GEOCHEMICAL SURVEY TO DETERMINE WATER-QUALITY CHARACTERISTICS OF THE BIG SIOUX AQUIFER IN EASTERN SOUTH DAKOTA

By Norman F. Leibbrand

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 85-4069

Prepared in cooperation with the

SOUTH DAKOTA DEPARTMENT OF

WATER AND NATURAL RESOURCES

Huron, South Dakota

1985

UNITED STATES DEPARTMENT OF THE INTERIOR

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SELECTED FACTORS FOR CONVERTING INCH-POUND UNITS TO THE INTERNATIONAL SYSTEM OF UNITS (SI)

For those readers who may prefer to use the International System of units rather than inch-pound units, the conversion factors for the terms used in this report are given below.

Multiply inch-pound unit	By	To obtain SI unit
acre-foot	1,233	cubic meter
cubic foot	0.02832	cubic meter
foot	0.3048	meter
cubic foot per second	0.02832	cubic meter per second
micromho per centimeter at 25°C (µmho/cm)	1.000	microsiemens per centimeter at 25°C
mile	1.609	kilometer
square mile	2.590	square kilometer
inch	25.40	millimeter

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level.

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ABSTRACT

A geochemical survey of the Big Sioux aquifer was undertaken to: (1) Make an estimate of the quality of the water in the aquifer, (2) determine if there are any water-quality problems in the aquifer, and (3) design a water-quality monitoring network to monitor changes in present and potential water-quality problems.

For most agricultural uses, the water in the Big Sioux aquifer is of acceptable quality. However, in some locations, the ground water is either marginally acceptable or unfit for human use. The major water-quality problem is the high nitrate concentrations (geometric mean of 3.9 and a maximum concentration of 120 milligrams per liter as nitrogen) found in many domestic water supplies. The fact that samples taken from observation wells located by roads away from houses and barnyards show lower concentrations of nitrate (geometric mean of 0.35 and a maximum concentration of 22 milligrams per liter as nitrogen) indicates that the source of nitrate pollution is probably localized and due to human or barnyard sewage.

A monitoring network is proposed consisting of at least: (1) Three wells adjacent to domestic wells, (2) three wells about 1,000 feet away and down the potentiometric gradient from domestic wells, and (3) three wells at least 3,000 feet from any source of pollution. This monitoring network would provide information on changes in both localized nitrate pollution and regional trends in nitrate pollution or other selected water-quality parameters.

INTRODUCTION

This report describes the results of a geochemical survey of the character and the chemical variation of ground water in the Big Sioux aquifer in eastern South Dakota. The survey was undertaken as part of a larger project that will assess the environmental impact of rapidly increasing land use and development on the aquifer during the past decade.

Despite the importance of the Big Sioux aquifer as the major source of water in the Big Sioux River basin, there has never been a comprehensive study made of its chemical quality. It is known that the sediments and soils that overlie the Big Sioux aquifer are thin and very permeable in many places, which may well mean that the aquifer is susceptable to contamination from the land surface. The ground water may be progressively degraded by land-use practices such as irrigation and application of fertilizers, feedlots for livestock, land fills, and domestic and municipal sewage wastes practices. Most of the glacial drift and soils were derived from Cretaceous Pierre Shale that underlies much of the Big Sioux River basin; the shale is enriched in selenium and many other potentially toxic trace elements.

A large quantity of geohydrologic and water-quality data exists, but it is localized and incomplete. Data for radionuclides, trace metals, and pesticides and other organic compounds are virtually nonexistent. The South Dakota Geological Survey has unpublished data indicating that nitrate (as nitrogen) concentrations in a few localized areas of the aquifer are greater than 10 mg/L (milligrams per liter), which poses a health hazard to infants.

The objectives of the geochemical survey by the U.S. Geological Survey were: (1) To make an estimate of the character and geochemical variation of the water in the aquifer; (2) determine if there are any water-quality problems in the aquifer; and (3) design a water-quality monitoring network to monitor changes in present and potential water-quality problems. The latter was accomplished by collecting two separate sample sets; the first sample set consisted of randomly chosen domestic wells adjacent to farm houses and barns, and the second sample set consisted of randomly chosen observation wells either adjacent to county roads or in remote pastures.

The study was conducted in cooperation with the South Dakota Department of Water and Natural Resources; a division of the Department, the South Dakota Geological Survey, collected and analyzed the samples.

Description of Study Area

The Big Sioux River basin has a drainage area of about 9,570 square miles of which the major part, 69 percent, is within South Dakota, 16 percent is within Minnesota, and 15 percent is within Iowa (fig. 1). The Big Sioux River originates in northeastern South Dakota and in general flows southward until it joins the Missouri River at Sioux City, Iowa. The river forms the boundary between Iowa and South Dakota from a point south and east of Sioux Falls, South Dakota, to its confluence with the Missouri River at Sioux City.

The Big Sioux aquifer, located along the Big Sioux River and its tributaries within parts of 12 counties, is one of the most extensively developed aquifers within South Dakota. About 204,600 people (1980 census) or nearly 32 percent of the population of South Dakota live in this basin. In addition to numerous public water supplies developed in the aquifer, there are more than 16,000 housing units using private wells for domestic, irrigation, and stock watering purposes according to records maintained by the South Dakota Department of Water and Natural Resources.

Climate and Physiography

Climate

The climate of South Dakota is a continental type, characterized by large seasonal and daily variations in temperature, minimal average winter precipitation, and marginal to adequate growing-season rainfall. The area is dominated by cold air masses from the north in winter and by warm air masses from the south in summer. Numerous rainstorms, associated with weather fronts, supply much of the precipitation during spring, summer, and fall. The average annual precipitation in the Big Sioux River basin is about 23 inches, but the annual precipitation varies widely from the average. The variability of annual precipitation is indicated by figure 2 which shows the annual discharge of the Big Sioux River at Akron, Iowa.

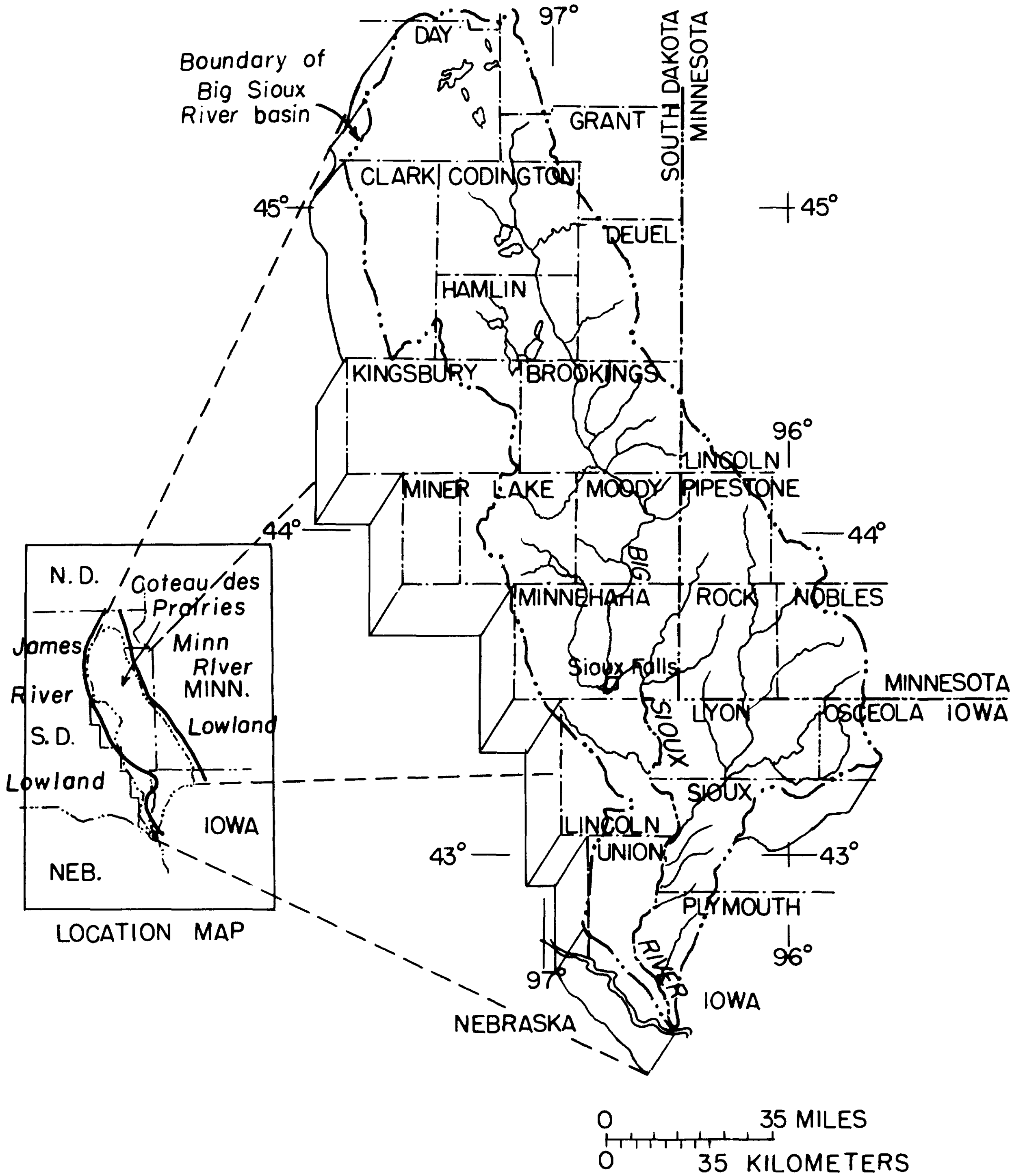


Figure 1.--Location of Big Sioux River basin.

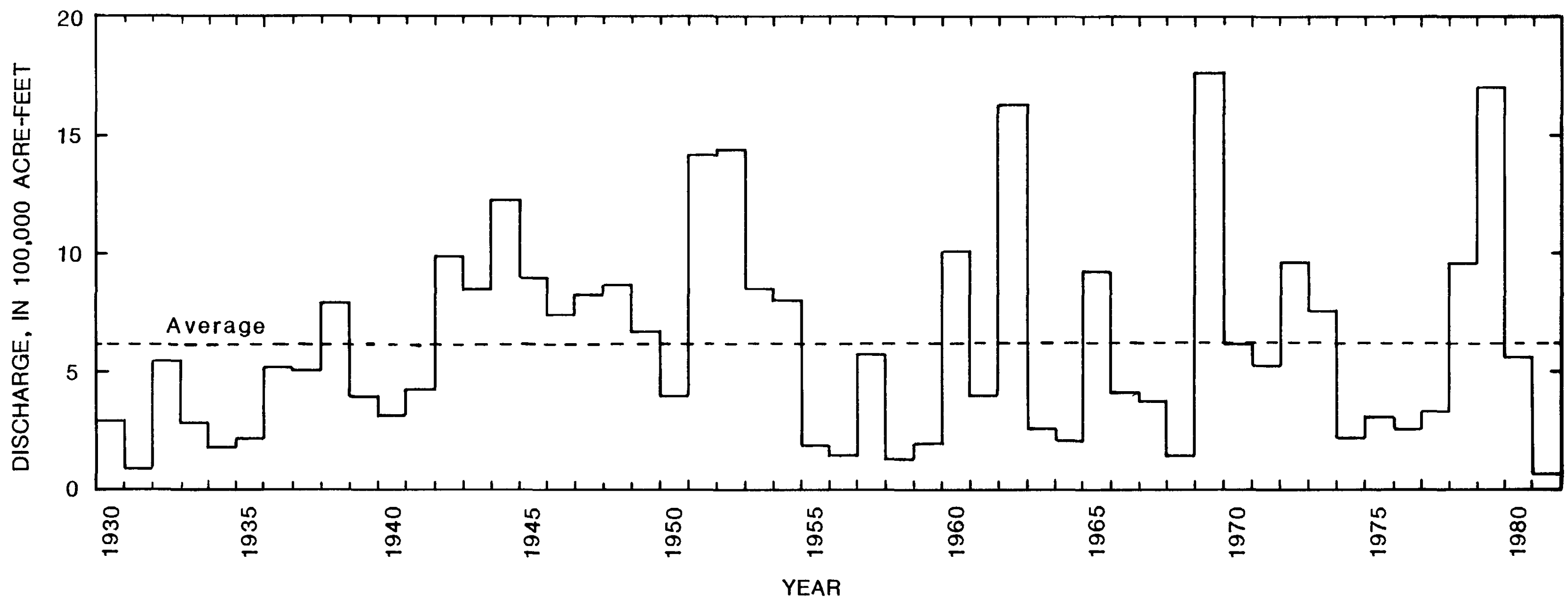


Figure 2.--Annual discharge of the Big Sioux River at Akron, Iowa.

Physiography

The Big Sioux River drains an extended highland or plateau, which is the largest single topographic feature in eastern South Dakota. French explorers and fur traders named the highland the Coteau des Prairies or Prairie Hills. The coteau, an erosion remnant, is a flatiron-shaped plateau some 200 miles long pointing north. The point or nose of the flatiron extends to the boundary between North Dakota and South Dakota, with an axis trending slightly east of south. The coteau broadens gradually from the point to a width of about 80 miles at its southern extremity (see fig. 1).

Along the northeastern margin, the coteau has elevations of more than 2,000 feet above sea level, whereas near the center the highest points seldom exceed 1,800 feet above sea level. The western margin of the coteau generally is 100 to 200 feet lower in elevation than the eastern margin. The general slope of this highland is, therefore, westward; however, because of the surface irregularities produced by glacial moraines and stream valleys, the regional slope is obscured.

The Big Sioux River originates about 40 miles south of the point of the flatiron and flows southward, approximately along the axis of the coteau, to join the Missouri River. As far south as Sioux Falls, the river's course seems to have been developed during one of the glacial ages when glacial meltwater flowed southward and confined the stream between two glacial lobes that flanked the coteau. Most of the streams tributary to the Big Sioux River enter the main stream from the east; very few enter it from the west, indicating an element in the stream pattern that is also a result of the glacial history of the coteau. The total area drained by the Big Sioux River in eastern South Dakota, southwestern Minnesota, and northwestern Iowa is about 9,570 square miles. The river is about 210 miles long.

The surface of this prairie highland is dotted with lakes and ponds both perennial and intermittent. The larger of these lakes are 5 to 10 miles in length. Many occupy parts of former valleys that have been blocked by glacial drift and have therefore ceased to be drainageways. Unlike the tributary streams, these lakes and ponds are more numerous west of the Big Sioux River than to the east of it.

Geology

The Coteau des Prairies is irregularly covered with glacial drift that owes its partial isolation to the erosion of large stream valleys northeast, northwest, and southwest of it. The oldest known rock of the area is the Precambrian Sioux Quartzite, which is exposed in the Big Sioux River valley at Sioux Falls and at several other points in the central part of the basin. Overlying the quartzite is a thin succession of sediments composed mainly of sand, shale, clay, silt, and chalk of marine origin, which are of Cretaceous age. The formations included in this succession, although they may not be present in all parts of the basin, are the Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Chalk, and Pierre Shale.

The thickness of the glacial drift overlying the Cretaceous sediments is extremely variable owing to the irregularity of the bedrock surface. The glacial drift is physically divided into till, outwash, and glacial-lake deposits. Black till constitutes the greatest bulk of the glacial drift in the basin. It consists of a heterogeneous mixture of silt, sand, and large rock fragments in a matrix of clay. Although conspicuous because of their size, the rock fragments constitute only a small fraction of the till. Outwash consists of crossbedded gravel, sand, and silt. Outwash is common along the Big Sioux River drainage system, and it ranges in thickness from a few feet to almost 200 feet. Outwash areas are usually a source of ground water and, where the gravels and sands are relatively thick, yields from wells are usually sufficient for irrigation. Glacial-lake sediments are fine-grained clay and silt that accumulated in temporary lakes or small depressions in the till area. These areas of lake sediments are relatively impermeable and usually are from 4 to 10 feet thick.

Recent alluvial deposits of clay, silt, and sand with some gravel occur along both sides of the Big Sioux River and its tributaries. The alluvial deposits normally range from 3 to 15 feet thick. It is this system, including the outwash, that is named the Big Sioux aquifer and is the subject of this report (fig. 3). Generally, ground water is not very abundant in the basin from deposits other than those comprising the Big Sioux aquifer.

GEOCHEMICAL SURVEY OF THE BIG SIOUX AQUIFER

Sampling Plan

In order to determine the chemical quality of water in the Big Sioux aquifer, the following sample plan was used. First a single water sample was collected from each of 27 randomly selected domestic water wells in the study area. The results of this initial sample set indicated that water from many domestic wells in the study area contained large concentrations of nitrate. In order to determine if the large nitrate concentrations were only associated with pollution in the vicinity of domestic wells, or if the large nitrate concentrations occurred throughout the study area, a second set of ground-water samples was obtained away from houses and barnyards. This second set of water-quality samples was obtained from observation wells drilled alongside roads throughout the area. A set of 95 water samples was collected from randomly chosen observation wells in the area. Locations of the 27 domestic wells sampled during July 1980 are shown in figure 4. Locations of 85 of the observation wells sampled between the spring of 1981 and the summer of 1982 are shown in figures 5 and 6.

Data Collection and Laboratory Analyses

All water samples were collected and analyzed by personnel of the South Dakota Department of Water and Natural Resources. In general, their procedures are very similar to U.S. Geological Survey procedures. The data for the chemical analyses have been published by the U.S. Geological Survey (U.S. Geological Survey, 1981-83).

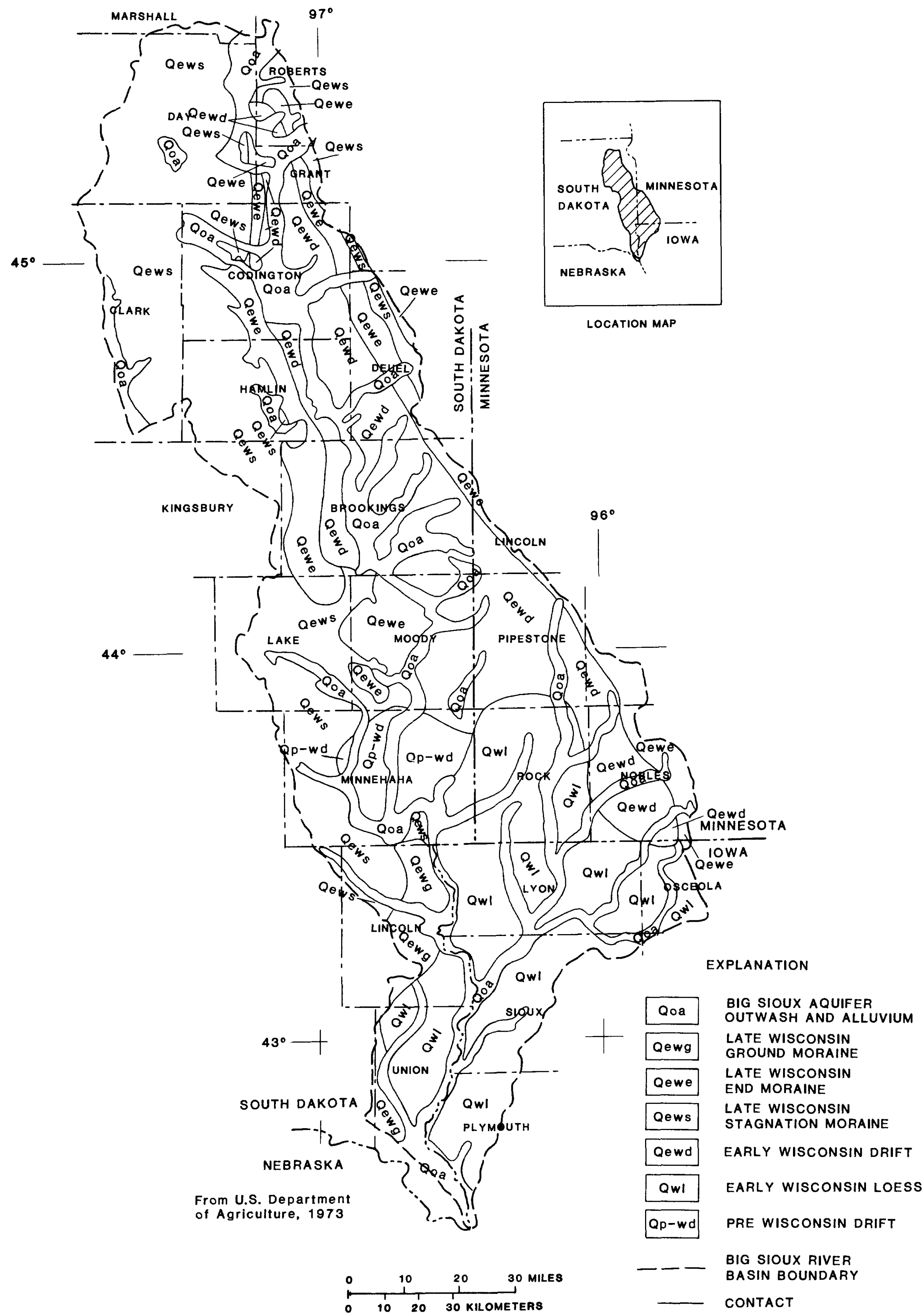


Figure 3.--Pleistocene geology of the Big Sioux River basin.

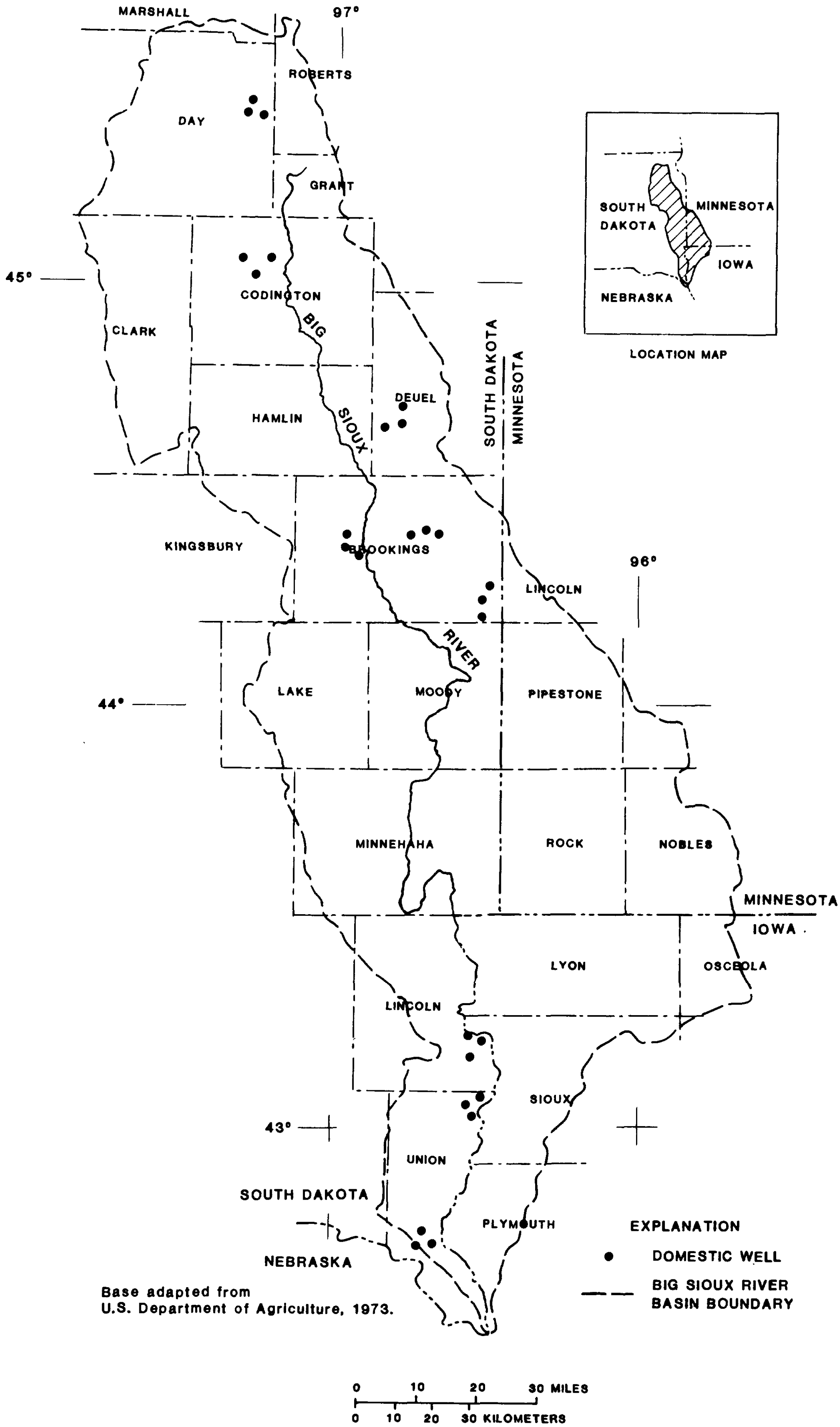


Figure 4.--Locations of domestic wells sampled during the summer of 1980.

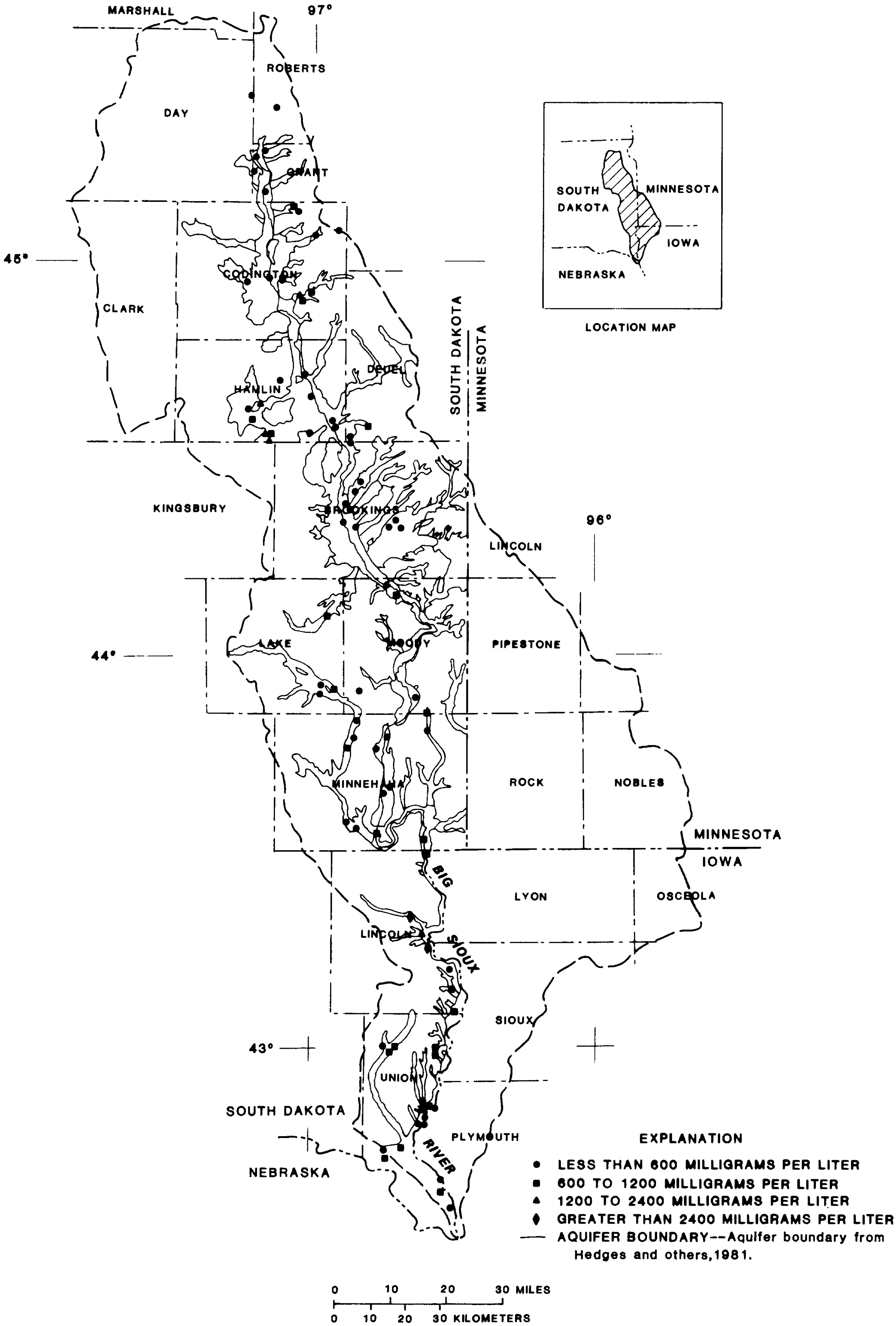


Figure 5.--Distribution of concentrations of dissolved solids in water from selected wells in the Big Sioux aquifer in South Dakota.

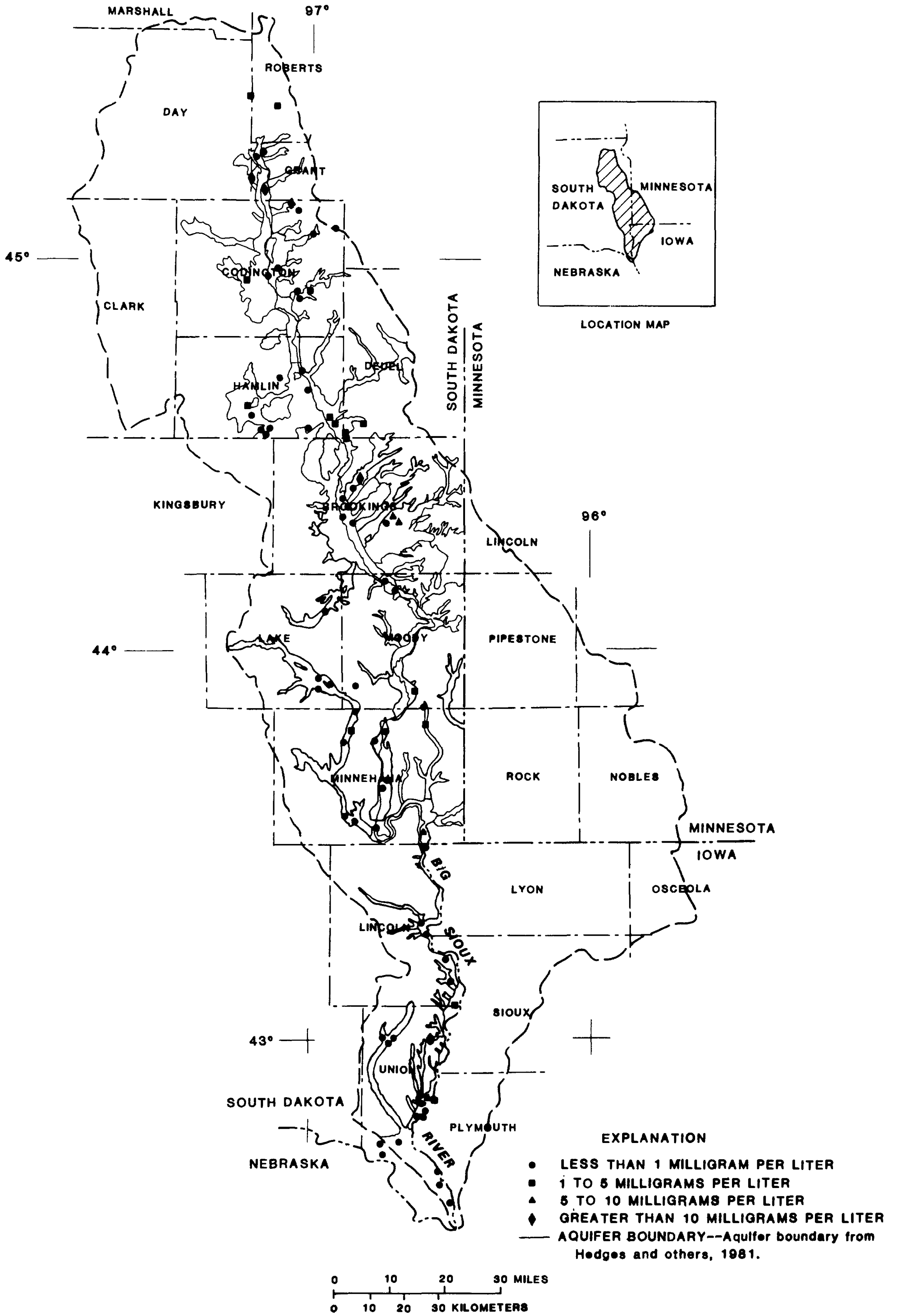


Figure 6.--Distribution of concentrations of nitrate nitrogen in water from selected wells in the Big Sioux aquifer in South Dakota.

Table 1.--Statistical summary of chemical-quality data for water samples collected from the domestic wells

[GM, the geometric mean that is the antilog of the mean logarithm of the concentration and specific-conductance values; GD, the geometric standard deviation that is the antilog of the mean logarithm of the standard deviation of the concentration and specific-conductance values; SAR, sodium-adsorption ratio; mg/L, milligrams per liter; µg/L, micrograms per liter; µmhos/cm, micromhos per centimeter at 25°C; °C, degrees Celsius]

Variable	GM	GD	Minimum value	Maximum value
Calcium (mg/L)	142	1.77	58	416
Magnesium (mg/L)	56	1.85	25	344
Sodium (mg/L)	25	2.52	6.0	133
SAR	.43	2.13	.1	1.7
Potassium (mg/L)	3.7	2.97	.30	17
Bicarbonate (mg/L)	283	1.36	164	482
Sulfate (mg/L)	142	3.58	25	1,720
Chloride (mg/L)	16	4.80	2.0	313
Fluoride (mg/L)	.35	1.66	.20	1.9
Nitrate nitrogen (mg/L)	3.9	9.50	.10	120
Iron (µg/L)	135	5.10	50	11,600
Manganese (µg/L)	198	4.50	50	2,800
Zinc (µg/L)	42	9.18	.05	1,150
Dissolved solids (mg/L)	723	1.97	290	3,470
Specific conductance (µmhos/cm)	1,103	1.64	599	3,500
Hardness (mg/L)	623	1.88	280	2,500
Temperature1/ (°C)	16.0	3.0	11.0	22.0

1/ The temperature data were not converted to logarithms because these data are normally distributed. The mean and standard deviation are an arithmetic mean and an arithmetic standard deviation.

RESULTS OF GEOCHEMICAL SURVEY

The laboratory data for both sample sets are summarized in tables 1 and 2.

Stratification of pollutants that may exist in the aquifer as a result of contamination from the surface were not considered by this investigation. More data are needed such as aquifer thickness including distance from land surface to the water table (unsaturated zone), and distance from water table to the well screen. More wells probably are needed.

Small areas of anomalous water-quality or local contamination might be missed by random sampling design using a small number of samples. If finding those areas were the goal, then a much more detailed sampling plan, based on a grid method, needs to be used.

One result of the sample design used here was the indication of the nitrate nitrogen problem mentioned previously--approximately 40 percent of the domestic well samples contained dissolved nitrate nitrogen in concentrations ranging from 0.10 to 120 mg/L. This indicates that if these larger nitrate concentrations are being derived from land-surface contamination, then the process causing the contamination probably is occurring around most houses and barnyards throughout the study area.

Table 2.--Statistical summary of chemical-quality data for water samples collected from the observation wells

[GM, the geometric mean that is the antilog of the mean logarithm of the concentration and specific-conductance values; GD, the geometric standard deviation that is the antilog of the mean logarithm of the standard deviation of the concentration and specific-conductance values; SAR, sodium-adsorption ratio; mg/L, milligrams per liter; µg/L, micrograms per liter; µmhos/cm, micromhos per centimeter at 25°C; °C, degrees Celsius]

Variable	GM	GD	Minimum value	Maximum value
Calcium (mg/L)	107	1.81	8.0	494
Magnesium (mg/L)	40	1.70	4.8	162
Sodium (mg/L)	25	2.33	1.0	133
SAR	.53	2.07	.1	3.1
Potassium (mg/L)	3.5	2.30	.1	19
Bicarbonate (mg/L)	419	1.72	38	1,070
Sulfate (mg/L)	127	2.95	5.0	1,500
Chloride (mg/L)	6.5	2.59	1.0	62
Fluoride (mg/L)	.33	1.61	.1	1.0
Nitrate nitrogen (mg/L)	.35	5.33	.1	22
Boron (µg/L)	120.0	2.66	0.0	575
Cadmium (µg/L)	.56	1.95	0.0	3.6
Iron (µg/L)	172	6.07	10	5,880
Manganese (µg/L)	320	5.17	10	5,000
Zinc (µg/L)	14	3.55	5.0	2,120
Dissolved solids (mg/L)	554	1.70	104	2,740
Specific conductance (µmhos/cm)	848	1.55	146	2,960
Hardness (mg/L)	434	1.74	55	1,900
Temperature[1/] (°C)	9.0	1.8	4.0	12.0

1/ The temperature data were not converted to logarithms because these data are normally distributed. The mean and standard deviation are an arithmetic mean and an arithmetic standard deviation.

Geochemical Variation

The Big Sioux aquifer as discussed previously is quite variable in chemical quality throughout its extent. The data in tables 1 and 2 show summary statistics for the chemical constituents and properties determined in this study. The means and standard deviation are geometric rather than arithmetic because they were derived from lognormally distributed values for both the domestic and observation-well populations. As such they are antilogs. About 68 percent of the values of the two well populations are estimated to occur in the range (GM)/(GD) to (GM)X(GD). About 95 percent of the values for the two well populations are expected to be in the range from $(GM)/(GD)^2$ to $(GM)X(GD)^2$.

Dissolved solids (fig. 5) and nitrate nitrogen (fig. 6) were selected from the observation-well data base for mapping to show their variation; dissolved solids was chosen to show the general water quality of the region; nitrate nitrogen was chosen because this study shows that nitrates may be a problem in the study area and its variability may be a direct reflection of land use.

The largest dissolved-solids concentrations are found near the edge of the aquifer where the aquifer is the thinnest and where it also may be affected by adjacent water-yielding zones containing more mineralized water. In the northern sampling area, the most mineralized water is found along the tributaries where the aquifer is very narrow and thin. In contrast, in Brookings County where the depth to the water table is the shallowest, the most dilute water occurs. Recharge (from snowmelt and rainfall) is much more rapid here than elsewhere in the aquifer. Wells located close to the Big Sioux River indicate that the recharge is increased by high flows in the river during periods of snowmelt and rainfall. This recharge water usually contains minimal dissolved solids.

Nitrate nitrogen in concentrations less than 1.0 mg/L probably occurs throughout most of the region; however, water from the domestic wells generally contained greater concentrations. Water from about 40 percent of the domestic wells had nitrate-nitrogen concentrations in excess of the Federal drinking-water limit of 10 mg/L (U.S. Environmental Protection Agency, 1976), whereas water from only about 4 percent of the observation wells had nitrate-nitrogen concentrations that equaled or exceeded the 10-mg/L limit. Thus, if water samples from only 27 randomly selected wells show local nitrate-nitrogen contamination, there probably is a problem around houses and barnyards.

The domestic wells probably are more subject to man-made pollution sources than the observation wells. Many may have been drilled too close to or downgradient from septic-tank drain fields and feedlots. Observation wells were usually drilled in ditches along section-line roads and are not directly subject to contamination from the land surface. However, the horizontal movement of ground water downgradient from a polluted domestic well to an observation well is possible.

In chemical composition, the water from both well populations varies throughout the aquifer but can be classed as mostly very hard and a calcium bicarbonate type. Random selection of 30 of the 95 observation-well samples show the following types of chemical compositions of the water:

Water type	Number of analyses
Calcium bicarbonate	27
Calcium magnesium sodium bicarbonate sulfate	1
Sodium sulfate	1
Calcium sodium magnesium bicarbonate	1

The predominant water type in the Big Sioux aquifer is the calcium bicarbonate type.

The occurrence of the sodium sulfate type water is anomalous compared to the chemical composition of most ground water in the region, but it may represent the effects of recharge water from an adjacent formation. A comparison of a typical calcium bicarbonate water from the Big Sioux aquifer with a sodium sulfate water is given in table 3.

Table 3.--Comparison of a typical calcium bicarbonate water and a typical sodium sulfate water

[Data in milligrams per liter except as indicated. SAR, Sodium-adsorption ratio; µg/L, micrograms per liter; µmhos/cm, micromhos per centimeter at 25°C]

Constituent or property	Calcium bicarbonate water	Sodium sulfate water
Calcium	77	8.0
Magnesium	27	10.0
Sodium	26	56.0
SAR	.6	3.1
Potassium	2.9	7.7
Bicarbonate	329	38
Sulfate	79	96.0
Chloride	6	13.0
Fluoride	.26	.4
Nitrate	2.9	.10
Boron (µg/L)	60	200
Cadmium (µg/L)	.9	1
Iron (µg/L)	50	10
Manganese (µg/L)	50	10
Zinc (µg/L)	7	22
Dissolved solids	394	262
Specific conductance (µmhos/cm)	598	408
Hardness	300	61

Table 4.--Environmental Protection Agency mandatory and recommended drinking-water standards for selected chemical constituents in the Big Sioux aquifer

[U.S. Environmental Protection Agency, 1976. Leaders (--), not determined]

Constituent or property and type of standard	Drinking-water standard (milligrams per liter 1/)	Number of samples equal to or in excess of drinking-water standard, in percent	
		27 domestic wells	95 observation wells
Arsenic (mandatory)	0.05	0	--
Cadmium (mandatory)	.010	--	0
Chloride (recommended)	250	0	0
Chromium (mandatory)	.05	--	0
Iron (recommended)	.3	26	38
Lead (mandatory)	.05	--	0
Manganese (recommended)	.05	100	86.0
Nitrate (mandatory)	2/ 45	41	4.2
Selenium (mandatory)	.01	--	0
Sulfate (recommended)	250	37	25
Zinc (recommended)	5	0	0

1/ To convert milligrams per liter to micrograms per liter, multiply milligrams per liter by 1,000.
2/ Forty-five mg/L of nitrate equals 10 mg/L nitrate as nitrogen.

Suitability for Use

Municipal and Domestic Supplies

The water in the Big Sioux aquifer is mainly used for municipal and domestic purposes, stock watering, and irrigation. The extent of industrial use is not known but is considered small. Table 4 lists the Environmental Protection Agency mandatory and recommended drinking-water standards for selected chemical constituents in the Big Sioux aquifer.

Two constituents, as can be seen in table 4, were equal to or in excess of the Federal drinking-water standards. Iron and manganese occur in concentrations in the well water equal to or exceeding the drinking water standards throughout the region. However, most of the water is extremely hard. When softening processes are used to soften the water, both iron and manganese also are removed. These two constituents should, therefore, not be a problem in drinking water supplies.

Nitrate as nitrogen in concentrations in excess of 10 mg/L is dangerous to infants as it causes "blue baby disease" or methemoglobinemia. Of the 27 sampled domestic wells, about 40 percent contained water where nitrate-nitrogen concentration equaled or exceeded the 10-mg/L standard, indicating unsampled areas in the region are locally contaminated with excessive nitrate-nitrogen compounds. Only about 4 percent of the 95 sampled observation wells contained water with a concentration of 10 mg/L or more nitrate nitrogen. This indicates that most of the contamination is localized, and probably a result of septic tank or feedlot sources.

Sulfate in ground water exceeds the 250-mg/L limit in much of the area. Water containing excessive sulfate, usually sodium or magnesium sulfate, has a laxative effect on people who are unaccustomed to drinking the water. But wells yielding water containing less than 250 mg/L sulfate for municipal and rural pipeline supplies probably could be developed almost anywhere in a given township if transporting the water for a short distance is not objectionable.

Livestock and Poultry Supplies

Because livestock and poultry production is an important ranching or farming activity in the Big Sioux River basin, a summary of the water-quality requirements for these uses is shown below (Olson and Fox, 1976):

Concentration (milligrams per liter)	Comments
	Dissolved solids
Less than 1,000.	From the standpoint of its dissolved solids, this water should be excellent for all classes of livestock and poultry.
1,000 to 2,999	This water should be satisfactory for all classes of livestock. Those waters approaching the upper limit may cause some watery droppings in poultry, but they should not adversely affect the health or production of the birds.
3,000 to 4,999	This water should be satisfactory for livestock. It is a poor to unsatisfactory water for poultry. It may cause watery feces, and particularly near the upper limit it may cause increased mortality and decreased growth, especially in turkey poults.
	Nitrate nitrogen
Less than 100	Experimental evidence to date indicates that this water should not harm livestock or poultry.
100 to 300	This water should not by itself harm livestock or poultry. When feeds contain nitrates, this water could add greatly to the nitrate intake to make it dangerous.

One domestic well was found to yield water with dissolved solids in excess of 2,999 mg/L, but the nitrate-nitrogen concentration was 39 mg/L indicating the water from this well is satisfactory for livestock based on the summary above. However, it is unsatisfactory for poultry. Two of the domestic wells yield water with nitrate nitrogen in excess of the 100-mg/L-concentration limit. Concentrations were 120 mg/L. Although concentrations in water from both wells were less than the 300-mg/L-concentration limit, the water could be dangerous under extreme drought conditions. In general, water containing nitrate-nitrogen concentrations greater than 300 mg/L could cause nitrate poisoning.

All the observation wells were found to yield water of satisfactory quality for poultry and livestock. In general, most of the sampled domestic and observation wells contain water which can be classified as very satisfactory to excellent in chemical quality for livestock and poultry.

Irrigation Supplies

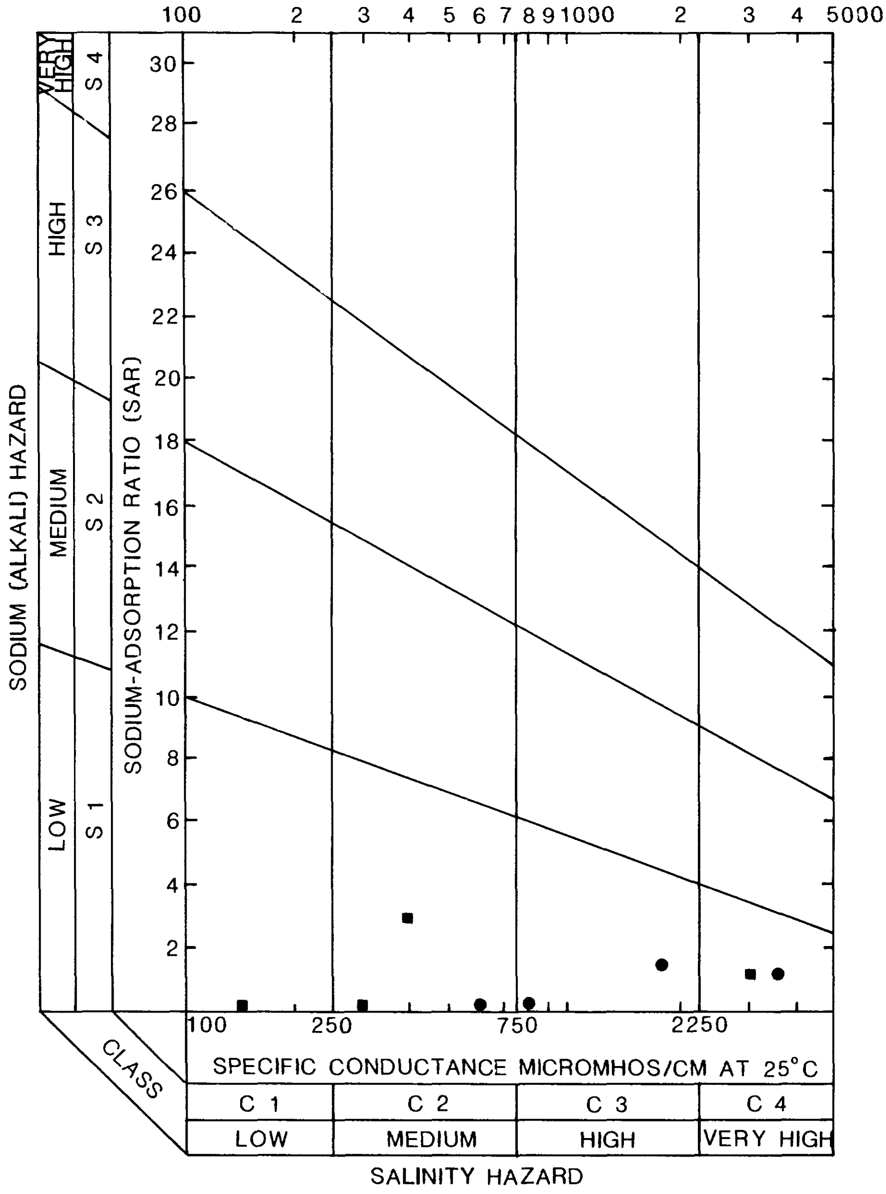
Water from wells is used for irrigation in many areas of the region. Sodium-adsorption-ratio (SAR) values were computed from both the domestic-well and the observation-well data bases. These values can be used to predict the suitability of a water supply for irrigation purposes using a diagram with the SAR values plotted along one axis and specific-conductance values plotted along another axis as shown in figure 7 (U.S. Salinity Laboratory staff, 1954).

On the diagram are plotted maximum and minimum SAR values with corresponding specific-conductance values and maximum and minimum specific-conductance values with corresponding SAR values. These are extreme values and most of the water throughout the Big Sioux region would plot between specific-conductance values of 200 and 2,000 μmhos/cm and the corresponding SAR ratios would be less than 3. Thus, the diagram shows that water in the Big Sioux aquifer has a low sodium hazard but has a medium to high salinity hazard.

The sodium hazard refers to sodium replacement of adsorbed calcium and magnesium, and this replacement is damaging to soil structure which can be detrimental to crops (Hem, 1970). Thus, sodium is of no consequence in ground-water supplies that are used for irrigation in the Big Sioux basin.

The salinity hazard probably is of no consequence during years of normal precipitation. A prolonged drought throughout the region may cause an undesirable increase in salinity.

In addition to sodium and salinity hazards, certain constituents in irrigation water are undesirable. One of these in the water in the Big Sioux aquifer is boron. It was determined only in the water samples collected from the observation wells and averaged about 120 μg/L (micrograms per liter) and ranged from 0.0 to 575 μg/L. The most sensitive crops can tolerate as much as 1,000 μg/L (Hem, 1970). Thus, boron should not be a problem.



EXPLANATION

● DOMESTIC WELL--Minimum and maximum salinity hazard and sodium adsorption ratio (SAR) values. All other SAR values will plot in between these points.

■ OBSERVATION WELL-- Minimum and maximum salinity hazard and sodium adsorption ratio (SAR) values. All other SAR values will plot in between these points.

Figure 7.--Diagram of classification of water for irrigation use. (Classification developed by United States Salinity Laboratory staff, 1954)

PERMANENT WATER-QUALITY MONITORING NETWORK

Based on the data obtained in this study, a permanent water-quality monitoring network would be desirable to monitor the possible spread of nitrate-contaminated ground water from its present occurrence mostly in the immediate vicinity of houses and barnyards to more remote areas. The monitoring network would also provide information on whether present areas of high-nitrate ground water are continuing to deteriorate. Data for the other water-quality parameters studied do not indicate any immediate or long-term threat to human or animal health, or to the water's suitability for intended agricultural uses. However, water-quality parameters not determined for the present study may be deemed important and worth monitoring at a later date. These later water-quality parameters may include herbicides, pesticides, and other organic compounds.

In order to monitor changes in nitrate contamination in the Big Sioux aquifer, the following minimal monitoring network is proposed. The monitoring network should consist of: (1) Four or more domestic wells. At least two of these should have water with more than 10 mg/L nitrate as nitrogen, and at least two should contain water with less than 5 mg/L nitrate as nitrogen. Monitoring the more polluted wells would provide information on whether a plateau for concentration of nitrate has been reached or if the levels of nitrate continue to increase with time. Also, if mitigating measures are taken, the monitoring wells would indicate the progress. The data from the less polluted wells would show if the less polluted wells are becoming more polluted, and also provide data on the rate of increase or decrease. (2) In the vicinity (approximately 500 feet) of each of the above monitoring wells, but outside the area of possible direct septic tank or barnyard pollution, at least two monitoring wells should be provided. One well should be up the potentiometric gradient from the source of pollution, and at least one well should be down the potentiometric gradient. Determining the potentiometric gradient in the vicinity of domestic wells was outside the scope of this study, but if a monitoring network is established, such data will have to be obtained. (3) At least three wells at remote locations which are at least 3,000 feet from any known source of pollution. These wells would provide data on more widespread changes due to the spread of localized contamination or other factors such as fertilizer use.

CONCLUSIONS

1. In general, the quality of water in the Big Sioux aquifer is suitable for the uses it is intended for in the region. However, most of the chemical constituents investigated in this study show large variations throughout the area. Most of the water is classified as hard to very hard and may require treatment prior to domestic use. In addition, large concentrations of iron and manganese also may require treatment prior to domestic use. Zinc and cadmium were the only other trace metals found in appreciable concentrations, but they did not exceed mandatory standards for drinking water established by the U.S. Environmental Protection Agency.

2. Nitrate-nitrogen concentrations of as much as 120 mg/L were found in water from some wells in the study area. The geometric mean of nitrate concentrations in water from the domestic wells was only 3.9 mg/L, and the geometric mean of nitrate concentrations in water from the observation wells was 0.35 mg/L. Only about 4 percent of the 95 observation wells yielded water with

nitrate-nitrogen concentrations greater than the recommended limit of 10 mg/L, whereas about 40 percent of the 27 domestic wells yielded water with concentrations greater than 10 mg/L. This indicates that there is a problem in this study area due to contamination of domestic water supplies. This problem needs to be studied further, especially the effects of possible vertical stratification of nitrate concentrations or other pollutants.

3. A ground-water monitoring network would help to determine changes in nitrate pollution in the study area. This should consist of at least 15 wells--three wells at least 3,000 feet from any known source of pollution to monitor regional trends; and to monitor domestic pollution, four domestic wells, each with a well approximately 500 feet up the potentiometric gradient and another well approximately 500 feet downgradient.

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☆ U.S. GOVERNMENT PRINTING OFFICE : 1985—566-924/20021