Bulletin 23

DIVISION OF WATERS
MINNESOTA CONSERVATION DEPARTMENT

# CHEMICAL QUALITY OF GROUND WATER IN THE MINNEAPOLIS – ST. PAUL AREA, MINNESOTA

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Prepared cooperatively by the
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St. Paul, Minnesota
April 1965

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# CHEMICAL QUALITY OF GROUND WATER IN THE MINNEAPOLIS-ST. PAUL AREA, MINNESOTA

By M. L. Maderak

## ABSTRACT

The Minneapolis-St. Paul investigation area of about 2,500 square miles includes Hennepin, Carver, Scott, Ramsey, Washington, and parts of Anoka, Dakota, and Sibley Counties in Minnesota. Almost every formation in the area will yield some water, but only the glacial drift, the St. Peter Sandstone, the Shakopee and Oneota Dolomites, the Jordan Sandstone, the Franconia and Galesville Sandstones, and the Mount Simon and Hinckley Sandstones of Winchell (1886) yield large amounts. The yield from the Franconia and Galesville and the yield from the Mount Simon-Hinckley Sandstones are about equal to the yield from the Jordan Sandstone. Almost all the ground water in the area, as well as the surface water from representative sites is the calcium bicarbonate type.

Four isocon[1]maps indicate that, except for recharge areas, the dissolved-solids concentrations of water from the major aquifers are lowest in the eastern or northeastern part of the area and highest in the western or southern part. The isocon maps can be used together with a system of curves and bar graphs to predict the quality of the water that is likely to be obtained from the major aquifers in the basin.

A comparison of chemical analyses from 1899 to 1963 for the major aquifers indicates little natural change in the chemical quality of the water. In some areas, contamination of water in shallow aquifers could have an effect on the quality of the water in the deeper aquifers. Hardness, dissolved solids, iron, manganese, and bicarbonate probably have the greatest effect on the suitability of water for most uses.

## INTRODUCTION

The chemical quality of ground water in the Minneapolis-St. Paul area was investigated by the U.S. Geological Survey in cooperation with the Minnesota Division of Waters during 1960-63. The objectives of the investigation were to determine the chemical quality of water from the different aquifers, the variations of the quality within an aquifer, the changes in the quality with time, the amount of contamination from domestic wastes in two communities, and the possible effect of contamination on the quality of water in the deep aquifers. The purpose of this report is to summarize the results of the investigation.

Previous reports that contain information on chemical quality of ground water in the Minneapolis-St. Paul area include those of Hall and others (1911), Thiel (1944), Prior and others (1953), Minnesota Div. Waters (1961), and Maderak (1963, 1964).

The investigation area of about 2,500 square miles includes Hennepin, Carver, Scott, Ramsey, Washington, and parts of Anoka, Dakota, and Sibley Counties. In general, the area is characterized by a gentle undulating topography that is typical of recently

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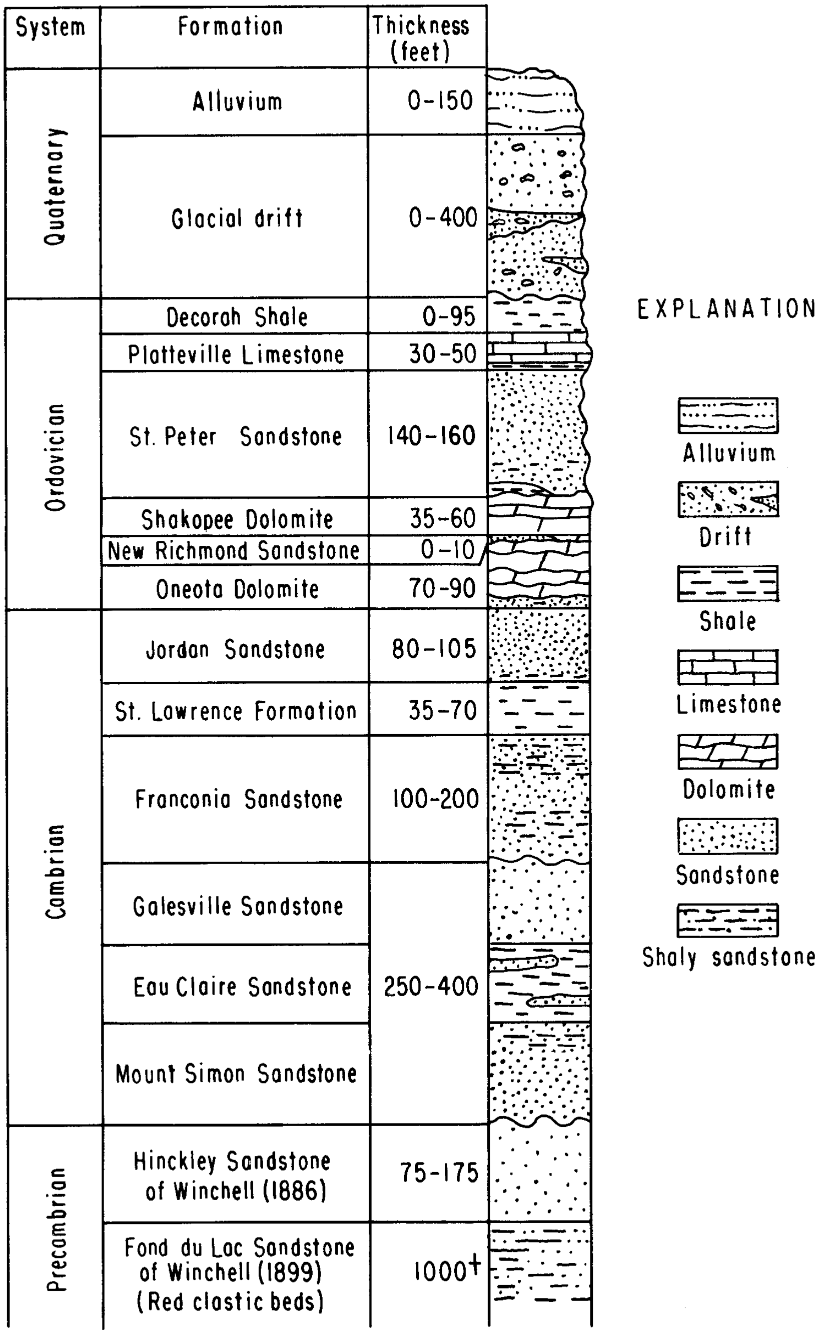
[1] Isocon lines on a map connect points at which dissolved-solids concentrations for the depicted formation are the same.

glaciated regions. Ground elevations range from about 1,000 to 690 feet above sea level near Hastings; plains in the northern part of the area are about 900 feet above sea level.

The temperature in the area has varied from 112°F at Maple Plain to -40°F at Farmington; the mean annual temperature is about 45°F. A maximum annual precipitation of 44.81 inches near Maple Plain in 1951 and a minimum annual precipitation of 11.59 inches at Minneapolis in 1910 have been recorded; the mean annual precipitation in the area is 27.5 inches.



| System | Formation | Thickness (feet) |
|---|---|---|
| Quaternary | Alluvium | 0-150 |
| | Glacial drift | 0-400 |
| Ordovician | Decorah Shale | 0-95 |
| | Platteville Limestone | 30-50 |
| | St. Peter Sandstone | 140-160 |
| | Shakopee Dolomite | 35-60 |
| | New Richmond Sandstone | 0-10 |
| | Oneota Dolomite | 70-90 |
| Cambrian | Jordan Sandstone | 80-105 |
| | St. Lawrence Formation | 35-70 |
| | Franconia Sandstone | 100-200 |
| | Galesville Sandstone | 250-400 |
| | Eau Claire Sandstone | |
| | Mount Simon Sandstone | |
| Precambrian | Hinckley Sandstone of Winchell (1886) | 75-175 |
| | Fond du Lac Sandstone of Winchell (1899) (Red clastic beds) | 1000+ |

Figure 1.--Generalized geologic section of the Minneapolis-St. Paul area.

## GEOLOGICAL SETTING

The physical characteristics and thickness of the geologic formations as recognized by the Geological Survey are shown on Figure 1. Except for alluvial deposits of Recent age, the youngest formation in the area is glacial drift of Wisconsin age, which was derived from two different source areas. Reddish-brown drift containing red sandstone, basalt, and felsite was deposited by the Superior Lobe that flowed into the area from the north and northeast. Subsequently, light-gray drift containing granite, limestone, and shale was deposited by the Grantsburg Sublobe that flowed into the area from the southwest. Previously deposited reddish-brown drift was incorporated into the Grantsburg ice, and in some areas a complex mixture of red and gray drifts was deposited. The bedrock formations of Paleozoic age (limestone, dolomite, shale, and sandstone) and the Binckley Sandstone of Winchell (1886) of Precambrian age represent marine deposition in shallow water. Small diastrophic forces warped the consolidated sedimentary rocks into a broad basin that is very slightly elongated northeast-southwest. The formations dip about 20 feet per mile toward the basin center, which is several miles north of the confluence of the Minnesota and Mississippi Rivers. The bedrock surface that underlies the glacial drift is very irregular and indicates a period of intensive erosion before and during glaciation.

## MAJOR AQUIFERS

Almost every formation in the area will yield some water, but only the glacial drift, the St. Peter Sandstone, the Shakopee and Oneota Dolomites and the Jordan Sandstone, the Franconia and Galesville Sandstones, and the Mount Simon and Hinckley Sandstones yield large amounts.

The glacial drift is a heterogeneous mixture that consists of deposits from several glacial stages. These till, outwash, and terrace deposits contain water-bearing sand and gravel. Usually the wells are dug or drilled into the first sand and gravel that will furnish enough water for a particular use. The water from most drift wells is used mainly for domestic purposes. Water-table conditions exist in most of the wells, but artesian conditions exist in some of the deeper drift wells.

In general, the upper confining layer for the St. Peter Sandstone is a shale at the base of the Platteville Limestone; where this basal shale has been removed by erosion the confining layer is impermeable glacial drift. The upper confining layers for the Shakopee and Oneota Dolomites and the Jordan Sandstone are low-permeability zones and thin shale laminae in the lower part of the St. Peter or impermeable glacial drift where the St. Peter has been removed by erosion. The St. Lawrence Formation is the confining layer that underlies the Jordan. In many parts of the basin the Shakopee, Oneota, and Jordan are hydraulically connected. According to Liesch (1961, p. 12-15), in the central or downtown Minneapolis-St. Paul part of the basin, water can move directly from the St. Peter through the dolomite sequence to the Jordan. In other parts of the basin, except for the recharge areas, some water is partly confined in the formations overlying the Jordan because of a shale or siltstone at the base of the Oneota

Water from most of the wells drilled to the St. Peter, Shakopee, Oneota, and Jordan is for municipal and industrial use. Many of the old industrial wells that penetrate the aquifers were cased a few feet into the St. Peter and were completed as open hole through the St. Peter, Shakopee, and Oneota; some of the wells were completed as open hole through the St. Peter, Shakopee, Oneota, and Jordan. Most new wells are cased through the Oneota and completed as open hole, slotted pipe, gravel pack, or a screen in the Jordan.

In the upland areas the St. Peter Sandstone is under water-table and artesian conditions. Near river valleys, where the upper part of the sandstone has been drained, the St. Peter is mainly under water-table conditions. In river valleys or in valleys buried by glacial drift, the water in the St. Peter is under artesian conditions. Artesian conditions also exist in the Shakopee and Oneota Dolomites and in the Jordan Sandstone. Recharge of the aquifers is mostly from the overlying glacial drift, and natural discharge in the form of springs and seeps takes place along the Minnesota and Mississippi Rivers.

The Franconia and Galesville Sandstones underlie the St. Lawrence Formation and are hydraulically connected. The Eau Claire Sandstone, composed of shale, siltstone, and sandstone, forms the confining layer between the Franconia and Galesville Sandstones and the Mount Simon and Hinckley Sandstones. The Eau Claire probably does not form as good a confining layer as the St. Lawrence Formation. The Mount Simon and Hinckley Sandstones are also hydraulically connected; the Fond du Lac Sandstone of Winchell (1899) forms the underlying confining layer.

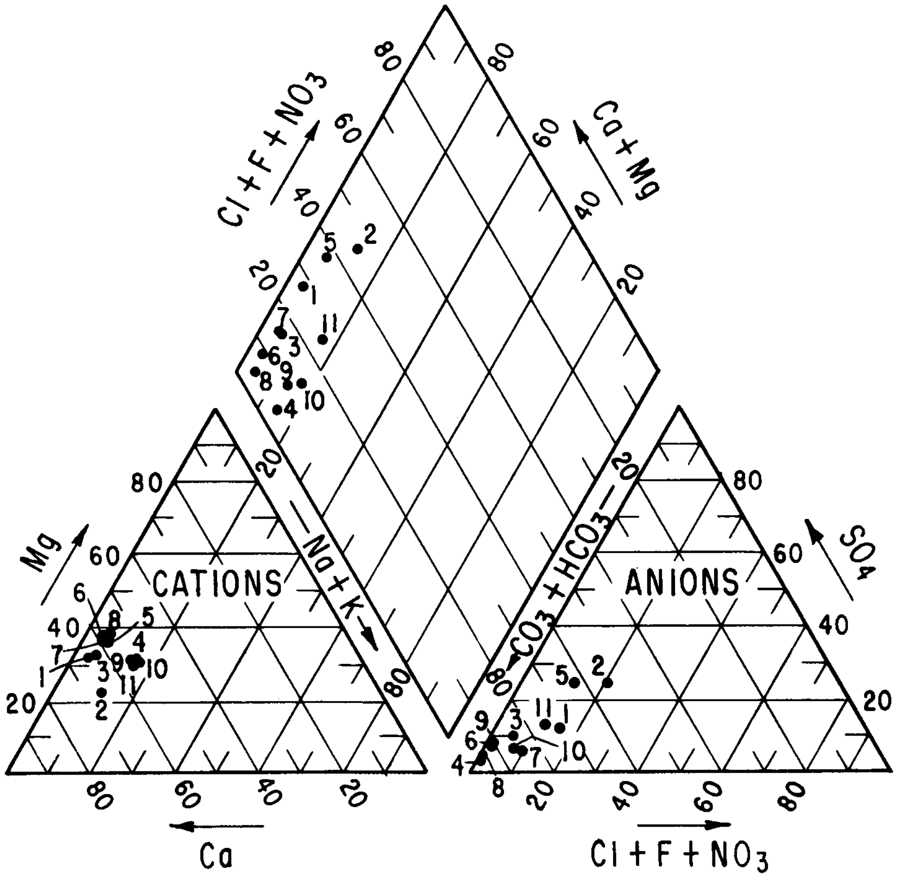
Most of the wells that obtain water from the Franconia-Galesville and Mount Simon-Hinckley aquifers were drilled for industrial purposes. The first wells drilled in the area were completed with open hole below the St. Lawrence, and some wells were completed with open hole from the base of the Oneota through the Hinckley. Most new wells are completed in only one aquifer and have cemented casing in the overlying formation.

Artesian conditions exist in both the Franconia-Galesville and the Mount Simon-Hinckley aquifers. Most recharge areas for the two aquifers are north of the basin, and recharge is mainly from the glacial drift.

Total ground-water withdrawal from all aquifers in the Minneapolis-St. Paul area is estimated to be 136 mgd (million gallons per day). Withdrawal of about 250 mgd may not cause a serious permanent lowering of the piezometric surface (Minnesota Div. Waters, 1961, p. 34); however, because most of the demand for ground water is localized, a sustained supply probably would be limited to 200 mgd.

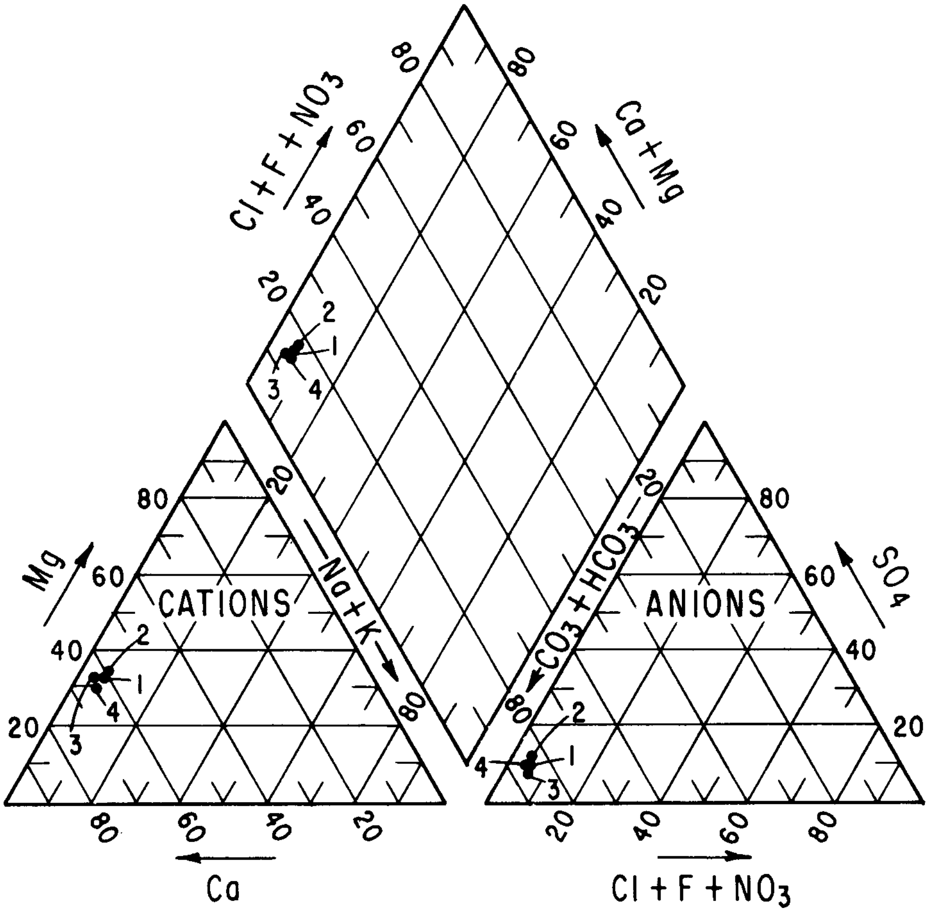
About two-thirds of the 88 mgd of the ground water withdrawn for industrial use is for meatpacking, malt-beverage processing, petroleum refining, milling, paper-products manufacturing, mineral-resources processing, and rubber-products manufacturing. Most of the water is obtained from the Jordan, Franconia-Galesville, and Mount Simon-Hinckley aquifers. The combined yield from the Franconia-Galesville and the Mount Simon-Hinckley aquifers is about equal to the yield from the Jordan sandstone.

About 48 mgd is withdrawn for domestic and municipal use; domestic supplies are obtained mainly from the shallow aquifers, and municipal supplies from ground-water sources are obtained mainly from the Jordan Sandstone. Minneapolis and St. Paul obtain their municipal water supplies from the Mississippi River.



| Number | Wells sampled | Average dissolved solids (ppm) | Geologic unit |
|---|---|---|---|
| 1 | 2 | 307 | Alluvium |
| 2 | 2 | 340 | Dune sand |
| 3 | 43 | 384 | Glacial drift (undifferentiated) |
| 4 | 1 | 270 | Decorah Shale |
| 5 | 2 | 510 | Platteville Limestone |
| 6 | 8 | 360 | St. Peter Sandstone |
| 7 | 7 | 343 | Shakopee and Oneota Dolomites |
| 8 | 29 | 272 | Jordan Sandstone |
| 9 | 13 | 341 | Franconia and Galesville Sandstones |
| 10 | 9 | 310 | Mount Simon Sandstone and Hinckley Sandstone of Winchell (1886) |
| SURFACE WATER | | | |
| 11 | 9 (sites) | 205 | 8-lakes, 1-stream |

Figure 2.--Chemical quality of ground and surface waters expressed as percentage of equivalents per million.



| Number | Wells sampled | Median dissolved solids (ppm) | Geologic unit |
|---|---|---|---|
| 1 | 43 | 350 | Glacial drift (undifferentiated) |
| 2 | 20 | 400 | Light-gray drift |
| 3 | 14 | 265 | Reddish-brown drift |
| 4 | 9 | 390 | Reddish-brown drift overlain by light-gray drift |

Figure 3.--Chemical quality of water from the glacial drift expressed as percentage of equivalents per million.

## CHEMICAL QUALITY OF THE WATER

Many of the wells in the area produce water from several formations or aquifers. Samples of water were taken only from wells for which casing records were available in order to be reasonably certain that the sample represented the water from a single formation or from formations that have similar lithology.

Percentages of equivalents per million show that the water from all formations is the calcium-bicarbonate type, which is the same type as the surface water from representative sites in the area (fig. 2). Average chemical compositions of the water were computed for all analyses, including those that might not be representative because of contamination from domestic or industrial wastes. Some differences are evident in percentages of individual constituents and in average dissolved solids for water from the major aquifers. The water from the glacial drift and from the Shakopee-Oneota Dolomites has slightly larger percentages of chloride plus fluoride plus nitrate than the water from the St. Peter and Jordan Sandstones. If the percentages of chloride and nitrate are hypothetically corrected for the possible effect of contamination, the waters from the major aquifers above the St. Lawrence Formation are similar in average percentage of dissolved constituents and are only slightly different in average dissolved solids. The waters from the major aquifers below the St. Lawrence also are similar in average percentage of dissolved constituents and are only slightly different in average dissolved solids. The percentage of sodium plus potassium tends to be slightly larger in water from the major aquifers below the St. Lawrence than from the major aquifers above the St. Lawrence.

The different materials that compose the light-gray and reddish-brown glacial drifts have little effect on the average percentage composition of constituents in the water, but they do have a significant effect on the median dissolved solids in the water (fig. 3). The effect on the median dissolved solids is probably due to differences in the degree of weathering and leaching of the parent materials.

Areal variations in the concentration of dissolved solids in the Minneapolis-St. Paul area for the major aquifers are shown on four isocon maps (figs. 4-7). The isocons on the maps indicate equal concentration of dissolved solids. The concentration of dissolved solids was determined by evaporating a sample to dryness on a steam bath and then drying the residue for 1 hour at 180°C; the residue may include some water of hydration and probably some organic matter.

In the water from glacial drift, the highest concentration of dissolved solids tends to be in the western and southwestern parts of the area, and the lowest concentration tends to be in the eastern part (fig. 4). On the average, water from the reddish-brown drift has a lower concentration of dissolved solids than water from the light-gray drift. Anomalous areas indicated by closed isocons of 500 ppm (parts per million) probably are caused by partial confinement of water, and the area of low concentration near Wayzata is a recharge area for the underlying aquifers (Maderak, 1964). Differences in depth of the wells could also tend to cause anomalous areas, particularly if the aquifers are confined; the depth of the wells that were sampled ranged from about 20 to 200 feet. Because other anomalous areas may exist, figure 4 should be used with care for predicting the concentration of dissolved solids in water from future wells.

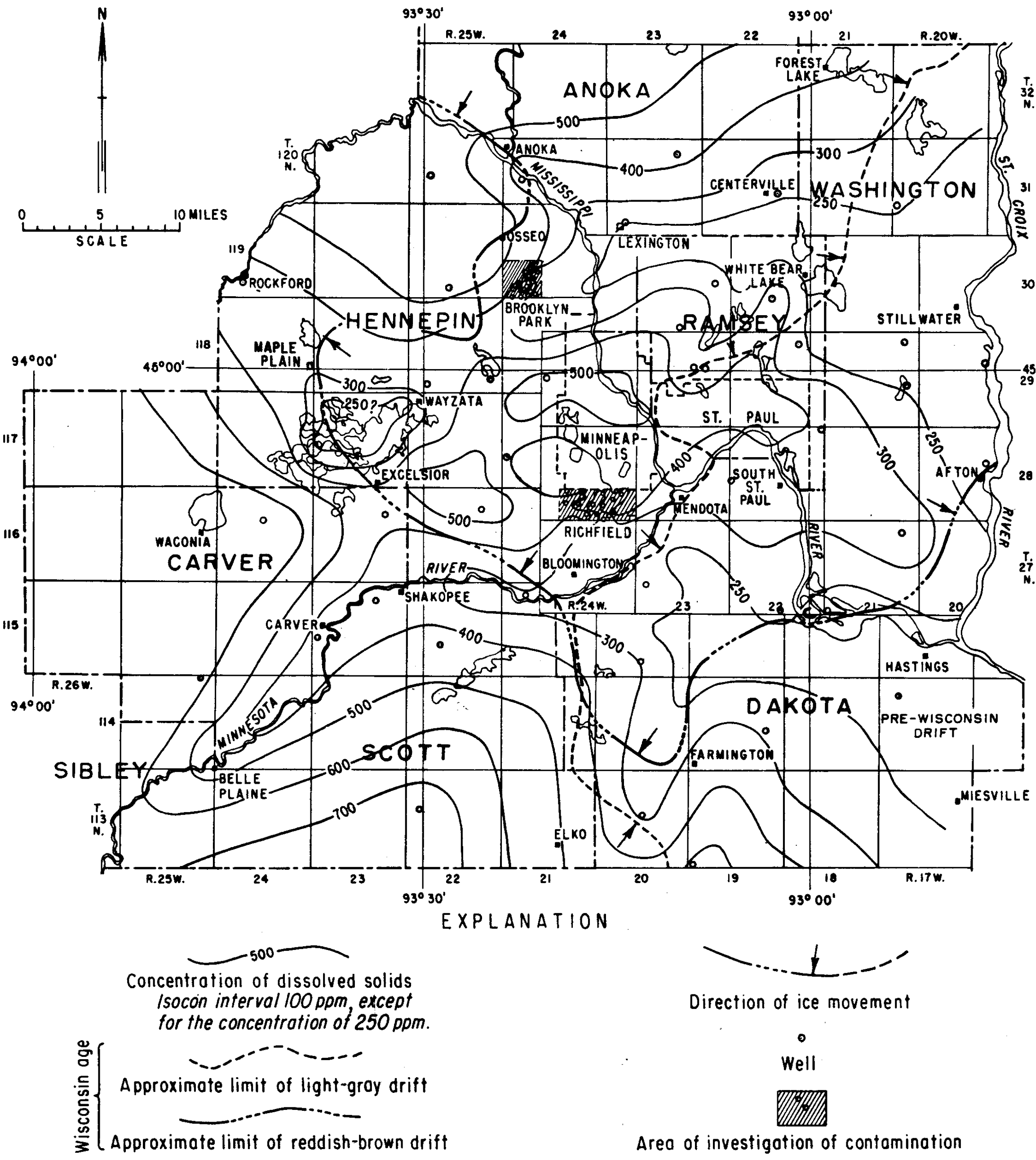


Figure 4.--Isocon map of dissolved solids in water from the glacial drift.

The St. Peter Sandstone or the Shakopee and Oneota Dolomites do not underlie all the Minneapolis-St. Paul area (fig. 5). Many pre-glacial valleys have been eroded in the water-bearing formations; however, the valleys evidently have little effect on the quality of water from the three formations. The dissolved solids tend to increase, but not uniformly, southward and westward from St. Paul. The concentration of about 450 ppm of dissolved solids at Golden Valley may be caused by infiltration from the overlying drift of some water having a concentration of about 500 ppm of dissolved solids. An anomaly of high concentration near Hastings is the result of local contamination rather than the result of natural conditions. Recharge areas are indicated by the anomalies of low concentrations near White Bear Lake and near Wayzata. The median concentration of dissolved solids for water from the St. Peter Sandstone or Shakopee and Oneota Dolomites is 344 ppm, which is slightly lower than 350-ppm median for water from the glacial drift.

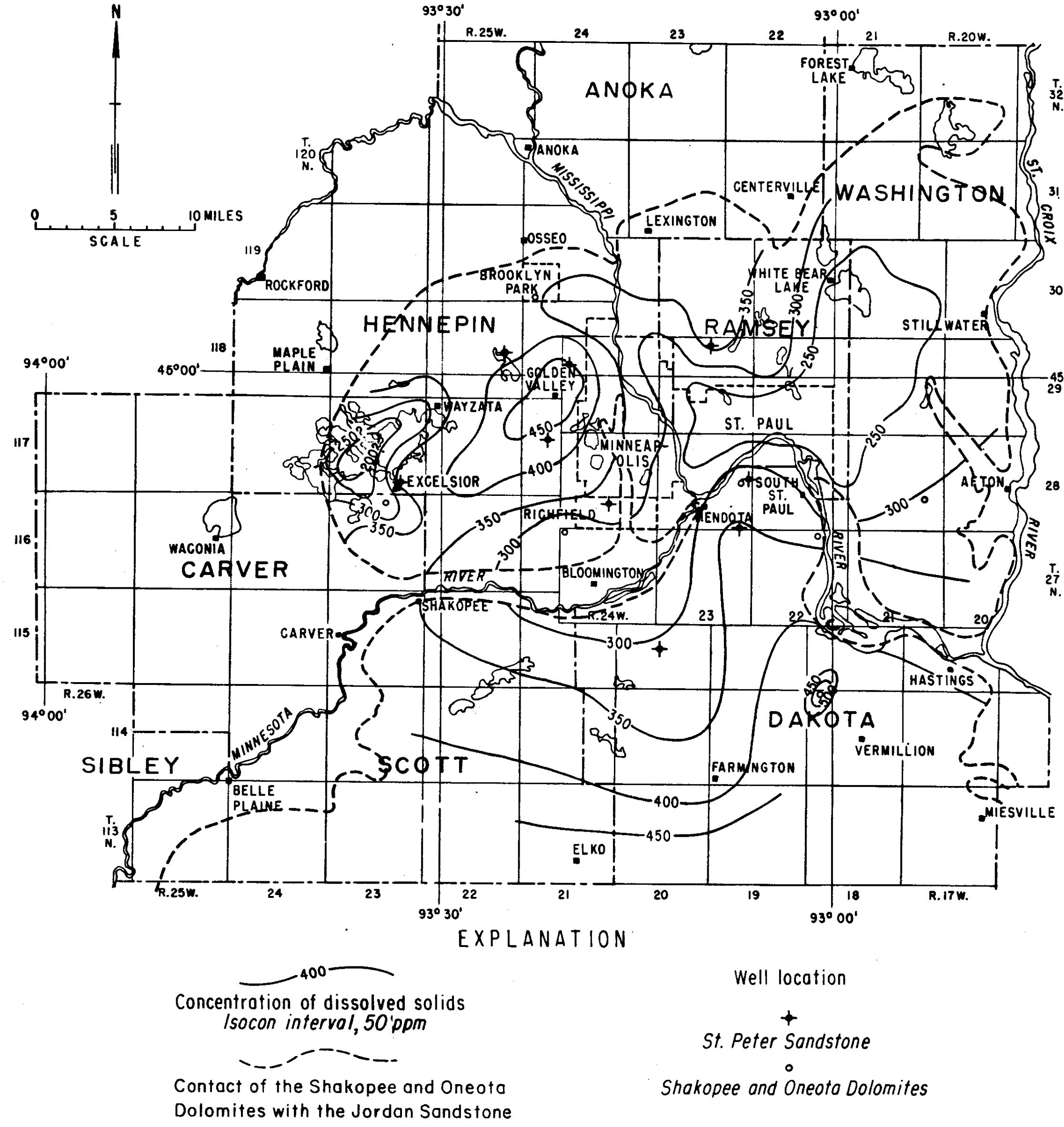


**Figure 5.**—Isocon map of dissolved solids in water from the St. Peter Sandstone or the Shakopee and Oneota Dolomites.

The Jordan Sandstone underlies almost all of the area (fig. 6). The isocons indicate a more uniform westward increase in dissolved solids than that observed for the overlying aquifers. The range of dissolved solids is narrower for the Jordan than for the overlying aquifers. Also, the median concentration of 275 ppm is lower than the 344-ppm median for the overlying St. Peter, Shakopee and Oneota.

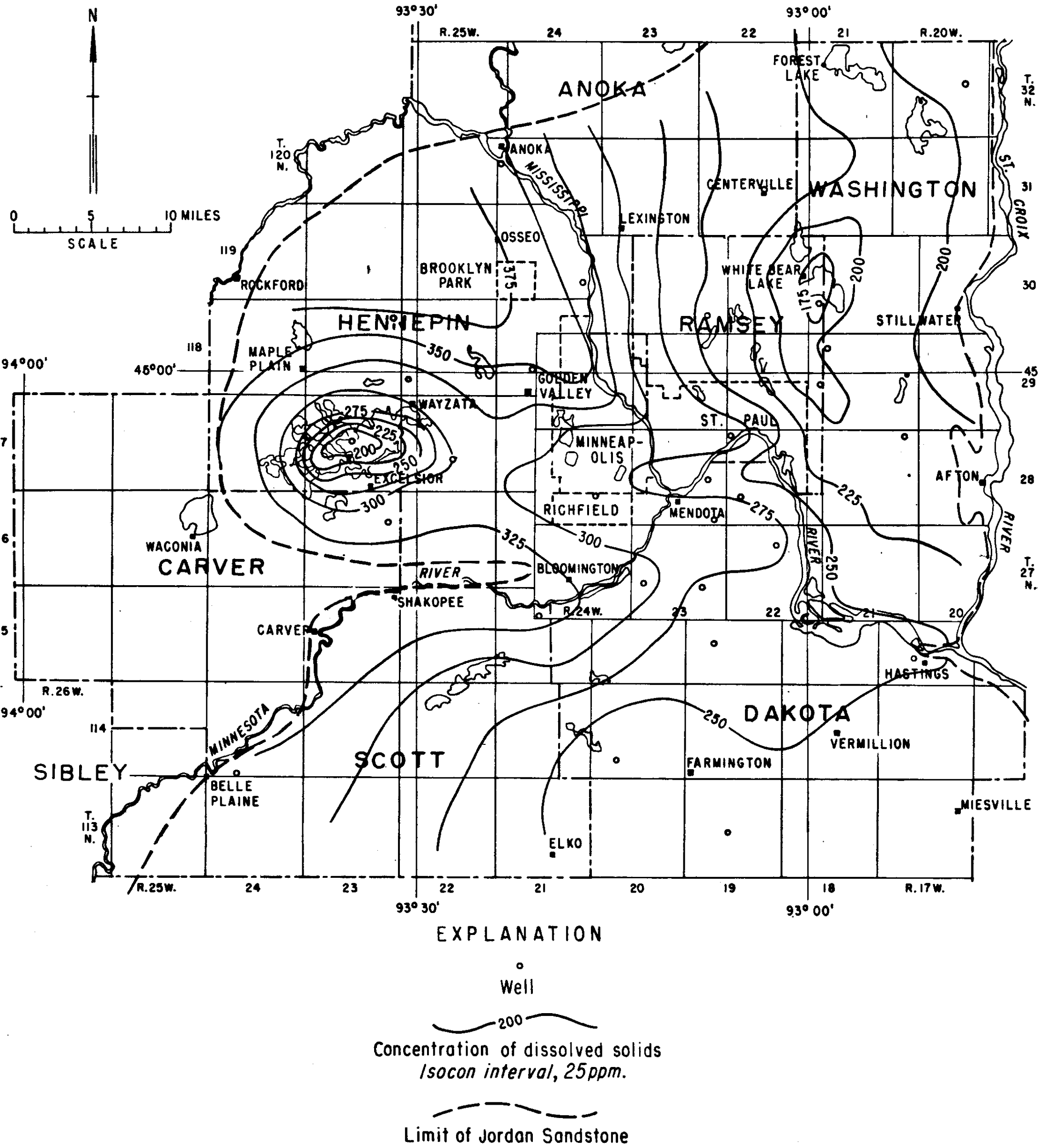


**Figure 6.**—Isocon map of dissolved solids in water from the Jordan Sandstone.

The two anomalies near Wayzata and White Bear Lake represent areas of recharge to the Jordan aquifer (Maderak, 1964). The water in the recharge areas moves downward with little difficulty from the drift aquifers through the St. Peter, Shakopee, and Oneota to the Jordan, and locally moves directly from the drift into the Jordan. Thus, wells that pump water from the Jordan in the recharge areas will lower the water level in the glacial drift (fig. 8). Some recharge in the Minneapolis-St. Paul downtown area from the St. Peter, Shakopee and Oneota (Liesch, 1961) may account for the irregularity of the isocons in the downtown area. Because much of the soluble material was removed from the recharge areas before and during glaciation, the water presently entering the Jordan has low concentrations of dissolved solids.

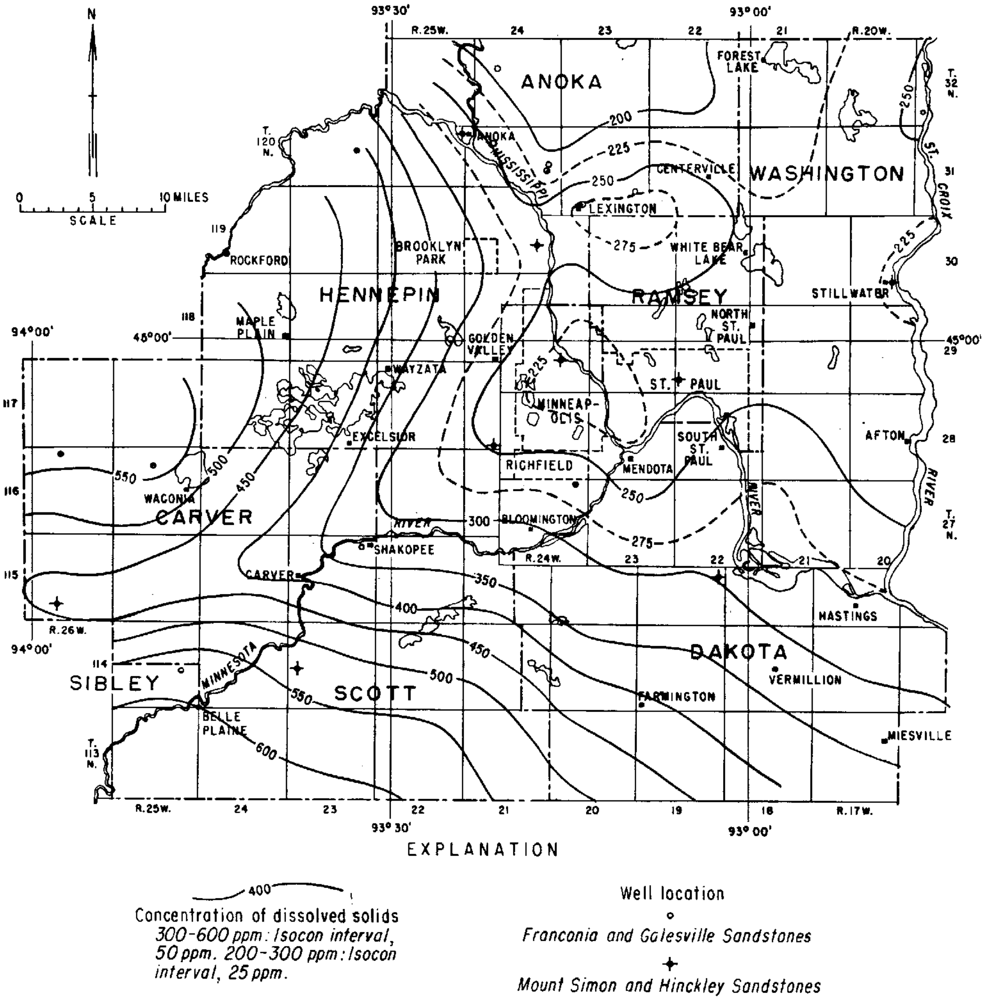


Figure 7.--Isocon map of dissolved solids in water from the Franconia and Galesville or Mount Simon and Hinckley Sandstones.

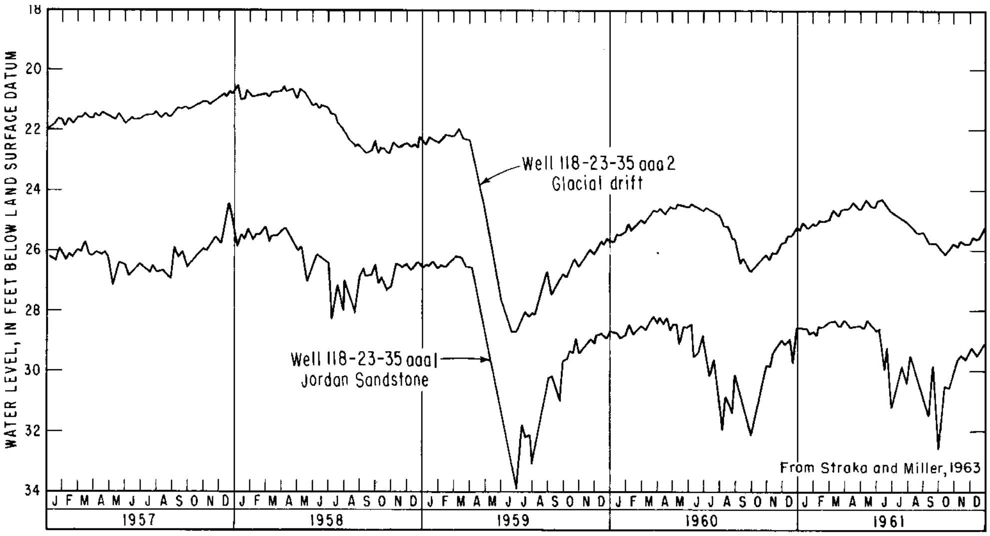


Figure 8.--Water levels for a pumped well in the Jordan Sandstone and for an observation well in the glacial drift.

In many parts of the basin a shale or siltstone at the base of the Oneota forms a partial aquiclude. The small amount of water that enters the Jordan through the partial aquiclude has little effect on the overall quality of the water in the Jordan. As a result, the median concentration of dissolved solids is less than that in water from the overlying formations. The similarity in the amount of dissolved solids in water from the Jordan and from the underlying Franconia and Galesville and Mount Simon and Hinckley could result from common areas of recharge and possibly from the similarity in lithology of the aquifers.

The Franconia and Galesville and Mount Simon and Hinckley Sandstones underlie all the Minneapolis-St. Paul area (fig. 7). The dissolved solids for water from these aquifers increase in concentration westward from St. Paul; the median concentration of 272 ppm is slightly less than the 275-ppm median for the Jordan.

The low concentration of dissolved solids in water from the Franconia and Galesville and Mount Simon and Hinckley in the downtown area probably is because of movement of water into the area from the north and east. The anomaly at Lexington probably results from a permeability change; and the trend of the isocons in the vicinity of, and especially west of Carver may indicate recharge along the buried glacial valley in that area (fig. 7).

## Variations in individual constituents and hardness

Variations in the individual constituents and in hardness of water from the different aquifers are indicated in figures 9 to 13. For the constituents that have a relationship to dissolved solids (figs. 9-12), each point represents one analysis or the average of several analyses for a given well. A system of three curves shows the median and the confidence interval for each constituent and for hardness. The confidence interval is the distance between the two curves that were drawn, one above and one below the median curve, so that one-sixth of the points are in contact with or outside each of the curves; thus, the confidence interval is indicated by 67 percent of the points. The closer the two curves are to the median curve, the better the accuracy of the relation. For the constituents that do not show a relationship to dissolved solids (fig. 13), lines showing the median and the confidence interval have been drawn through each bar graph.

Calcium, magnesium, and bicarbonate, because of less scatter on figures 9 to 12, show a more accurate relationship to dissolved solids than sodium plus potassium and sulfate. The median concentration of sodium plus potassium for a given dissolved-solids concentration increases slightly with the age of the aquifer.

Figure 13 indicates that the median concentration of silica decreases with the age of the aquifer and that the median concentration of iron increases with the age of the aquifer. The median concentrations of chloride and manganese decrease with age to the Jordan, whereas fluoride and orthophosphate remain almost unchanged. The median hardness for a given dissolved-solids concentration is less for the Franconia and Galesville or Mount Simon and Hinckley aquifers than for the other aquifers (figs. 9-12). At any specific location in the basin, the median hardness is less for the aquifers that have the lowest dissolved-solids concentration. Thus, water from the Jordan in the areas of recharge has a median hardness that is less than that of the Franconia and Galesville or Mount Simon and Hinckley aquifers. In all parts of the basin the water is considered to be hard (121 to 180 ppm) or very hard (181 ppm or more).

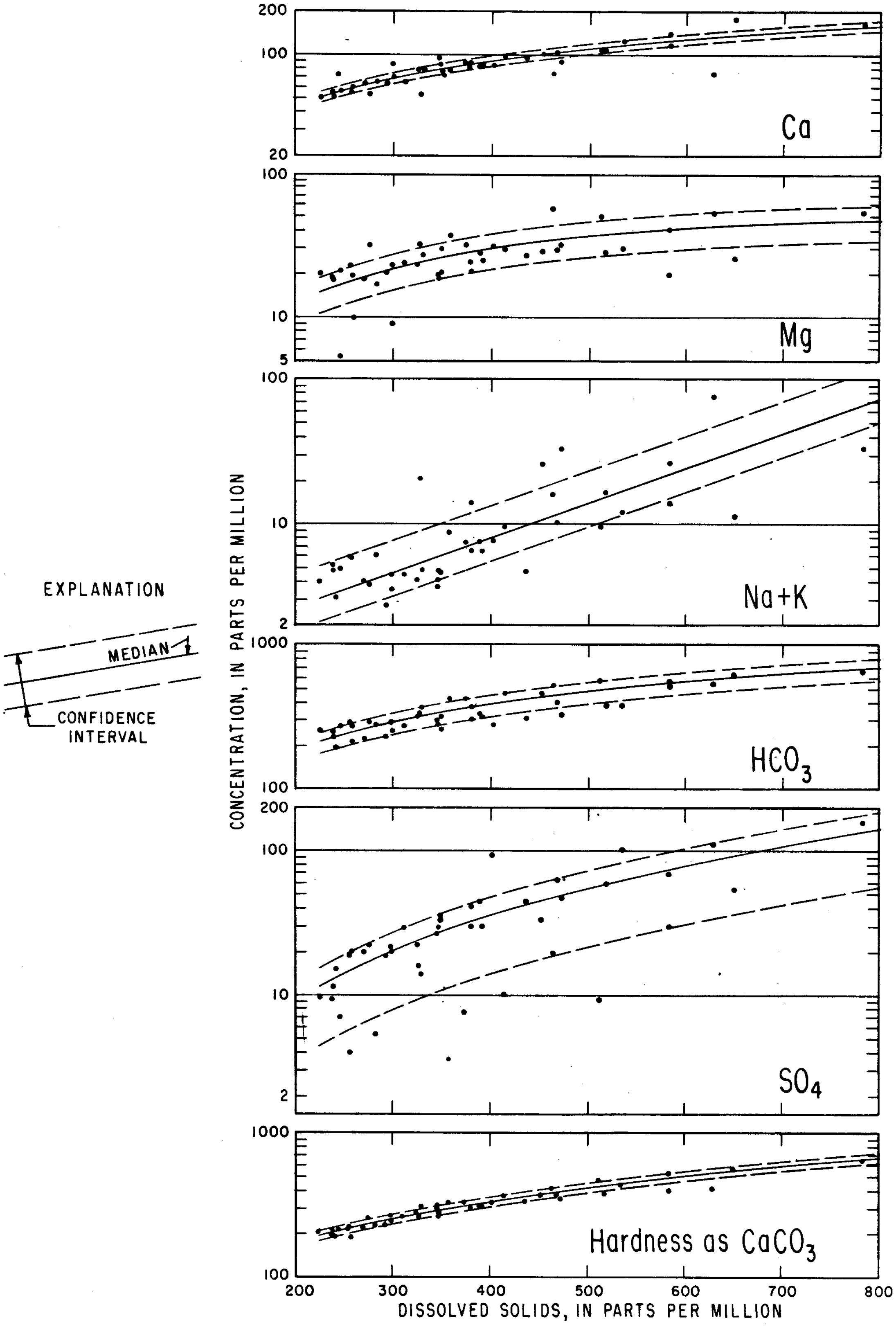


**Figure 9.--Relation of some constituents and of hardness as CaCO$_3$ to dissolved solids for water from the glacial drift.**

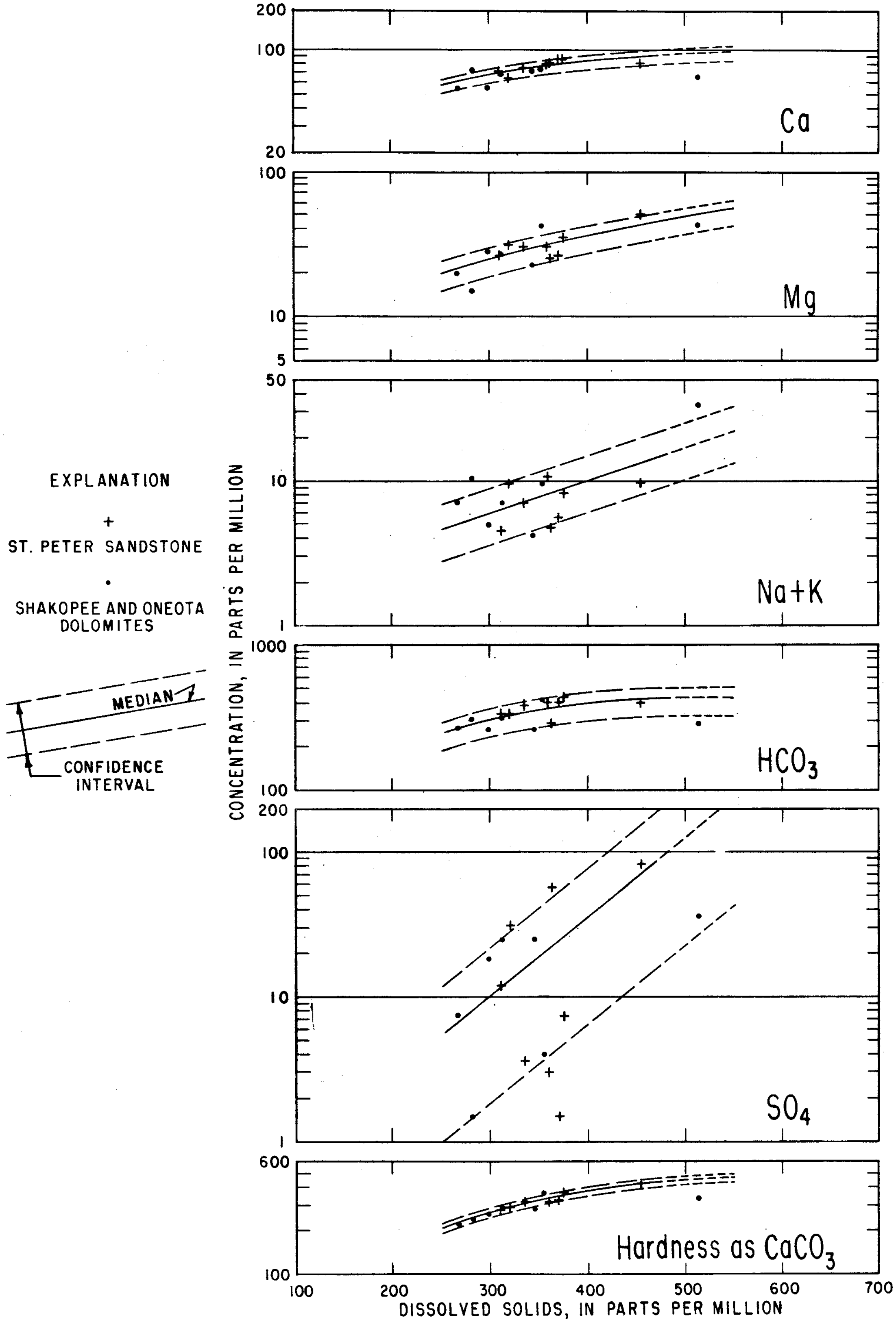


**Figure 10.**--Relation of some constituents and of hardness as $CaCO_3$ to dissolved solids for water from the St. Peter Sandstone or the Shakopee and Oneota Dolomites.

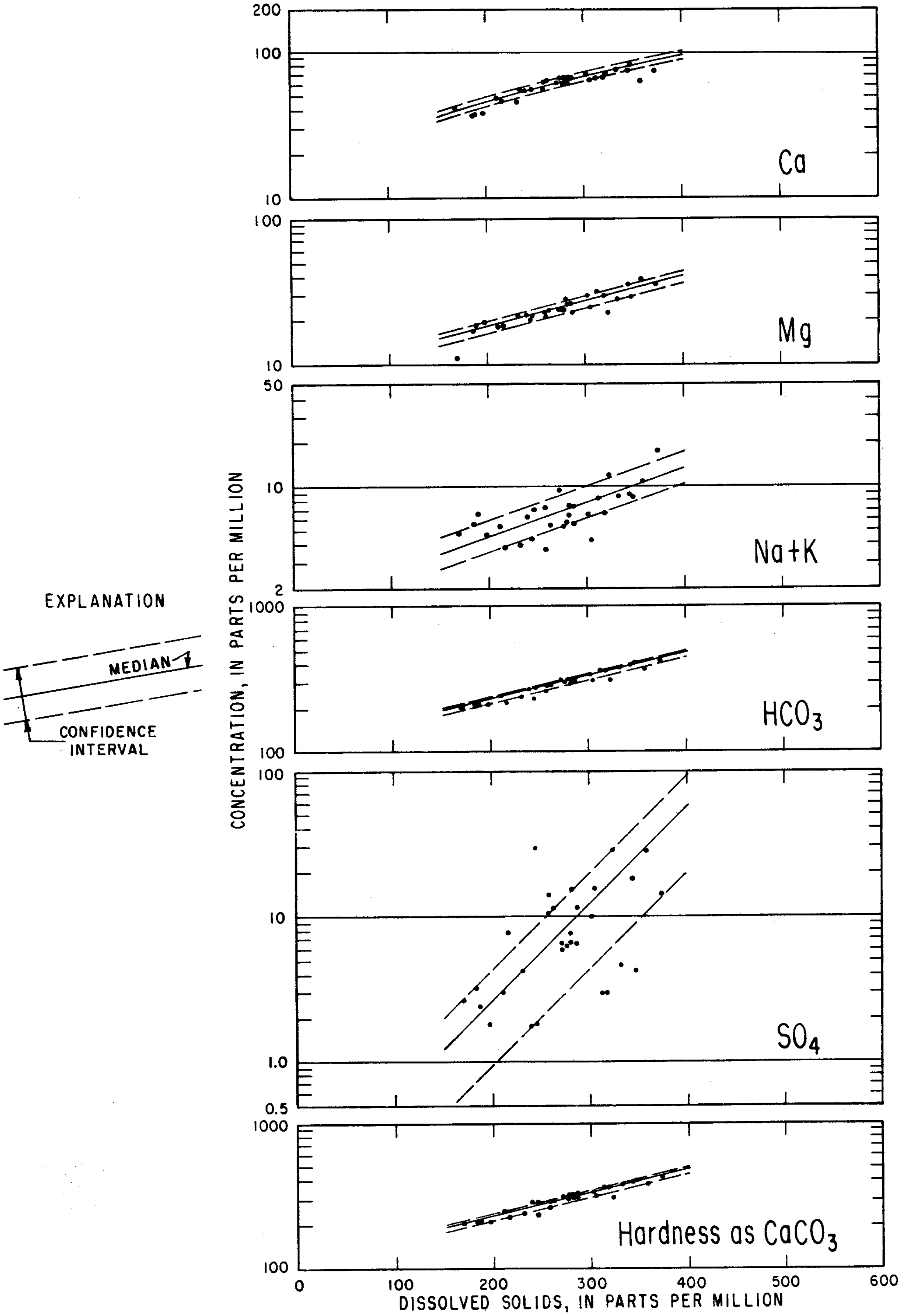


**Figure 11.--Relation of some constituents and of hardness as $CaCO_3$ to dissolved solids for water from the Jordan Sandstone.**

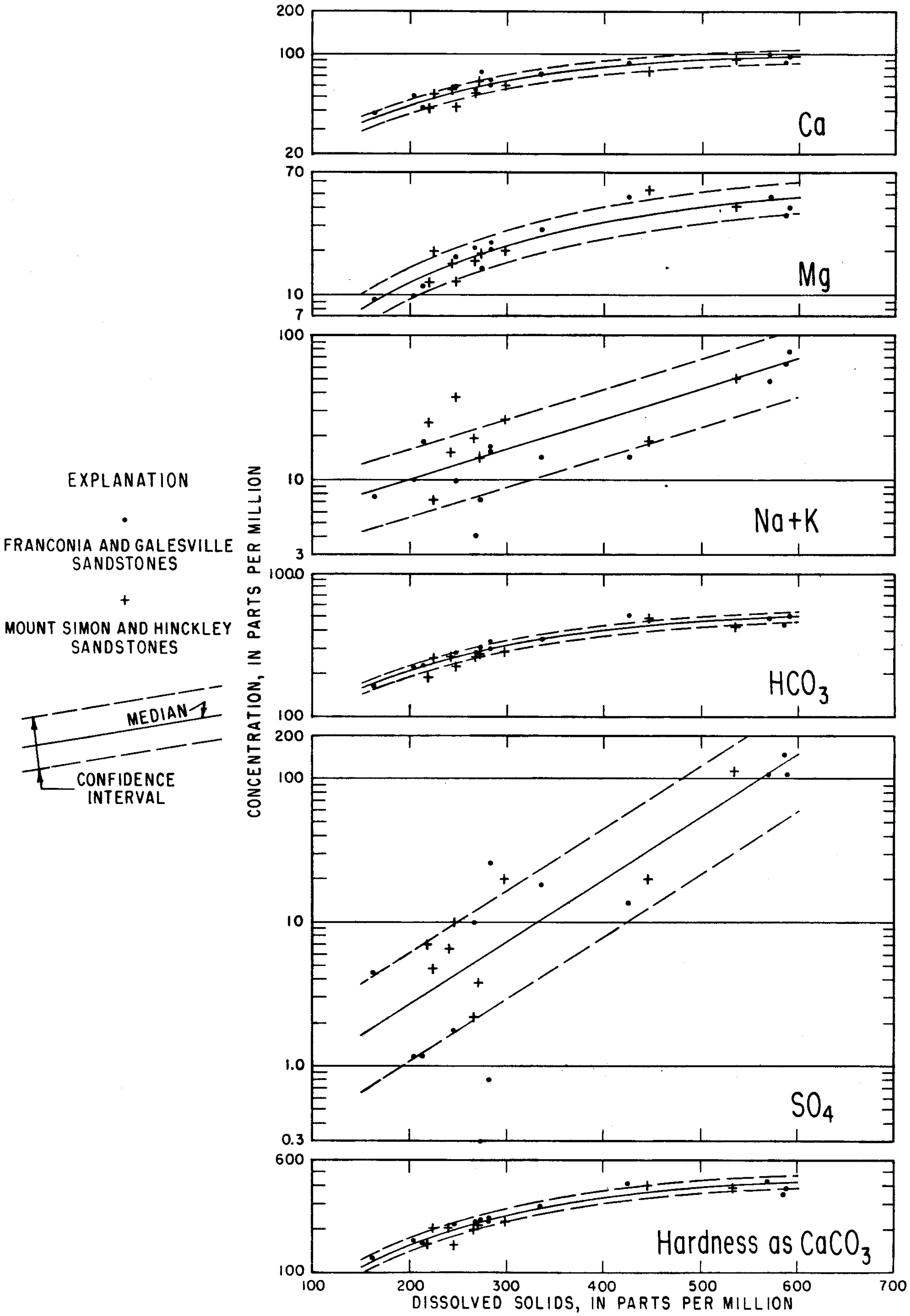
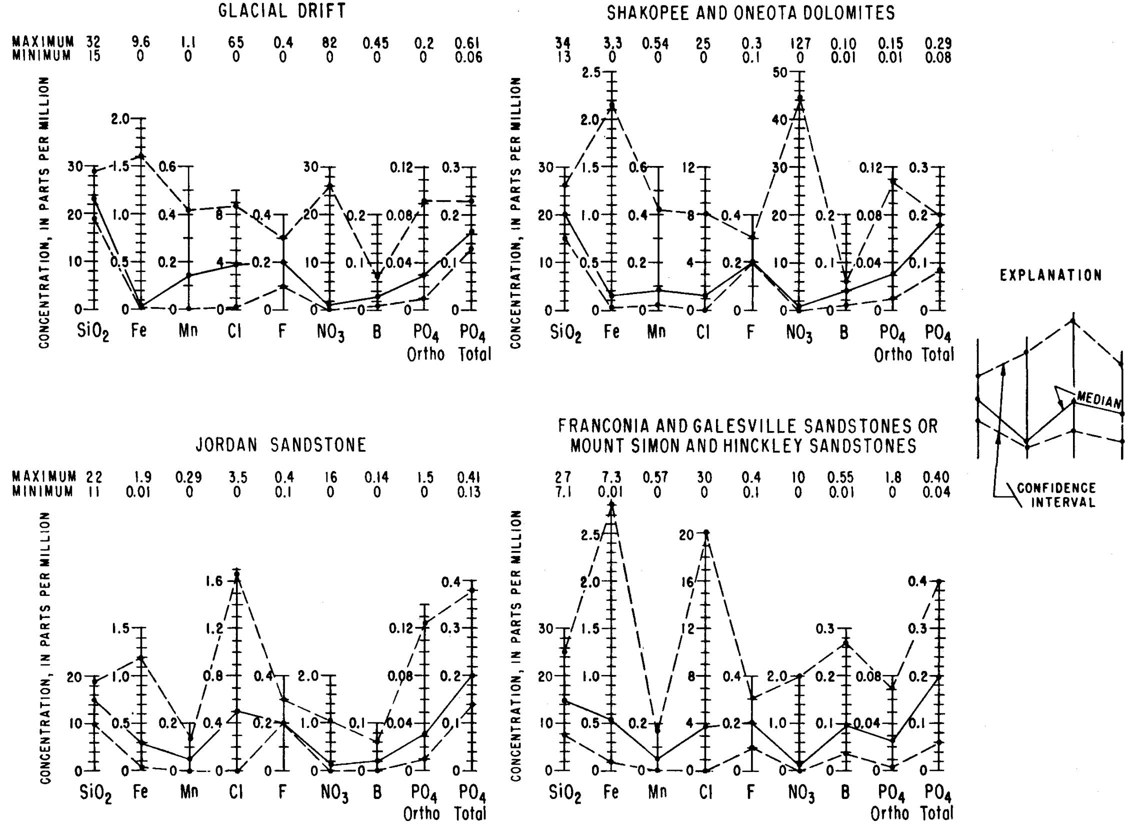


Figure 12.--Relation of some constituents and of hardness as $CaCO_3$ to dissolved solids for water from the Franconia and Galesville or Mount Simon and Hinckley Sandstones.

The quality of the water that is likely to be obtained from each of the major aquifers in the basin can be estimated by using figures 9 to 12 with the isocon maps on figures 4 to 7. For an example, water from the Jordan Sandstone near Hastings would have an estimated dissolved-solids concentration of about 250 ppm (fig. 6), and calcium and bicarbonate concentrations of about 58 and 280 ppm, respectively (fig. 11). Although the constituents shown on figure 13 do not show a relation to dissolved solids similar to that shown by figures 9 to 12, the maximum, median, and minimum do indicate the possible concentrations of these constituents in a potential water supply.

Because confinement of some glacial drift aquifers causes high concentrations of dissolved solids or causes anomalous areas, estimating the quality of water from the drift is not feasible except where it is known that the water is moving downward to recharge deeper aquifers. Also, estimating the quality is not recommended for water from a well that is uncased through more than one aquifer or through the aquifers as grouped on the isocon maps (figs. 4-7) unless the quantity of water from each of the aquifers is known.


GLACIAL DRIFT

ST. PETER SANDSTONE OR SHAKOPEE AND ONEOTA DOLOMITES

JORDAN SANDSTONE

FRANCONIA AND GALESVILLE SANDSTONES OR MOUNT SIMON AND HINCKLEY SANDSTONES

EXPLANATION

Figure 13.--Median, maximum and minimum concentrations of constituents that do not show a relation to dissolved solids in water from the major aquifers.

## Change in quality of water with time

A comparison of analyses from 1899 to 1963 of water from the major aquifers indicates that the natural change in the quality of the water with time has been minor (table 1). All the analyses, except for the possibly contaminated water from a well in the Jordan Sandstone near Hastings having 16 ppm nitrate, were supposedly for non-contaminated wells. The analyses were of water from wells that were generally less than

6 miles apart and that had different depths; the water from some of the old wells probably was from more than one aquifer. Although many wells were drilled between 1899 and 1963, and although many of these wells were uncased through as many as four aquifers, the increased withdrawals and the possible mixing of water from different aquifers evidently have not caused significant changes in water quality. The quality of water in an aquifer can change because of variations in the quality of surface water entering recharge areas and because of large withdrawals that may cause water of different quality to migrate into the aquifer.

**Table 1.**--Chemical quality of water from the major aquifers, 1899-1963

[Chemical analyses in parts per million]

| Location | Date | Depth (feet) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium as Na | Bicarbonate ($HCO_3$) | Sulfate ($SO_4$) | Chloride (Cl) | Silica ($SiO_2$) | Dissolved solids |
|---|---|---|---|---|---|---|---|---|---|---|
| ANOKA COUNTY<br>Glacial drift | | | | | | | | | | |
| Near Centerville-- | 1899 | 80 | 55 | 25 | 6.6 | 307 | ------- | 1.3 | 20 | 260 |
| Do------------ | 1961 | 60 | 56 | 23 | 6.0 | 294 | 4.0 | .5 | 20 | 256 |
| Jordan Sandstone | | | | | | | | | | |
| At Centerville---- | 1900 | 420 | 57 | 24 | 6.7 | 308 | ------- | 1.3 | 21 | 264 |
| Do------------ | 1961 | 300 | 57 | 22 | 6.1 | 293 | 1.8 | .0 | 11 | 239 |
| Franconia and Galesville or Mount Simon and Hinckley Sandstones | | | | | | | | | | |
| Near Anoka-------- | 1907 | 420 | 65 | 18 | 31 | 264 | 20 | 48 | 8.8 | 332 |
| Do------------ | 1961 | 660 | 62 | 18 | 14 | 270 | 4.0 | 22 | 10 | 270 |
| Do------------ | 1961 | 250 | 59 | 18 | 10 | 280 | 2.0 | 6.5 | 14 | 247 |
| DAKOTA COUNTY<br>St. Peter Sandstone or Shakopee and Oneota Dolomites | | | | | | | | | | |
| Near Mendota------ | 1900 | 90 | 50 | 38 | 7 | 333 | 17 | 7.3 | 15 | 303 |
| Do------------ | 1960 | 318 | 66 | 31 | 10 | 330 | 37 | .0 | 15 | 319 |
| Do------------ | 1961 | 1/ 318 | 66 | 29 | 8.9 | 334 | 25 | .5 | 14 | 321 |
| Do------------ | 1900 | 69 | 68 | 28 | 9 | 352 | 6 | 7.7 | ------ | 295 |
| Do------------ | 1960 | 348 | 72 | 29 | 7.0 | 322 | 45 | 2.1 | 13 | 322 |
| Do------------ | 1961 | 1/ 348 | 67 | 25 | 7.1 | 334 | 8.8 | .5 | 13 | 302 |
| Jordan Sandstone | | | | | | | | | | |
| Near South St. Paul------------ | 1905 | 340 | 72 | 18 | ---------- | 312 | ------- | -------- | ------ | 247 |
| Do------------ | 1961 | 400 | 63 | 22 | 6.8 | 297 | 8.0 | 1.4 | 14 | 259 |
| Do------------ | 1963 | 1/ 400 | 60 | 21 | 7.7 | 288 | 14 | .5 | 11 | 255 |
| Do------------ | 1961 | 606 | 66 | 24 | 5.4 | 319 | 6.5 | .1 | 18 | 275 |
| Near Farmington--- | 1906 | 160 | 49 | 23 | 4.4 | 222 | 13 | 5.3 | ------ | 263 |
| Do------------ | 1962 | 302 | 47 | 22 | 4.0 | 247 | 4.3 | 1.5 | 19 | 231 |
| Near Hastings----- | 1907 | 140 | 55 | 25 | 35 | 264 | 61 | 26 | ------ | 358 |
| Do------------ | 1961 | 301 | 56 | 22 | 3.6 | 254 | 11 | 1.4 | 17 | 254 |
| Do------------ | 1963 | 1/ 301 | 55 | 24 | 3.5 | 258 | 16 | 2.4 | 17 | 263 |
| HENNEPIN COUNTY<br>Franconia and Galesville or Mount Simon and Hinckley Sandstones | | | | | | | | | | |
| At Minneapolis---- | 1907 | 880 | 65 | 27 | 3.5 | 330 | 5.9 | 1 | 15 | 281 |
| Do------------ | 1960 | 1,300 | 41 | 13 | 25 | 185 | 7.0 | 30 | 7.6 | 218 |
| Do------------ | 1961 | 1/1,300 | 43 | 12 | 26 | 190 | 7.3 | 29 | 7.3 | 219 |
| Near Bloomington-- | 1899 | 640 | 60 | 27 | 2.2 | 374 | ------- | Trace | 1.5 | 300 |
| Do------------ | 1907 | 1,000 | 63 | 24 | 2.6 | 285 | 20 | 4 | 19 | 275 |
| Do------------ | 1960 | 1,130 | 41 | 13 | 37 | 229 | 11 | 25 | 7.1 | 251 |
| Do------------ | 1961 | 1/1,130 | 42 | 12 | 37 | 229 | 8.0 | 24 | 7.3 | 241 |
| Do------------ | 1960 | 688 | 62 | 21 | 16 | 288 | 29 | .0 | 7.6 | 278 |
| Do------------ | 1961 | 1/ 688 | 68 | 20 | 16 | 300 | 24 | .0 | 7.3 | 286 |
| RAMSEY COUNTY<br>Jordan Sandstone | | | | | | | | | | |
| At St. Paul------- | 1900 | 310 | 53 | 22 | 5.5 | 275 | 6 | 3.4 | 9.5 | 240 |
| Do------------ | 1960 | 416 | 62 | 27 | 6.8 | 309 | 13 | 3.2 | 14 | 285 |
| Do------------ | 1961 | 1/ 416 | 61 | 26 | 8.0 | 301 | 18 | 3.5 | 16 | 279 |
| Franconia and Galesville or Mount Simon and Hinckley Sandstones | | | | | | | | | | |
| At St. Paul------- | 1899 | 510 | 56 | 22 | 7 | 302 | Trace | 3.5 | 1.5 | 240 |
| Do------------ | 1933 | 982 | 56 | 20 | 13 | 264 | 8.6 | 9.0 | 7.6 | 244 |
| Do------------ | 1954 | 1,083 | 50 | 16 | 19 | 252 | 5.9 | 10 | 9.5 | 226 |
| Do------------ | 1961 | 1/1,083 | 55 | 15 | 15 | 251 | 5.8 | 9.6 | 7.9 | 236 |
| Do------------ | 1963 | 1/1,083 | 54 | 17 | 15 | 256 | 7.8 | 10 | 8.2 | 241 |

1/ Water from preceding well resampled.

## Contamination

With time contamination of the surface water and of the water in the glacial drift can have an effect on the quality of water in the underlying aquifers. In 1960 and 1961 some quality data of ground water from Richfield and Brooklyn Park (fig. 4) were obtained to determine the amount of contamination from domestic wastes and to determine the possible effect of contamination on the quality of water in the deep aquifers. At that time, neither community had municipal water nor municipal sewage systems. Although the wells sampled were picked at random, the distribution of the wells was fairly uniform in both communities. The results of the laboratory analyses are given by Maderak (1963).

Contamination of ground water, as indicated by nitrate concentrations (table 2), is fairly widespread in both communities. In Richfield, nitrate was detected at depths less than 201 feet; and in Brooklyn Park, at depths of 100 feet or less. Nitrate, however, was more widespread at Brooklyn Park than at Richfield. Of the 41 wells sampled in the two communities, the water from 6 wells had nitrate concentrations of more than the recommended maximum of 45 ppm (U.S. Dept. Health, Education, and Welfare, 1962), and the water from 11 wells had concentrations of more than 4.0 ppm. The maximum concentrations of nitrate were 58 ppm in Richfield and 82 ppm in Brooklyn Park.

Table 2.--Average concentrations, in parts per million, of some constituents in water from wells in the Brooklyn Park and Richfield communities

| Number of wells | Depth (feet) | Nitrate ($NO_3$) | Alkyl benzene sulfonate (ABS) | Boron (B) | Ortho-phosphate ($PO_4$) | Phos-phorus as $PO_4$ |
|---|---|---|---|---|---|---|
| Brooklyn Park | | | | | | |
| 3 | 15-25 | 32 | 0.04 | 0.03 | 0.05 | ------- |
| 9 | 26-50 | 30 | .07 | .06 | .01 | ------- |
| 5 | 51-75 | 11 | .03 | .03 | .05 | ------- |
| 5 | 76-100 | .8 | .04 | .05 | .02 | ------- |
| 1 | 101-200 | .0 | .03 | .02 | .03 | ------- |
| Richfield | | | | | | |
| 8 | 25-50 | 7.9 | 0.05 | 0.04 | ----------- | 0.35 |
| 3 | 51-75 | 1.2 | .03 | ------- | ----------- | .29 |
| 2 | 76-100 | .0 | .03 | ------- | ----------- | .29 |
| 3 | 101-200 | .3 | .02 | .03 | ----------- | .33 |
| 2 | > 201 | 2.4 | .02 | .06 | ----------- | .50 |

Average concentrations in ground water of alkyl benzene sulfonate (ABS), a compound used in detergents, ranged from 0.02 to 0.07 ppm for the two communities. Probably only concentrations of 0.05 ppm or more are indicative of detergent contamination. Phosphates and borates are also used in detergents. The average concentration for boron of 0.06 ppm at depths of 25 to 50 feet for Brooklyn Park and for total phosphate of 0.50 ppm at depths greater than 201 feet for Richfield may have resulted from detergent contamination.

Most of the wells in the two communities obtain water from the glacial drift, which has very good porosity and permeability. The vertical permeability in the Richfield area is high, and water may move downward from the drift through the St. Peter Sandstone and the Shakopee and Oneota Dolomites to the Jordan Sandstone. In the Brooklyn Park area the Oneota forms a partial aquiclude, which undoubtedly prevents migration of large quantities of water to the Jordan. The lateral or vertical migration of water in the St. Peter probably does not exceed several hundred feet per year; however, water in the dolomites may migrate laterally as much as 500 or 600 feet per month. The rate of movement is especially high where the Jordan is heavily pumped and where much of the recharge is directly from the overlying formations. Thus, contamination should not be allowed to occur in the recharge areas and in the areas having large vertical permeabilities if the water in the Jordan is to retain its good quality.

Some local contamination of water in the Franconia and Galesville or Mount Simon and Hinckley aquifers could result if wells have large uncased sections that would allow the contaminated water to enter from the overlying aquifers. Because most of the recharge areas for these aquifers are outside the Minneapolis-St. Paul area, contamination of the aquifers in the basin is not likely.

## Suitability of the water

Ground-water use in an area depends on the local economy and on the desires of the inhabitants. A company or an individual may find that the quality of the water is not suitable for a particular purpose. Additives, filtering, or ion exchangers, however, will change the quality of the water and industrial processes can be modified to utilize the available water. Thus, because of advanced technology in treating water, standards for the quality of water no longer hinder many industrial processes. Excessive concentrations of iron, manganese, and hardness necessitate treatment of the water used in most industries, and dissolved solids and bicarbonate affect the suitability of the water used in boilers, brewing, and carbonate beverages. Calcium or calcium sulfate in concentrations up to several hundred parts per million, however, is advantageous in brewing. Calcium and magnesium bicarbonate may be an advantage in furnishing additional nutrients for the yeast in the fermentation process of malt preparation.

Standards for drinking water are necessary because they help protect the public health. Some of the drinking-water standards of the U.S. Department of Health, Education, and Welfare (1962) are shown in table 3. The quality of the water from all the major aquifers in most of the basin is suitable for municipal and domestic supplies. Most municipalities, however, improve the quality of the water by treatment to decrease hardness, iron, and manganese.

Table 3 .--Drinking-water standards

[From U.S. Dept. Health, Education, and Welfare, 1962]

| | Concentration (ppm) |
|---|---|
| Alkyl benzene sulfonate (ABS) | 0.5 |
| Chloride (Cl) | 250 |
| Fluoride (F) | 1/ 1.5 |
| Iron (Fe) | .3 |
| Manganese (Mn) | .05 |
| Nitrate ($NO_3$) | 45 |
| Sulfate ($SO_4$) | 250 |
| Dissolved solids | 500 |

1/ Based on average annual maximum daily temperature for 5 years.

## CONCLUSIONS

1. On the average the water from all the formations is the calcium-bicarbonate type.
2. The average concentration of dissolved solids in the water from the major aquifers is highest in the glacial drift and lowest in the Jordan Sandstone.
3. The different materials that compose the reddish-brown and light-gray drifts have little effect on the average percentage composition of constituents in the water, but they do have a significant effect on the median dissolved solids in the water.
4. Except for recharge areas, dissolved solids are lowest in the eastern or northeastern part of the area and highest in the western or southern part.
5. Prediction of the quality of water that is likely to be obtained from the major aquifers in the basin is possible with the use of isocon maps, a system of curves, and bar graphs.
6. The natural change in the quality of water for the major aquifers from 1899 to 1963 has been minor.
7. Contamination, as indicated by nitrate concentrations, of the ground water is fairly widespread in the Richfield and Brooklyn Park communities.
8. Contamination of drift aquifers in recharge areas could affect the quality of water in the Jordan Sandstone.
9. Excessive concentrations of iron and manganese and of hardness necessitate treatment of the water used in most industries.
10. The quality of the water from all major aquifers in most of the basin is suitable for municipal and domestic supplies.

# REFERENCES

Hall, C. W., and others, 1911, Geology and underground waters of southern Minnesota: U.S. Geol. Survey Water-Supply Paper 256, 406 p.

Liesch, B. A., 1961, Geohydrology of the Jordan aquifer in the Minneapolis-St. Paul area, Minnesota: Minnesota Div. of Waters Tech. Paper 2, 24 p.

Maderak, M. L., 1963, Quality of waters, Minnesota, A compilation, 1955-62: Minnesota Div. of Waters Bull. 21, 104 p.

________ 1964, Relation of chemical quality of water to recharge to the Jordan Sandstone in the Minneapolis-St. Paul area, Minnesota: U.S. Geol. Survey Prof. Paper 501-C, p. 176-179.

Minnesota Division of Waters, 1961, Water resources of the Minneapolis-St. Paul metropolitan area: Minnesota Div. of Waters Bull. 11, 52 p.

Prior, C. H., and others, 1953, Water resources of the Minneapolis-St. Paul area, Minnesota: U.S. Geol. Survey Circ. 274, 49 p.

Straka, G. C., and Miller, W. A., 1963, Graphs of ground-water levels in Minnesota, 1957-1961: Minnesota Div. of Waters Bull. 18, 58 p.

Thiel, G. A. 1944, The geology and underground waters of southern Minnesota: Minnesota Geol. Survey Bull. 31, 506 p.

U.S. Department of Health, Education, and Welfare, 1962, Public Health Service drinking water standards--1962: Public Health Service Pub. 956, 61 p.

Winchell, N. H., 1886, Revision of stratigraphy of the Cambrian in Minnesota: Minnesota Geol. Survey Ann. Rept. 14.

________ 1899, Geology of St. Louis County, Minn.: Minnesota Geol. Survey final rept., v. 4, p. 502-580.