.0180	.200	3.2290	.800	.020	<0	.030	7.30	8	--
Booth	W	Walworth	308	1.482	1.9510	.1170	.0440	3.410	.2300	.0010	.0	--	3.5940	--	.020	--	--	8.20	--	--
Little Pine	M	Ottertail	311	1.856	1.6890	.1920	.0520	3.437	.1240	.0340	--	--	3.7870	--	--	--	--	--	--	43
Hoglot	W	Langlade	318	1.996	1.4480	.0740	.0380	3.513	.0420	.0100	.0	--	3.5560	--	.020	--	--	7.40	--	--
Vadnais	M	Ramsey	321	2.000	1.1510	.2960	.0610	3.083	.2500	.1180	<0	.200	3.5080	2.500	.030	.020	.100	7.30	14	--
Speigal	W	Langlade	321	1.976	1.4810	.1040	.0330	3.482	.0850	.0150	.0	--	3.5940	--	.010	--	--	7.60	--	--
Louise	S	Ward	329	1.452	1.0210	.6180	.3000	2.498	.5720	.3130	.0140	.170	3.3910	5.750	.090	.040	.090	7.30	24	--
Minnetonka	M	Hennepin	342	1.497	1.3580	.5610	.1480	2.673	.1580	.6660	.0110	.150	3.5640	1.880	.020	.020	.050	7.06	5	--
Beulah	W	Walworth	347	1.377	2.4530	.1480	.0380	4.022	.0930	.0	.0	--	4.0160	--	.040	--	--	8.30	--	--
Mt. Spring	W	Oconto	348	1.996	1.3500	.3480	.0510	3.425	.3670	.0080	.0	--	3.7450	--	.070	--	--	7.80	--	--
Grove	M	Pope	349	1.568	2.2420	.1840	.1030	3.480	.4370	.0660	--	--	4.0970	--	--	--	--	--	--	83
Pleasant	W	Walworth	351	1.332	2.2300	.1170	.0310	3.707	.1410	.0010	.0	--	3.7100	--	.010	--	--	8.20	--	--

Lake Name	State	County	K-µmhos	epm-Ca	epm-Mg	epm-Na	epm-K	epm-alk	epm-SO4	epm-Cl	epm-T-N	epm-F	tot-cat	ppm-SiO2	ppm-Fe	ppm-Mn	ppm-B	pH	color	opt.dens
Green	W	Walworth	351	1.527	2.2060	.1170	.0380	3.954	.0850	.0	.0	--	3.8880	--	.010	--	--	8.40	--	--
Mill 1	W	Walworth	360	1.567	2.2800	.1170	.0380	3.950	.1270	.0	.0	--	4.0020	--	.050	--	--	8.30	--	--
Sallie	M	Becker	361	1.368	2.3770	.5160	.1230	3.606	.4920	.1670	--	--	4.3840	--	--	--	--	--	--	39
Cowdry	M	Douglas	362	1.324	2.7000	.2470	.1250	3.709	.4480	.0270	--	--	4.3960	--	--	--	--	--	--	38
Calhoun	M	Hennepin	362	2.650	.4030	.6530	.1080	2.772	.4370	.5640	.0240	.200	3.8140	1.700	.050	<0	.060	7.40	15	--
Rockland	W	Racine	363	1.886	2.7320	.1610	.0720	4.583	.2200	.0020	.0	--	4.8510	--	.120	--	--	8.20	--	--
Browns	W	Racine	369	1.761	2.4530	.3480	.0280	4.195	.3950	.0010	.0	--	4.5900	--	.060	--	--	8.50	--	--
Fish	M	Cottonwood	372	1.084	2.4440	.3930	.2000	3.190	.7870	.1150	--	--	4.1210	--	--	--	--	--	--	74
Mill 2	W	Walworth	379	1.826	2.1480	.1220	.0410	4.138	.1270	.0	.0	--	4.1370	--	.040	--	--	8.10	--	--
Clearwater	M	Carver	388	1.300	1.8910	.6530	.2560	3.362	.3740	.3950	.0030	.200	4.1000	.600	.030	<0	.080	7.40	7	--
Maple	M	Douglas	390	1.182	2.9950	.2790	.1440	4.162	.3870	.0770	--	--	4.6000	--	--	--	--	--	--	25
Bohners	W	Racine	390	2.415	2.4530	.1350	.0490	4.702	.1780	.0040	.0	--	5.0520	--	.070	--	--	8.60	--	--
Floyd	M	Becker	393	1.707	2.4360	.1220	.1280	3.687	.6820	.0820	.0020	.260	4.3930	17.400	.050	<0	.040	7.76	11	--
Rock	N	Towner	404	1.572	1.2350	1.0660	.2940	2.878	.8630	.3530	.0580	.150	4.1670	10.250	.020	.130	.100	7.15	33	--
Square	N	Benson	413	1.347	1.7280	1.1310	.2120	3.493	.7700	.0850	.0500	.300	4.4180	16.000	.030	<0	.110	7.00	35	--
Middle	W	Walworth	417	2.091	2.3370	.1170	.0360	4.451	.0990	.0030	.0	--	4.5810	--	.020	--	--	8.30	--	--
Long	M	Ramsey	418	2.150	1.0690	.9140	.1130	2.870	.5410	.8740	.0190	.200	4.2460	1.600	.020	<0	.090	7.00	17	--
Frieda	W	Racine	419	2.570	2.6990	.0830	.0510	5.494	.0710	.0010	.0	--	5.4030	--	.160	--	--	8.00	--	--
Lower Phantom 1	W	Waukesha	420	2.061	2.2630	.1350	.0360	4.525	.1470	.0090	.0	--	4.4950	--	.070	--	--	8.20	--	--
Eagle 2	W	Racine	423	2.265	2.3950	.4130	.0870	4.846	.4790	.0010	.0	--	5.1600	--	.090	--	--	8.20	--	--
Army	W	Walworth	424	1.637	2.5920	.1910	.0690	4.293	.2060	.0020	.0	--	4.4890	--	.010	--	--	8.30	--	--
Lower Phantom 2	W	Waukesha	431	2.106	2.2220	.1220	.0310	4.510	.1440	.0020	.0	--	4.4810	--	.080	--	--	8.10	--	--
Eagle 1	W	Racine	432	2.216	2.2880	.4130	.0720	4.744	.4880	.0010	.0	--	4.9890	--	.140	--	--	8.00	--	--
Starring	M	Hennepin	433	1.951	2.6940	.3960	.0790	3.877	.6510	.4550	--	--	5.1200	--	--	--	--	--	--	86
Beulah 1	W	Walworth	440	2.236	2.4770	.1390	.0360	4.969	.0790	.0	.0	--	4.8880	--	.020	--	--	8.20	--	--
Mina	M	Douglas	460	1.832	3.1570	.4440	.1130	3.644	1.5080	.1920	--	--	5.5460	--	--	--	--	--	--	--
Spring	W	Waukesha	461	2.440	2.2470	.0830	.0260	4.830	.0930	.0330	.0	--	4.7960	--	.070	--	--	8.30	--	--
Wind 2	W	Racine	469	2.720	2.5600	.3740	.0870	5.290	.5640	.0040	.0	--	5.7410	--	.080	--	--	8.40	--	--
Eagle Spring	W	Waukecha	478	2.610	2.2880	.1170	.0310	4.945	.1860	.0290	.0	--	5.0460	--	.070	--	--	8.10	--	--
Pickerel	S	Day	485	1.946	2.9870	.3390	.1740	4.084	1.1610	.0790	.0050	.200	5.4460	16.100	.010	.030	.090	7.93	13	--
Enemy Swim	S	Day	491	1.597	3.4980	.3220	.2070	4.488	.9360	.0990	.0030	.280	5.6240	13.000	.030	.030	.070	8.20	15	--
Cherry	S	Clark and Kingsbury	491	2.325	1.8350	.6920	.5940	3.631	1.3400	.2620	.0660	.450	5.4460	22.200	.030	.460	.080	7.65	38	--
Battle	N	Eddy	505	1.048	3.3740	.7830	.2250	4.625	.3950	.2140	.1290	.040	5.4300	22.000	.030	<0	.190	7.40	13	--
Wind 1	W	Racine	511	2.720	2.4850	.3700	.0840	5.290	.5580	.0040	.0	--	5.6590	--	.130	--	--	8.40	--	--
Kee Nong Go Mong	W	Racine	511	2.894	2.6170	.2520	.0770	5.620	.3670	.0040	.0	--	5.8400	--	.120	--	--	8.00	--	--
Tichigan	W	Racine	513	2.844	2.6750	.5090	.0670	5.533	.6710	.0040	.0	--	6.0950	--	.080	--	--	8.40	--	--
Kampeska	S	Codington	523	2.680	2.4690	.5050	.2590	4.086	1.5140	.1270	.0240	.230	5.9130	13.630	.020	.030	.090	7.95	14	--
Wood	N	Benson	550	1.347	3.5390	.9140	.3330	5.314	.8110	.1300	.0060	.400	6.1330	12.000	.010	.020	.090	7.80	12	--
Buena	W	Racine	597	3.653	3.1520	.4570	.4990	6.928	.6430	.0060	.0	--	7.7610	--	.340	--	--	8.60	--	--
Talge	M	Clearwater	599	3.992	2.4690	.4790	.1200	6.219	.6030	.2200	.0110	.300	7.0600	21.000	.050	.080	.070	8.30	42	--
Blue Dog	S	Day	603	2.585	3.3330	.3000	.1560	4.998	1.0880	.1100	.0080	.230	6.3740	21.750	.020	.020	.100	8.23	26	--
Rediron	S	Marshall	605	1.861	4.2380	.4310	.3070	4.592	1.9140	.2170	.0240	.330	6.8370	2.880	.020	.030	.130	7.83	24	--
Elm	S	Brown	615	2.136	1.6300	2.2840	.3330	3.093	2.5440	.6430	.0110	.200	6.3830	10.380	.030	2.080	.120	7.80	25	--
Manganika	M	St. Louis	625	2.950	2.6300	.9570	.1230	3.116	2.3300	.9310	.1770	.300	6.6600	12.000	.050	1.200	.080	7.30	10	--
Saylesville	W	Waukesha	655	3.383	2.8810	.2000	.0360	6.456	.3100	.0630	.0	--	6.5000	--	.110	--	--	8.10	--	--

Irvine	N	Ramsey	690	2.774	2.4850	1.4960	.5170	4.287	2.4500	.4710	.0370	.200	7.2720	14.500	.050	.030	.090	7.66	49	--
Bedashos	S	Buffalo	693	2.395	1.2840	3.0670	.2710	1.911	4.6700	.4600	.0290	.200	7.0170	11.900	.060	.270	.150	6.90	19	--
Lac Qui Parle	M	Lac Qui Parle	716	3.760	3.7790	1.0650	.3000	4.469	4.0200	.0800	--	--	8.9040	--	--	--	--	--	--	73
Dry	N	Day	717	2.196	2.7980	2.2190	.5890	5.346	1.7060	.7900	.0480	.200	7.8020	28.000	.070	<0	.130	7.50	32	--
Sweetwater	N	Ramsey	751	1.856	2.5600	2.2750	.6220	4.074	2.5750	.5720	.0610	.200	7.3130	13.790	.050	.080	.110	7.73	46	--
Buffalo South	S	Marshall	770	2.485	5.5140	.5220	.3530	4.431	4.0350	.1950	.0060	.300	8.8740	5.750	.030	.040	.120	8.00	13	--
Big Stone	M	Big Stone	778	3.473	3.4650	1.4400	.2300	2.929	5.2460	.3050	.0530	.190	8.6080	8.210	.070	.130	.190	7.28	11	--
Mallard	N	Benson	793	1.946	4.2800	2.3060	.4860	7.331	1.2480	.2620	.2090	.500	9.0180	17.000	.040	<0	.200	7.70	43	--
Lac Aux Mortes	N	Ramsey	803	3.353	3.1600	1.8750	.4510	4.474	3.6840	.5440	.0340	.250	8.8390	8.040	.070	.120	.060	7.67	54	--
Minnewaska	M	Pope	812	2.350	5.4250	1.3050	.2410	5.592	3.3900	.3950	.0020	.200	9.3210	27.000	.010	<0	.140	7.70	3	--
Sinai	S	Brookings	815	2.011	2.9630	2.5330	1.0240	5.986	1.9610	.4430	.0920	.270	8.5510	25.330	--	--	.160	7.83	30	--
Big Kandiyohi	M	Kandiyohi	826	2.524	4.9600	1.2350	.3450	3.796	4.6700	.4900	--	--	9.0640	--	--	--	--	--	--	64
Clear	S	Marshall	830	2.161	5.9260	.6530	.4530	4.423	4.5280	.1750	.0270	.330	9.1930	11.670	--	--	.100	7.90	5	--
Shetek	M	Murray	864	4.685	3.9030	.8950	.2190	3.371	5.6200	.6890	.0350	.300	9.7020	13.000	.030	.150	.090	7.60	17	--
Sully	S	Sully	867	3.074	2.1560	3.8370	.4920	3.269	5.9760	.3240	.0310	.240	9.5590	9.920	.180	.070	.120	7.48	35	--
Morrison	N	Ramsey	942	4.192	3.0450	2.3060	.7420	3.870	5.4700	.5640	.1580	.200	10.2850	32.000	--	--	.190	7.30	--	--
Benton	M	Lincoln	948	4.750	4.8500	.6960	.4100	2.952	7.2590	.4230	.0110	.300	10.7060	18.000	.020	<0	.130	7.20	9	--
Thief	M	Marshall	956	7.969	4.7250	.2570	.1240	9.494	3.7280	.0980	--	--	13.0750	--	--	--	--	--	--	200
East Vermilion	S	McCook	969	4.805	4.7730	1.2180	.3710	3.447	7.2900	.1860	.0260	.280	11.1670	15.980	.030	.710	.110	8.00	19	--
Parmley	S	Edmunds	970	2.485	1.9180	4.9720	.5070	4.080	3.4010	2.3270	.0110	.350	9.8820	8.830	.030	3.800	.300	7.88	23	--
Mud	M	Marshall	983	3.892	4.6500	2.0450	.3200	2.039	8.3780	.3330	.0450	.200	10.9070	3.200	--	--	.170	6.85	38	--
Richmund	S	Brown	995	2.086	1.9750	5.5190	.4740	4.204	3.8170	1.9120	.0160	.330	10.0540	7.650	.060	1.600	.270	7.90	20	--
Silver	N	Benson	1,030	2.545	3.5390	4.3070	.6140	4.690	4.8880	.9310	.1400	.200	11.0050	15.000	.030	<0	.170	7.10	26	--
Poinsett	S	Hamlin	1,064	2.086	6.3700	2.8800	.5680	4.414	6.0110	1.1730	.0840	.320	11.9040	11.720	.020	.020	.290	7.76	18	--
Sand	S	Brown	1,095	3.258	3.6460	4.7420	.3840	6.499	3.7380	1.6640	.0270	.400	12.0300	18.330	--	--	.320	7.80	25	--
Herman	S	Lake	1,106	4.850	5.3000	2.2710	.4970	4.098	8.3780	.2280	.0370	.220	12.9180	16.940	.060	.410	.130	7.82	18	--
Elk	M	Grant	1,135	1.336	11.0740	1.1940	.7650	7.036	6.7600	.2400	--	--	14.3690	--	--	--	--	--	--	44
Round	N	Benson	1,150	2.695	4.5270	4.6760	.7040	3.985	7.4360	.9590	.0520	.200	12.6020	21.500	.030	<0	.210	7.15	42	--
Crystal Spring	N	Kidder	1,170	2.745	6.6660	3.1320	.4860	6.432	5.9900	.5640	.0110	.400	13.0290	35.000	--	--	.410	8.40	82	--
Elbow	N	Benson	1,170	.948	3.3740	8.1780	.5890	10.234	1.8100	.9590	.0080	.300	13.0890	20.000	.020	.060	.500	7.80	21	--
Wall	S	Minnehaha	1,195	3.608	7.3910	2.0140	.6990	3.116	9.8490	.2620	.0480	.180	13.7120	5.630	.020	.190	.150	7.68	18	--
Henry	S	Kingsbury	1,247	2.535	7.7770	3.4150	1.0620	7.344	6.0800	.8460	.0470	.400	14.7890	24.750	.030	.290	.290	8.10	46	--
Dead Coon	M	Lincoln	1,260	6.360	7.0400	.9910	.3800	3.760	10.3000	.3400	--	--	14.7710	--	--	--	--	--	--	65
Roy	S	Marshall	1,413	2.984	11.7690	1.8400	.8450	5.346	11.2420	.2930	.0050	.380	17.4380	17.750	.020	.030	.260	8.20	13	--
Traverse	M	Traverse	1,414	5.858	7.0000	3.5840	.4250	3.500	12.6460	.5080	.0430	.310	16.8670	15.960	.080	--	.490	7.47	--	--
Mud	M	Traverse	1,462	12.445	8.2260	.4910	.1560	10.676	10.1600	.1300	--	--	21.3300	--	--	--	--	--	--	290
Mitchell	S	Davison	1,470	5.514	5.0200	5.0240	.4220	3.305	11.2320	.9450	.0030	.430	15.9800	8.000	.020	.140	.520	7.80	14	--
Swan	N	Nelson	1,500	3.244	4.6090	7.5690	.5120	2.952	11.7310	1.6920	.0080	.100	15.9340	12.000	.060	.070	.260	6.90	28	--
Madison	S	Lake	1,505	5.629	6.9790	4.2200	.5760	4.317	9.9070	2.6870	.0140	.250	17.4040	24.750	.050	.310	.170	7.98	13	--
Nordon	S	Hamlin	1,545	6.188	9.2830	3.7980	.6220	3.805	15.1170	.3840	.0110	.330	19.8910	14.500	.040	.100	.340	7.95	24	--
Broken Bone	N	Benson	1,610	1.198	9.7110	7.3520	.8960	11.447	7.3220	.5640	.0080	.600	19.1570	16.000	.010	<0	.530	7.60	47	--
Coon	N	Nelson	1,690	4.142	7.5720	6.8730	2.3550	4.461	13.5410	1.0150	1.0140	.200	20.9420	17.000	.040	<0	.290	7.00	45	--
Brant	S	Lake	1,770	7.086	10.4520	3.6980	.8190	4.723	15.6000	.8460	.0310	.200	22.0550	29.000	.110	.010	.250	7.50	--	--
Cottonwood	M	Lyon	1,824	2.131	3.9480	12.7720	.7250	7.899	8.1790	3.5530	.0180	.430	19.5760	23.139	.269	.057	.601	7.89	35	--
Waste	S	Day	1,828	1.886	15.9660	3.2540	1.4540	9.843	11.4570	.8400	.0140	.330	22.5600	13.050	.010	.030	.400	8.45	20	--

Lake Name	State	County	K-µmhos	epm-Ca	epm-Mg	epm-Na	epm-K	epm-alk	epm-SO4	epm-Cl	epm-T-N	epm-F	tot-cat	ppm-SiO2	ppm-Fe	ppm-Mn	ppm-B	pH	color	opt.dens
Rose	N	Nelson	1,860	3.244	5.0200	10.7880	.5120	4.674	12.7920	2.3410	.0230	.200	19.5640	14.000	.060	<0	.270	7.60	42	--
Cottonwood 2	S	Sully	1,886	3.144	4.3210	11.7970	1.1780	7.304	10.9720	2.2170	.0180	.280	20.4400	20.270	.060	.780	.580	7.92	16	--
Cottonwood 1	S	Spink	1,936	2.136	4.2060	13.6890	.7550	8.254	8.8630	3.8270	.0240	.440	20.7860	20.980	.110	.040	.620	7.86	25	--
Henry	S	Bonne Homme	1,950	6.078	9.4230	7.3300	.4680	3.381	16.6050	3.0460	.0320	.350	23.2990	3.650	.050	.490	.580	7.98	21	--
Albert	S	Kingsbury & Hamlin	1,974	5.205	12.0240	6.3990	1.0340	4.128	18.9220	.7220	.1290	.310	24.6620	27.010	.030	.440	.500	7.66	27	--
East Oakwood	S	Brookings	2,267	7.700	16.1310	4.2330	1.0320	2.957	24.8210	.3860	.0890	.370	29.0960	34.330	--	--	.370	7.27	8	--
Long	N	Benson	2,325	2.470	11.2750	11.1360	1.7540	6.478	17.0350	2.7070	.0210	.250	26.6350	10.850	.050	<0	.270	7.40	43	--
Buffalo Lodge	N	McHenry	2,360	1.846	8.7240	14.4420	.9220	9.364	14.3100	2.7640	.0350	.400	25.9340	12.000	.090	.010	.280	8.20	--	--
Juanita	N	Foster	2,400	7.435	12.3450	8.0910	.9220	6.773	19.7600	2.0870	.0310	.600	28.7930	7.500	.050	.010	.290	7.80	--	--
Twin	N	Benson	2,460	2.096	12.2630	12.5280	1.4340	7.216	18.2210	3.0460	.0470	.300	28.3210	9.500	.030	<0	.570	7.30	44	--
Fort Sisseton	S	Marshall	2,723	3.877	24.1960	6.8300	1.7330	4.259	30.7840	.6120	.0480	.470	36.6360	14.130	--	--	.490	7.53	20	--
Byron	S	Beadle	2,952	4.775	8.2450	16.8020	1.0570	5.676	21.1970	4.1300	.0490	.515	30.8790	22.365	.657	1.204	1.342	7.56	23	--
Shinbone	N	Benson	2,970	.429	1.7280	27.7530	1.9200	22.493	2.5790	6.8530	.0060	.500	31.8300	23.000	.040	<0	1.700	8.60	70	--
Andes	S	Charles Mix	3,565	27.520	10.3530	8.9390	2.0990	2.640	39.8840	5.0840	.0210	1.350	48.9110	32.750	.100	1.930	.430	7.55	21	--
Piyas	S	Marshall	3,740	2.345	38.0230	8.4960	3.2440	10.621	38.8960	1.8330	.0320	.300	52.1080	12.870	--	--	.710	8.13	35	--
Red	S	Brule	4,618	24.651	18.7230	15.0730	2.6570	6.171	38.7400	14.3820	.0180	1.650	61.1040	20.080	.290	3.910	.330	7.48	41	--
Morelock's Slough	S	McPherson	5,153	1.082	24.1960	29.9570	6.5200	12.420	42.5010	7.6050	.0230	.233	61.7550	12.333	.010	--	1.433	8.73	20	--
Waubay	S	Day	7,203	5.205	78.1850	24.8250	5.3680	8.618	97.7600	4.6810	.0790	.200	113.5800	5.530	--	--	2.330	6.40	18	--
Spring	N	Benson	8,440	2.944	39.9160	58.7250	3.9680	9.053	82.7840	17.4560	.1010	.200	105.5500	15.000	.030	<0	2.300	7.40	45	--
Horse Shoe	N	Benson	9,530	.649	2.4690	99.1800	4.4030	27.768	58.0320	23.9420	.0900	.200	106.7000	14.000	.020	<0	2.200	8.80	34	--
Free People	N	Benson	9,690	.649	7.6540	103.9600	3.2770	30.679	62.4000	20.8960	.0240	.200	115.5400	16.000	.020	<0	4.500	8.60	25	--
Tweady	N	Stutsman	10,600	1.098	46.6640	81.7800	6.7580	11.316	81.1200	40.3260	.0020	.100	136.3000	6.100	--	--	3.100	8.70	--	--
Devil's	N	Ramsey	11,717	4.147	35.6770	100.0700	6.2820	13.743	103.0300	30.2560	.0310	.260	146.1700	7.870	.040	.050	1.900	8.27	49	--
Bitter	S	Day	12,642	6.452	152.1400	68.4340	8.3200	15.150	200.6100	12.7970	.0770	.230	235.3500	8.400	.030	.140	2.700	8.38	40	--
Stony	N	Kidder	12,900	.599	42.4670	119.1900	9.9070	29.094	126.8800	15.9050	.0130	.100	172.1600	7.900	--	--	6.200	8.90	68	--
Ordway	N	McLean	14,000	.269	.7490	177.9100	2.0220	99.130	77.5840	2.3970	.0240	.500	180.9500	6.700	.060	<0	5.900	9.60	--	--
Hazelden	S	Day	15,013	12.475	154.6600	87.2480	9.6590	5.178	246.6800	8.9960	.0210	.100	264.0400	4.470	--	--	3.370	7.77	45	--
Bird	N	Kidder	15,300	.309	25.6780	171.8200	8.4990	32.638	141.2300	28.4820	.0450	.200	206.3100	4.300	--	--	5.200	8.90	70	--
West Stump	N	Nelson	16,214	8.368	63.3630	150.1100	6.5200	6.953	167.8400	58.9800	.0660	.200	228.3600	16.060	.120	.100	2.800	7.91	50	--
Salt	M	Lac Qui Parle	17,366	17.840	42.2000	207.4000	3.8100	4.680	208.8000	50.4000	--	--	271.3000	--	--	--	--	--	--	156
Devil's (Mission Bay)	N	Ramsey	21,056	3.248	68.6140	208.4700	11.2050	15.145	217.1400	59.2680	.0770	.120	291.5400	15.120	.100	.080	2.840	8.00	53	--
Stink	N	Benson	34,800	3.393	73.6590	427.6000	6.0420	11.335	449.2800	62.3220	.0100	.200	510.6900	1.200	.120	<0	7.700	8.80	41	--
Medicine	S	Codington	42,725	20.509	856.9400	262.1900	20.5640	20.537	1,087.8000	22.8980	.0180	.950	1,160.2000	15.880	.140	3.090	15.000	7.98	29	--
East Devils	N	Ramsey	47,721	3.283	204.3100	577.1300	28.0500	31.811	648.5200	136.2900	.0840	.170	812.7800	7.090	.050	.060	5.910	8.51	55	--
Cranberry	N	Lakota	55,000	1.397	.3620	943.9500	7.1680	371.596	534.5600	36.3780	.0160	1.800	952.8700	--	.450	<0	21.000	9.40	45	--
Stink	N	Stutsman	64,200	4.491	292.1600	848.2500	44.5440	15.564	936.0000	215.7300	.0480	.200	1,189.4000	3.200	--	--	14.000	8.20	90	--
East Stump	N	Nelson	73,478	14.002	527.1800	993.2400	35.2950	18.025	1,240.7000	321.5100	.1220	.270	1,569.7000	11.090	.080	.270	12.840	8.04	51	--