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Appraisal of Data for Ground-Water Quality In Nebraska

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Appraisal of Data for Ground-Water Quality in Nebraska

By RICHARD A. ENGBERG

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Appraisal of Data for Ground-Water Quality in Nebraska

By R. A. Engberg

Abstract

This report summarizes existing data for ground-water quality in Nebraska and indicates their adequacy as a data base. Analyses have been made of water from nearly 10,000 wells by 8 agencies. Those analyses that meet reliability criteria have been aggregated by geologic source of water into four principal aquifer groupings—Holocene-Pleistocene aquifers, Tertiary aquifers, Mesozoic aquifers, and Paleozoic aquifers.

For each aquifer grouping, data for specific conductance and 24 constituents in the water are summarized statistically. Also, diagrams are presented showing differences in statistical parameters, or in chemical composition, of water from the different aquifer groupings. Additionally, for each grouping except Paleozoic aquifers, maps show ranges in concentration of dissolved solids, calcium, alkalinity, and sulfate. In areas where data are insufficient to delimit, ranges in concentration also are shown on the maps.

Point-source contamination has been identified at 41 locations and nonpoint-source contamination in 3 areas, namely, the central Platte Valley, Holt County, and Boyd County. Potential for nonpoint-source contamination exists in 10 major areas, which together comprise more than one-third of the State.

Existing data are mostly from specific projects having limited areas and objectives. Consequently, a lack of data exists for other areas and for certain geologic units, particularly the Mesozoic and Paleozoic aquifers. Specific data needs for each of the four principal aquifer groupings are indicated in a matrix table.

INTRODUCTION

Ground-water-quality problems in Nebraska (fig. 1) are typical of those in many States in the central and western United States. Planners and managers in Nebraska, as elsewhere, are concerned both with nonpoint and point-source contamination by waste disposal practices and with other land-use activities. To determine the extent of contamination and develop methods for safe disposal of toxic substances, these planners and managers need to be aware of existing ground-water quality and to have a basic knowledge of hydrologic and geologic factors that affect it.

An initial requirement for dealing with problems of ground-water quality is a representative data base of ground-water-quality information. The purpose of this report is to summarize existing data for ground-water quality in Nebraska and to appraise their adequacy as a data base.

To summarize existing data, agencies that have obtained data regarding the quality of Nebraska ground waters were identified. Chemical analyses available from those agencies were examined to see if adequate descriptive information was given for the sampled wells, and certain computations, such as ionic balance, were made to check on the apparent reliability of analytical results reported. Data for those analyses for which adequate descriptive information was available and for which the analytical results appeared reliable were then aggregated into four aquifer groupings depending on the geologic age of the aquifers from which the water samples were taken. Finally, the data were summarized for each of these principal aquifer groupings using statistical techniques.

NATURAL CONDITIONS THAT AFFECT GROUND-WATER QUALITY

Topography

Topographic regions are shown on a map prepared by the Conservation and Survey Division of the University of Nebraska-Lincoln (fig. 2). The Nebraska Sand Hills, shown as random dot pattern, represent one of the largest natural ground-water reservoirs in the conterminous United States. Much of the Sand Hills is characterized by closed basins. In these basins, precipitation is absorbed readily by the mantle of dune sand and, if not removed by evapotranspiration, infiltrates rapidly to the zone of saturation. Streams draining the Sand Hills generally are hydraulically connected with the water table. Because areas contributing overland runoff to streams are very small, streamflow is composed almost entirely of ground-water discharge. This relationship between surface water and ground water seldom is affected greatly by short-term climatic changes.

Topography affects land use and is an important



Map prepared by Conservation and Survey Division, University of Nebraska - Lincoln

EXPLANATION

-  **VALLEYS**—Flat-lying land along the major streams. The materials of the valleys are stream-deposited silt, clay, sand, and gravels.
-  **VALLEY-SIDE SLOPES**—Moderately sloping land that occurs between the escarpments and the major stream valleys in western Nebraska. These areas are mostly siltstone bedrock covered by a few feet to a few tens of feet of sand, gravel, or silt.
-  **LARGE RESERVOIRS**—Constructed for purposes such as water storage for irrigation, generation of electricity, flood control, or recreation.

-  **PLAINS**—Flat-lying land that lies above the valley. The materials of the plains are sandstone or stream-deposited silt, clay, sand and gravel overlain by wind-deposited silt (loess).
-  **DISSECTED PLAINS**—Hilly land with moderate to steep slopes, sharp ridge crests, and remnants of the old, nearly level plain. The Dissected Plains are old plains eroded by water and wind.
-  **SAND HILLS**—Hilly land composed of low to high dunes of sand stabilized by a grass cover. The sand dunes mantle stream-deposited silt, sand and gravel, and sandstone.

-  **ROLLING HILLS**—Hilly land with moderate to steep slopes and rounded ridge crests. In eastern Nebraska, the Rolling Hills are mostly glacial till that has been eroded and mantled by loess, while in northwestern Nebraska the hills were produced by the erosion of clay and clay-shale beds.
-  **BLUFFS AND ESCARPMENTS**—Rugged land with very steep and irregular slopes. Bedrock materials, such as sandstone, shale and limestone, commonly are exposed in these areas.

Figure 2. Map showing topographic regions.

factor in determining which land can or cannot be cultivated and irrigated. Because areas of increased nitrate concentrations in ground water correlate with areas of irrigation development, topography and related land use indirectly affect the quality of ground water in the State. Topography also affects the location of storage reservoirs for irrigation, flood control, and power generation. Where stored surface water is used for irrigation, ground-water levels may rise because of accelerated recharge. The eventual result may be that the quality of the ground water in the irrigated areas becomes similar to the quality of the surface water used for irrigation.

Soils

Generalized soil permeabilities and soil textures are depicted in figure 3, taken from Dugan (1984). The soil permeabilities represent an average for 60-inch soil profiles. Soil textures are those commonly associated with the permeability ranges given.

The degree of mineralization of ground water in specific areas may be related to soil chemistry, soil permeability, and texture. Large concentrations of dissolved solids often are associated with fine-textured soils with little permeability. Such soils are developed mostly on loess or glacial drift, both of which contain abundant soluble mineral material. Water percolating to the ground-water reservoir through such soils not only comes into contact with much relatively soluble mineral material but remains in contact with it long enough to dissolve significant quantities of it.

Small concentrations of dissolved solids ordinarily are associated with coarse-textured soils with significant permeability. Such soils are developed mostly on sandy material that contains few readily soluble minerals. Water percolating to the ground-water reservoir through such soils does so rapidly and has little contact with readily soluble mineral material except silica compounds, of which sand largely is composed.

The susceptibility to widespread contamination of ground water by agricultural practices generally is greatest where soils are the most permeable and where the ground-water table is nearest land surface. Where soils are very permeable and the water table is shallow, crop nutrients, pesticides, effluent from septic systems or feedlots, or other contaminants may be leached quickly from the soil surface or root zone to the ground-water reservoir. By these criteria, the areas labeled "Greater than 10.0 inches per hour" are the most susceptible to contamination.

Geology

Bedrock units in Nebraska are shown in figure 4. Older units are consolidated rocks consisting principally of sandstone, shale, limestone, and dolomite. Younger

units, such as the Ogallala Formation and the Arikaree Group, are unconsolidated deposits or semiconsolidated rocks consisting principally of sand, gravel, sandy silt and clay, sandstone, and volcanic ash. Most of the bedrock in the State is covered by unconsolidated deposits of Quaternary age.

Principal bedrock aquifers include the Tertiary deposits and the Niobrara Formation and Dakota Sandstone of Cretaceous age. Locally, in eastern Nebraska, Paleozoic deposits, including those of Pennsylvanian and Permian age, provide water for wells. Small quantities of water also are obtained from the Fox Hills and Lance Formations in western Nebraska and in a sand member of the Carlile Shale in northeastern Nebraska. Unconsolidated Quaternary deposits are principal aquifers throughout most of the State.

The mineral composition of formations affects water quality. For example, carbonates, in addition to occurring as limestone and dolomite, generally are cementing material in sandstone or other sandy deposits and may be dissolved by water infiltrating toward or stored in an aquifer. Where gypsum deposits are found, sulfates may be dissolved by infiltrating water. In general, most ground water in Nebraska is of the calcium carbonate type.

Solubility and chemical equilibria control the degree of mineralization of ground water. Stresses cause changes in the equilibria resulting in changes in mineralization or changes in ion ratios. Stresses may be caused by infiltrating water that is of different chemical composition than that in the aquifer, or by water of a different degree of mineralization that moves into an aquifer from other geologic units.

MAN'S ACTIVITIES THAT AFFECT GROUND-WATER QUALITY

Land Use

Cropland accounts for more than 40 percent of all land use in Nebraska (fig. 5). More corn is grown on these lands than any other row crop, although slightly more wheat than corn is grown on nonirrigated land. Grain sorghum and soybeans are other important row crops. Alfalfa and other types of hay are major crops in northern and central Nebraska. Pasture and rangeland account for about 50 percent of all land use in Nebraska. Most of the approximately 20,000 square miles of Sand Hills is used for raising cattle.

Approximately one-third of all cropland in Nebraska is irrigated, more than four-fifths by ground water and less than one-fifth by surface water. Croplands in the central Platte River basin from Buffalo to Merrick Counties and in the Big Blue River and Little Blue River basins are irrigated predominantly by ground water. Areas in

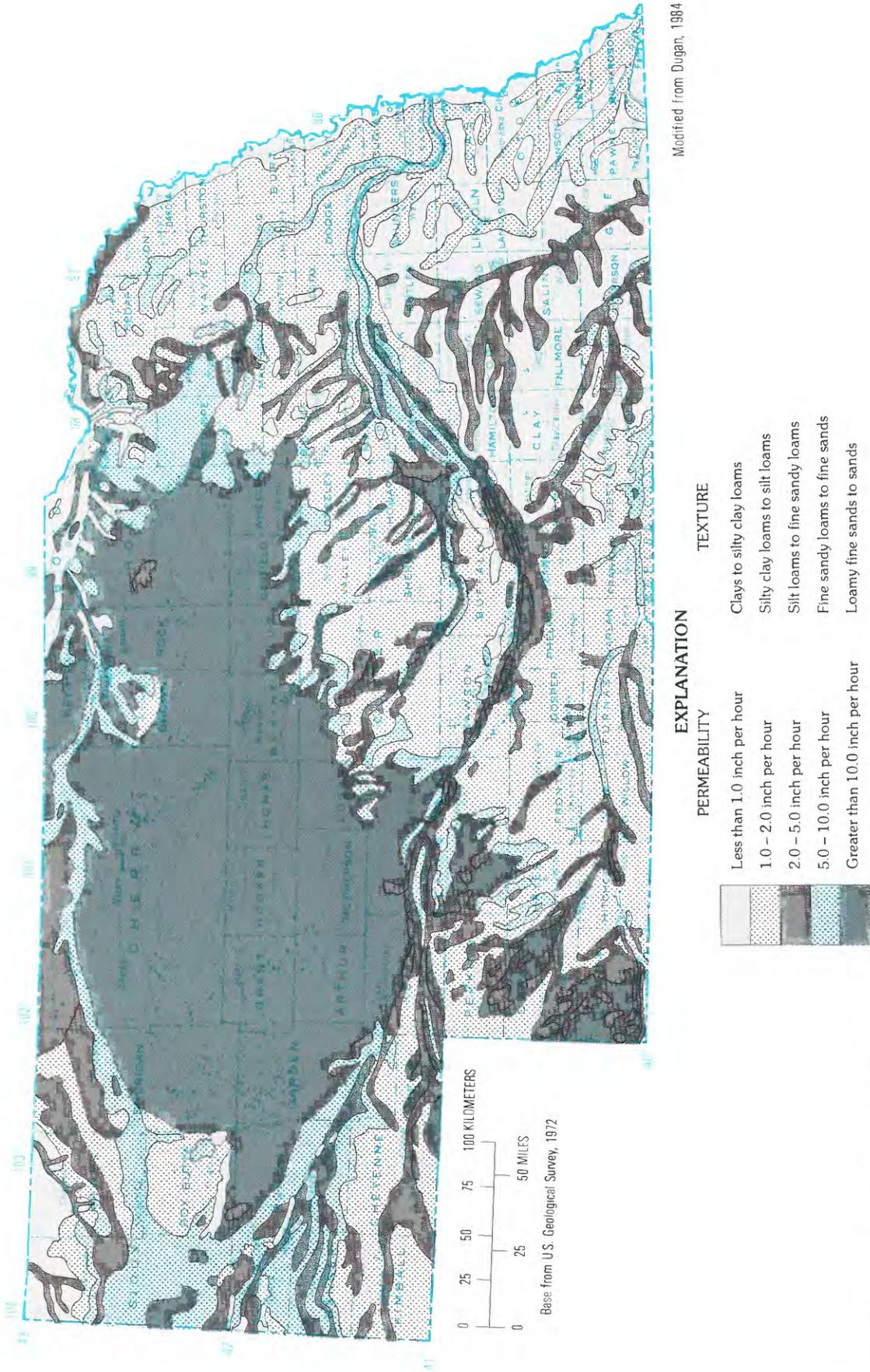


Figure 3. Map showing permeability and texture of soils.

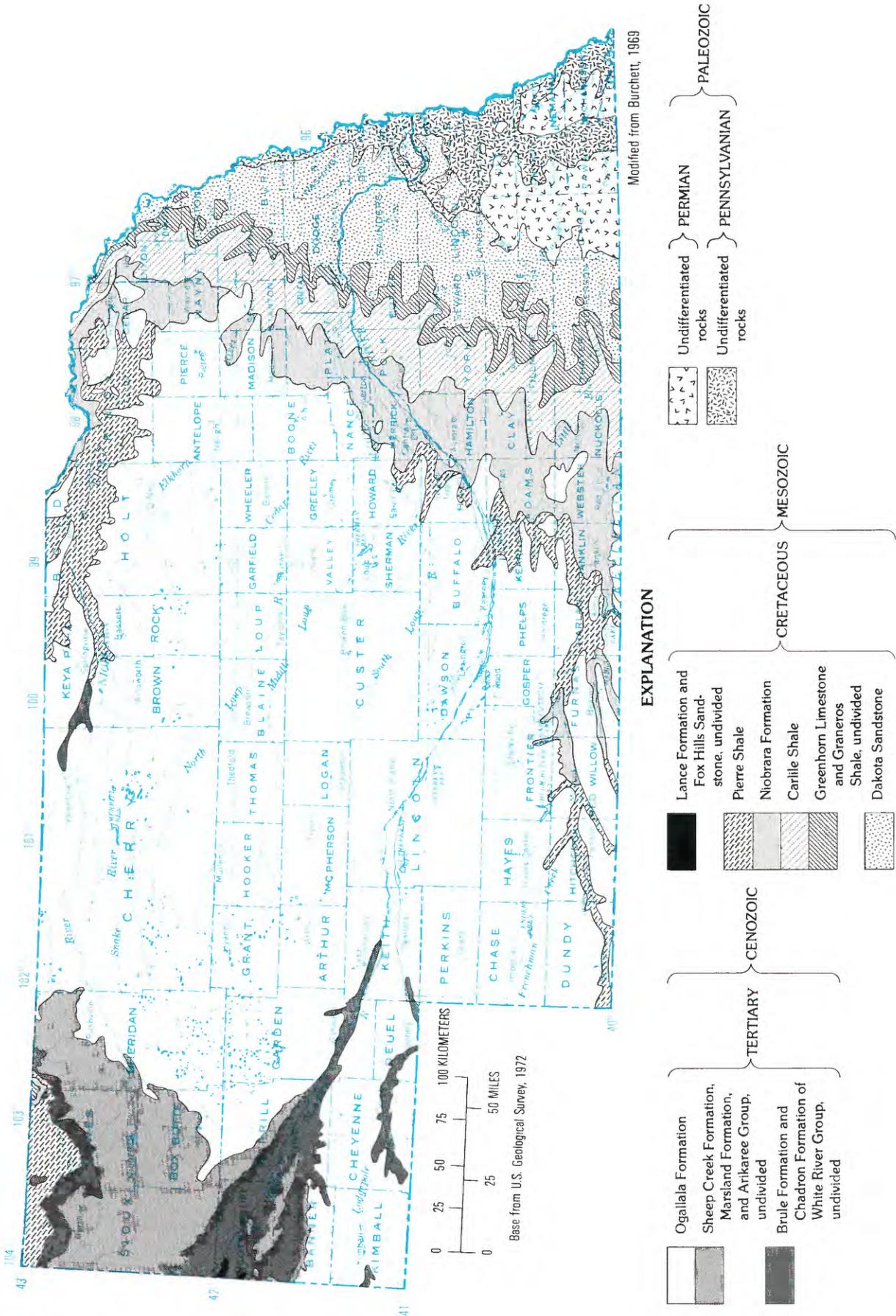
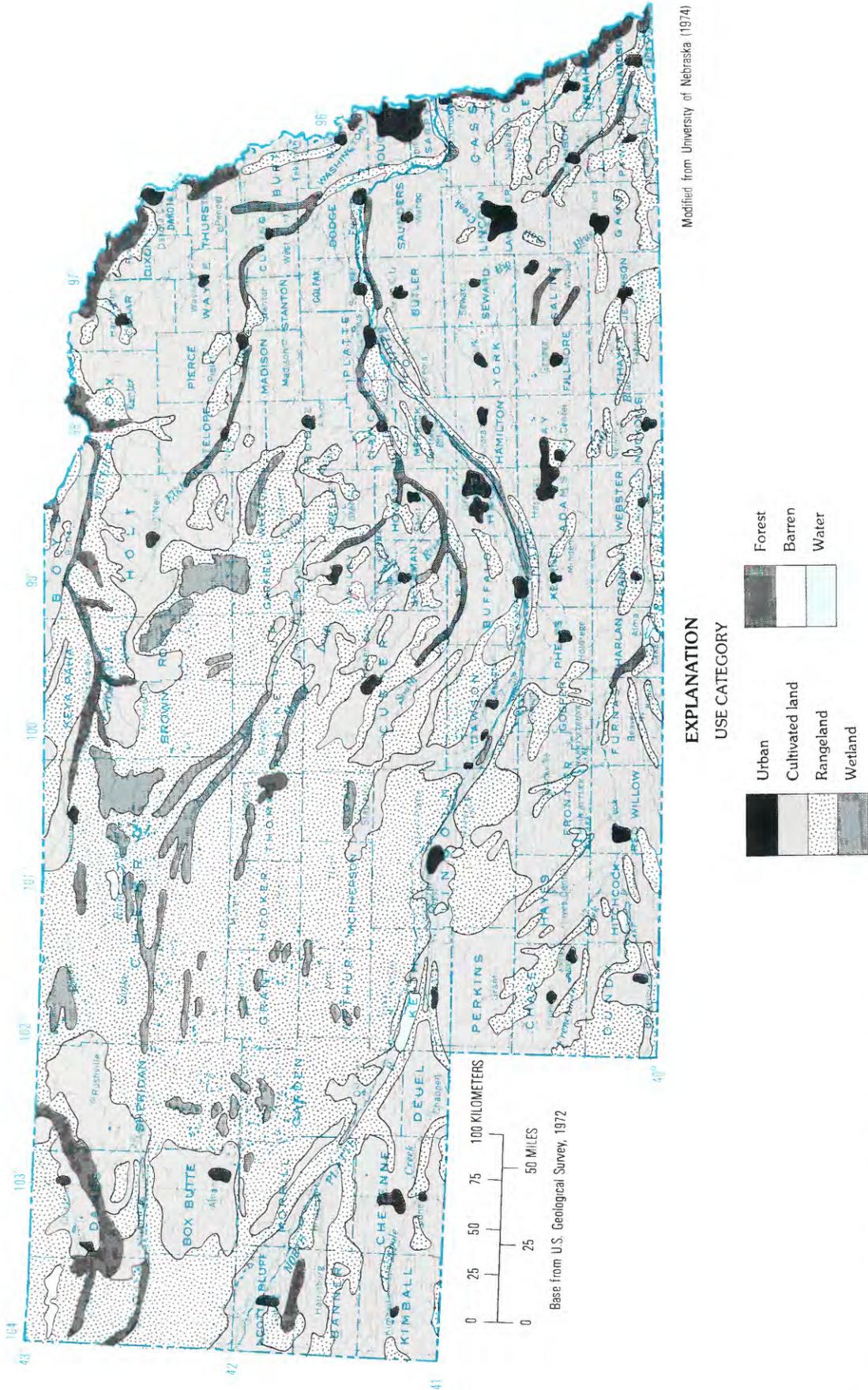


Figure 4. Map showing bedrock geology.



Modified from University of Nebraska (1974)

Figure 5. Map showing land use in 1973.

which irrigation development by ground water has accelerated recently include Holt County, the upper Republican River basin in Dundy and Chase Counties, and Box Butte County. Areas irrigated predominantly by surface water include numerous individual tracts along nearly all streams and major irrigation project areas as follows: The North Platte River and Republican River flood plains; Mirage Flats Project in Sheridan County; Farwell Unit in Sherman and Howard Counties; Ainsworth Unit in Brown County; and Tri-County Project in Gosper, Phelps, and Kearney Counties.

Temporal changes in ground-water quality are related indirectly to land use. Conversion of pastureland and nonirrigated cropland to irrigated cropland is accompanied by increased use of fertilizers and pesticides. Greater use of such agricultural chemicals means a greater possibility of movement of chemical residues into the ground-water supply. Concentrations of nitrate nitrogen of 30 milligrams per liter (mg/L) or more, derived mostly from commercial fertilizers, have been detected in the ground water in Hall, Merrick, and Holt Counties.

Ground-Water Use

Ground-water use in Nebraska increased from about 3,100 million gallons per day during 1970 to about 7,350 million gallons per day during 1980, according to E. K. Steele, Jr. (U.S. Geological Survey, oral communication, 1982) (fig. 6). During 1970, 85 percent of all ground water pumped was for irrigation. This percentage increased to 91 percent during 1980. Whereas domestic, stock, municipal, and industrial uses increased only modestly during this period, irrigation use more than doubled.

Irrigation use increased by an average of 19 percent per year during the first half of the period 1970 to 1980, but by an average of only 5.6 percent per year during the second half of the period. There are several reasons for this. First, costs of energy needed to pump water increased significantly during the second half of the period. Second, the cost of installing new, more sophisticated irrigation systems also increased significantly and investment credit was more difficult to obtain. Third, prices for farm products did not keep pace with increased production costs. Fourth, better irrigation-management practices were implemented by many farmers to conserve water.

During the same 1970–80 period, uses of water for domestic and stock purposes increased at a rate of about 3 percent per year. This is difficult to explain, because the rural farm population decreased during the period. However, the rural nonfarm population increased significantly as more people moved from cities into a rural setting. This influx, coupled with an increase in domestic water-use requirements, probably accounts for the slight rate of increase.

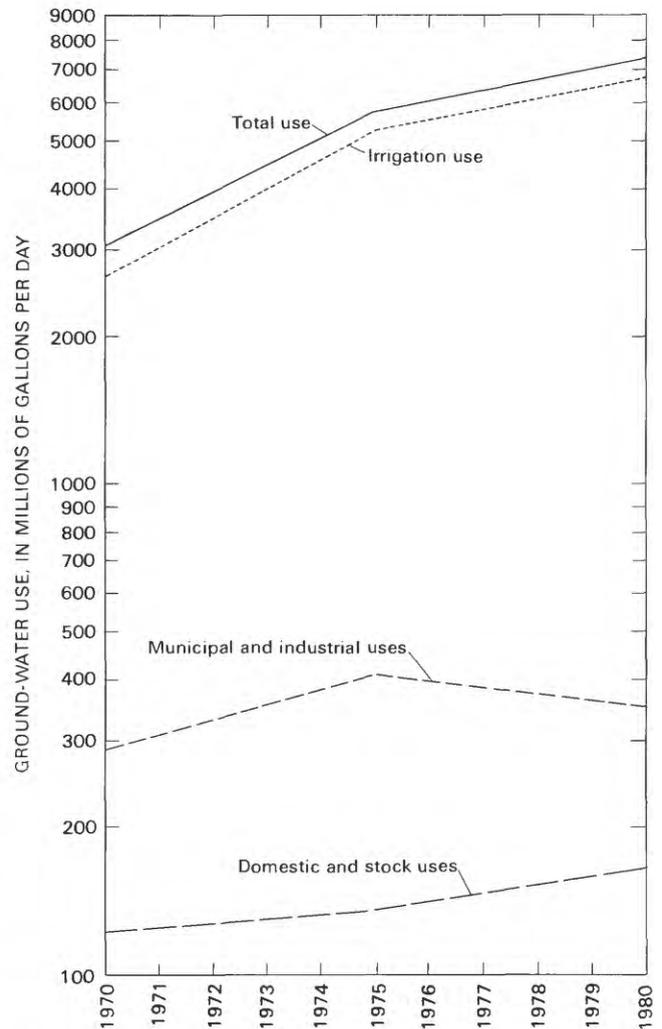


Figure 6. Graph showing ground-water use, 1970–80.

Municipal and industrial use increased by an average of 2.5 percent per year during the period 1970–80. During the first half of the period it increased by 8 percent per year; however, during the last half of the period it actually decreased by 3 percent per year. This decrease is related to increased energy costs. To minimize overhead, resulting from increased energy costs, some industries found ways of decreasing water consumption, such as through water reuse or recycling. In addition, municipal customers have become more cost conscious and have also decreased water use. Because the population of the State stabilized, the total consumption by municipal customers decreased slightly.

The large increase in use of ground water for irrigation during the 1970–80 period affected the quality of ground water in some areas. In Holt County, for example, the number of registered irrigation wells doubled during the period. During this same period, numerous instances of increased nitrate-nitrogen concentrations in ground water became evident where the water table is shallow

and the soil is sandy just north of the Elkhorn River. Increased fertilizer use accompanying irrigation development allowed excess nitrate-nitrogen leached from the root zone to be flushed into the ground-water system.

Irrigation

Ground water is used for irrigating about 85 percent of the more than 7 million acres of land irrigated in Nebraska. Locations of irrigation wells depend on the availability of ground water and on type of land use, and for this reason the density of registered wells varies greatly across the State (Johnson and Pederson, 1982) (fig. 7).

The greatest density of irrigation wells is in Buffalo, Hall, and Merrick Counties just north of the Platte River in south-central Nebraska. Merrick County, which is almost entirely in the Platte River Valley, has an average density of 7.7 registered irrigation wells per square mile. This density may be somewhat misleading because it was computed by counting all wells registered whether they were presently operable or not. Some of the wells have been abandoned or destroyed since they were registered. Furthermore, most wells in the central Platte Valley were of moderate capacity (300 to 500 gallons per minute) designed for gravity-irrigation systems. Some of these have been replaced by fewer but larger capacity (750 to 1,000 gallons per minute) wells designed for center-pivot systems irrigating much larger areas. Whether somewhat misleading or not, this well density indicates that most irrigable land in this area has been developed and that ground water is available and used in large quantities.

The density of irrigation wells also is great in Dawson County, located in the central Platte Valley, and in the Big Blue and Little Blue River basins. Eleven counties in these basins have more than 1,000 registered irrigation wells each. Intensive development of ground water for irrigation also has taken place in parts of Holt County in northeastern Nebraska and in Dundy and Chase Counties in southwestern Nebraska.

Irrigation development has been limited in southeastern and northwestern Nebraska because ground water of adequate quality for irrigation is not available. Irrigation development has been slow in the Sand Hills, where abundant ground water is available, for several reasons. Until recent years, techniques for successfully farming the shallow soils, extremely susceptible to wind erosion, were unknown; techniques for evenly distributing irrigation water over rough ground and maintaining required soil moisture and plant nutrients for crop growth in very sandy soils were inadequate; and a natural reluctance existed on the part of many to change from range to crop farming. With the advent of center-pivot irrigation and new techniques and equipment for farming these easily erodable soils, development of irrigation has proceeded at a more

rapid rate in peripheral areas of the Sand Hills on land previously considered too steeply sloping for gravity irrigation.

The development of the ground-water resource for irrigation has affected the quality of ground water in some areas of the State. Areas of increased nitrate-nitrogen concentrations associated with irrigation development, delineated in Holt County and in the Central Platte area in Buffalo, Hall, and Merrick Counties, are evidence of this. Heavy pumpage coupled with fertilizer and pesticide uses provides a potential for large-scale nitrate-nitrogen and pesticide nonpoint-source contamination of ground water in other areas also.

Water-Level Changes

Predevelopment ground-water levels are the approximate average of water levels that existed in wells prior to significant effect by man's activities. Areas where present (1982) ground-water levels are significantly lower or higher than predevelopment ground-water levels are indicated in figure 8. Irrigation by surface water from some major streams such as the North Platte River began nearly a century ago, and no data exist by which one may estimate with confidence changes in ground-water levels due to this irrigation. However, most irrigation-project developments in Nebraska, whether involving use of surface water or ground water, began after 1940. Because the most recent ground-water level data prior to development were used to define predevelopment water levels in different areas of the State, data from 1940 to 1957 were used to define predevelopment water levels.

Areas of significant water-level decline match quite well with areas of intensive ground-water development indicated in figure 7. The greatest declines have occurred in the Big Blue River basin, including Adams, Clay, Fillmore, and Hamilton Counties; in the upper Republican River basin, including Chase, Dundy, and Perkins Counties; and in Box Butte, Buffalo, Cheyenne, and Holt Counties. Declines of more than 20 feet occurred in these areas.

In contrast, water levels have risen by more than 50 feet in areas south of the North Platte, South Platte, and Platte Rivers between Keith and Kearney Counties, and in Sherman County. Rises in these areas are the result of surface-water irrigation. Surface water is diverted from reservoirs into canal systems and distributed to irrigable land in the project areas. Infiltration from canal seepage and surface spreading supplements natural recharge and has caused significant water-level rises. In parts of Howard and Sherman Counties, fields have become waterlogged as a result of these rises, and it has become necessary to install tile drainage to remove the excess ground water.

Water-level rises may be accompanied by changes

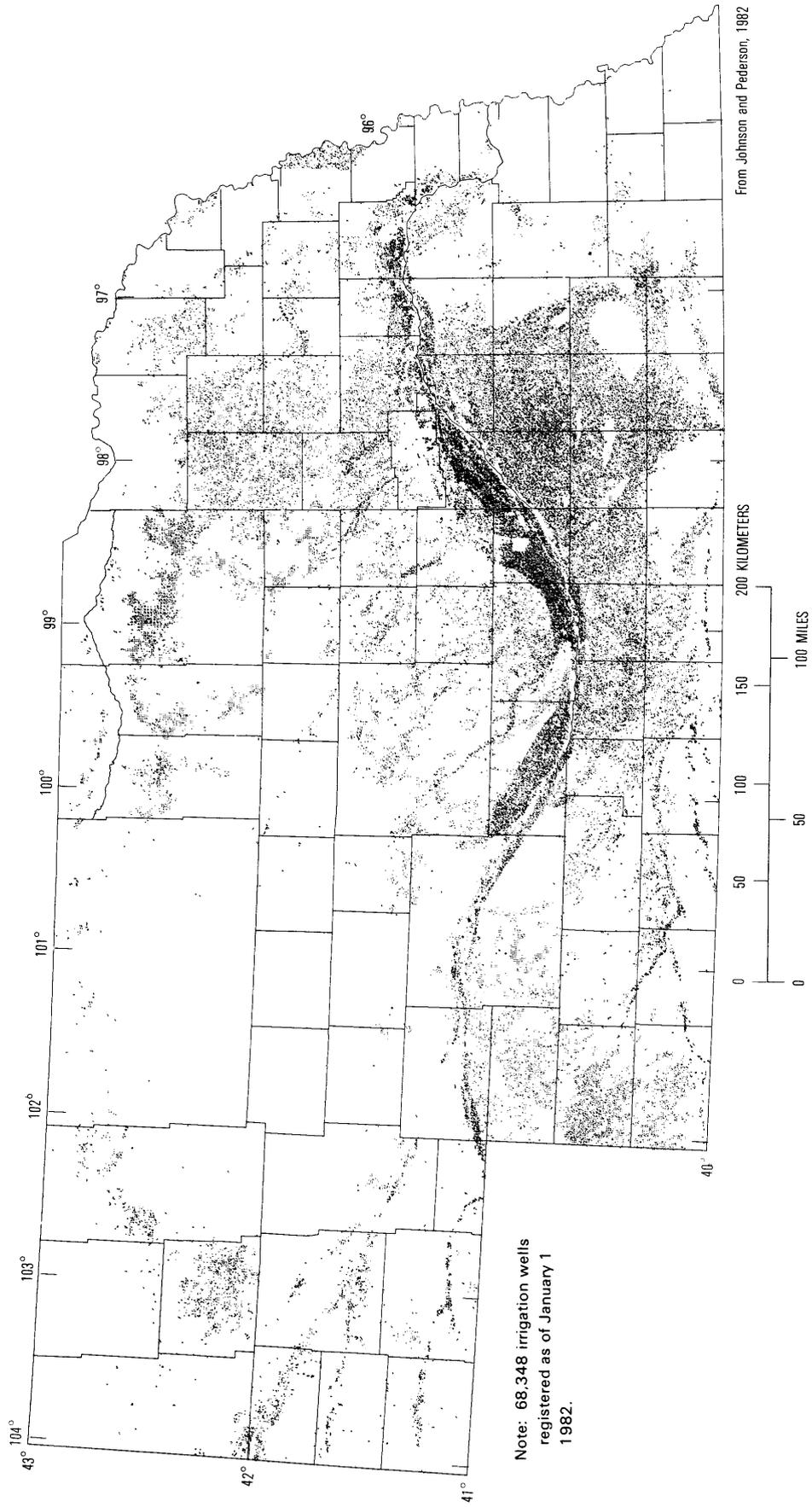
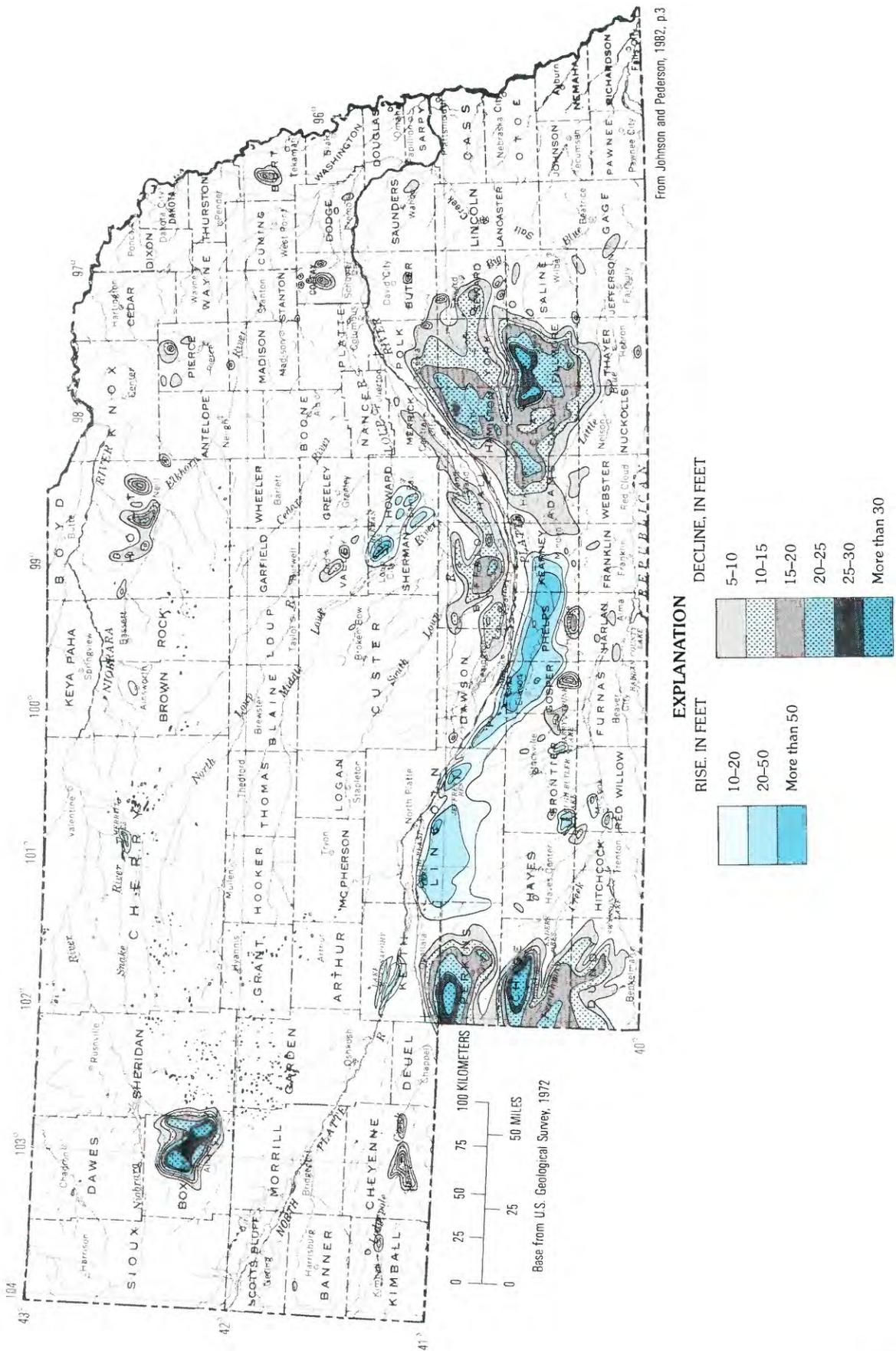


Figure 7. Map showing density of registered irrigation wells, January 1982.



From Johnson and Pederson, 1982, p.3

Figure 8. Map showing significant rises and declines in ground-water levels from predevelopment through 1982.

in ground-water quality. If water-level rises are caused by infiltration of large volumes of surface water that is less mineralized than the native ground water, the quality of the ground water improves. This has occurred in Sherman and Howard Counties. Conversely, if the rises are caused by infiltrating surface water that is more mineralized than the native ground water, the quality of the ground water worsens. This has happened in the area south of the Platte River where water diverted from the Platte River for irrigation in Gosper, Kearney, and Phelps Counties is more mineralized than the native ground water.

Water-level declines caused by excessive pumping also may be accompanied by water-quality changes. Changes caused by water-level declines ordinarily are less than those caused by water-level rises resulting from infiltrating surface water. Reduction in hydraulic head caused by excessive pumping may induce flow of ground water from overlying or underlying formations into the producing unit. If the quality of water from these formations is significantly different, the quality of water in the aquifer may be changed.

Recycling of ground water used for irrigation, coupled with evapotranspiration, may cause some increase in total mineralization of the water. Some of the water pumped from the aquifer for irrigation is lost to overland runoff and some to evapotranspiration, but some returns as recharge to the aquifer. This recharge, as it moves downward through the soil profile and the unsaturated zone, may dissolve chemical constituents, including fertilizer, and carry them to the aquifer. As this process repeats, enrichment in some chemical constituents may take place.

AVAILABLE WATER-QUALITY DATA

Data from eight agencies were examined in the preparation of this report. The agencies which have significant amounts of water-quality information, the type of data, its distribution, and discussions concerning these data are summarized in table 1.

All data used in subsequent parts of this report are from WATSTORE, the U.S. Geological Survey's Water Data Storage and Retrieval System. Data from other sources were not used for several reasons. Data from the Nebraska Department of Health were not used because they represent the quality of water from distribution systems rather than that of the aquifers. In some instances they may represent water from a single well, but in other instances they may represent a blend of water from as many as 30 wells. Data from some other agencies were not used because location or depths of wells sampled were not adequately documented, analytical methods lacked

sufficient accuracy or were not documented, or anions and cations failed to balance within acceptable limits, indicating insufficient accuracy.

Data from the National Uranium Resource Evaluation Program (NURE) were not used because they were received too late. Preliminary evaluation indicates that wells sampled under this program are adequately documented and that analyses were made by approved methods. Project time constraints did not allow evaluation of these data.

Chemical Constituents Summarized and Evaluated

Chemical analyses for nearly 100 different constituents have been performed at least once on some samples of Nebraska ground water. Some constituents, such as calcium and sulfate, have been determined for many years for hundreds of samples, because their importance as dissolved constituents has long been recognized. Furthermore, accurate and precise analytical methods for their analysis have long been available. Other constituents, whose importance has more recently been recognized or for which accurate and precise analytical methods either have been very expensive or have only recently become available, have been measured only a few times. Examples of these constituents include most pesticides.

Specific conductance and the 24 constituents selected for inclusion in this report are presented in table 2. In summarizing data for specific conductance and the 24 constituents for a given aquifer grouping, statistical parameters for specific conductance and for the 6 principal constituents used to determine ionic balance will be presented first. Statistical parameters for dissolved solids and 17 additional constituents, mostly minor elements, will be presented separately. In all the tables summarizing data in statistical format, the number of measurements used to compute the statistics is given under the column heading "N." This number also is the number of wells that were sampled. Some of the wells were sampled and analyzed several times; however, to avoid bias in the descriptive statistics, only measurements of the most recent sample were used.

Statistical terms used in summarizing the water-quality data are defined as follows:

Maximum is the largest value in a group of measurements.

Minimum is the smallest value in a group of measurements.

Mean is the sum of the values of individual measurements divided by the total number of measurements in the group.

Standard deviation is the square root of the sum of the squares of deviations from the mean of all measurements in a group divided by the number of all measurements.

Table 1. Summary of data available for the quality of ground water

Source of data	Sampling period	Number of wells sampled	Number of analyses available	Substances or properties analyzed	Areas represented by the analyses	Remarks
U.S. Geological Survey.	1936 to present (1981).	3,455	5,183	Common constituents, nutrients, trace constituents.	Entire State -- emphasis on project areas.	Mostly well documented; geologic units assigned; data stored in U.S. Geological Survey System. Water from irrigation, domestic, stock, industrial and observation wells.
Conservation and Survey Division, University of Nebraska.	1975 to present (1981).	a 900	a 1,200	Nutrients, pesticides, common constituents.	Holt County; Hall and Merrick Counties; southeastern Nebraska.	Data presently not available for entry into U.S. Geological Survey System. Water from irrigation, stock, domestic, and observation wells.
Nebraska Department of Health.	1963 to present (1981).	(b)	-----	Common constituents, nutrients, trace constituents, pesticides, bacteria.	Entire State.	Public supply distribution systems samples -- only a few analyses on individual wells.
Aeronomy Department, University of Nebraska; Irrigation Water Quality Survey.	1961, 1962, 1971.	1,166	a 1,300	Common constituents.	Entire State.	1,166 irrigation wells sampled during 1961. Some wells resampled in 1962 and 1971. All wells were sampled by landowners, and locations and well depths were not adequately documented for entry into U.S. Geological Survey System. Principal anion-cation balances differ by greater than 5 percent for more than one-half the analyses.
National Uranium Resource Evaluation Program.	1978, 1979.	3,384	3,384	Common constituents, radiochemical constituents, nutrients.	Panhandle; southeastern Nebraska; central Nebraska.	Data has just become available. Magnetic tapes of data acquired recently. Anion-cation balance performed on about 150 analyses -- results are favorable. Not entered in U.S. Geological Survey System. Water from irrigation, domestic, and public supply wells.
Upper Elkhorn Natural Resources District.	1976 to 1981.	116	181	Nitrate.	Holt, Wheeler, Antelope, and Rock Counties.	Semiquantitative determinations made with field kit.
Middle Republican Natural Resources District.	1974 to 1978.	88	300	pH and dissolved solids.	Southwestern Nebraska.	Locations documented by owner's name. Methods not documented.

a Estimated.

b 669 distribution systems sampled.

Median is the value of the middle measurement of an uneven number of ordered measurements, or the mean of the two middle measurements when there are an even number of measurements.

10th percentile is that value in a group of measurements below which 10 percent of the total number of measurements occur.

90th percentile is that value in a group of measurements below which 90 percent of the total number of measurements occur.

Maximums and minimums describe the range of values measured. For specific conductance and the six principal constituents, 10th- and 90th-percentile values are included to provide a more useful range. Values less than the 10th percentile or greater than the 90th percentile com-

monly are outliers representing extremes resulting from unusual hydrologic conditions or from man's activity.

Median (50th percentile) values also are included for specific conductance and for the six principal constituents. When data are highly skewed, frequency distributions represented by percentiles are more useful than means and standard deviations in interpreting data. Median and 10th- and 90th- percentile values also are used to represent graphically the statistical data for the six principal constituents in all but one of the aquifer groupings that follow.

Data for pH and water temperature are not presented in this report. The place for measuring pH has changed from the laboratory to the sampling site during the period of record. Because pH is dynamic, many of the early

Table 2. Chemical properties or constituents summarized and evaluated[μmho , micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter]

Property or constituent	Limit for public supply	Significance
Specific conductance, μmho -----	-----	Used to estimate total dissolved constituents in water.
Calcium, mg/L-----	-----	Principal cation in Nebraska ground water having specific conductance less than 1,000 μmho . Imparts hardness to water. Large ratio of calcium to sodium desirable in water for irrigation.
Magnesium, mg/L----	-----	Significant contribution to hardness. Large ratio of magnesium to sodium desirable in water for irrigation.
Sodium, mg/L-----	-----	Principal cation in Nebraska ground water having specific conductance greater than 1,000 μmho . Large ratio of sodium to calcium and magnesium undesirable in water for irrigation. May be harmful to individuals on a restricted sodium diet.
Alkalinity, mg/L---	-----	Capacity for neutralizing acidity. Attributed mostly to bicarbonate ion which is the principal anion in Nebraska ground water having a specific conductance less than 1,000 μmho .
Chloride, mg/L-----	a 250	Principal anion in Nebraska ground water having a specific conductance greater than 1,000 μmho . Contributes to salinity of irrigation water. May cause salty taste in drinking water.
Sulfate, mg/L-----	a 250	Principal anion in water from some bedrock aquifers and in recharge from irrigation return. Contributes to salinity of irrigation water. Concentrations greater than 250 mg/L may have laxative effect on some people.
Potassium, mg/L----	-----	Important cation in Nebraska ground water. Essential in animal nutrition. Solubility regulated by absorptive properties of the host rock.
Dissolved solids, residue, mg/L----	-----	Represents total concentration of dissolved constituents. Normally, the smaller the concentration, the better the quality of the water for use.
Silica, mg/L-----	-----	A principal constituent in ground water from the sandhills. Essential plant nutrient. Contributes to boiler scale.
Nitrate plus nitrite as N, mg/L-	b 10	May constitute health hazard to infants. Large concentrations in ground water commonly associated with pollution by human activities.
Phosphorous, dissolved, mg/L---	-----	Essential plant and animal nutrient. Not likely to be toxic to animals. Large concentrations may stimulate dense algal bloom in surface waters.
Boron, $\mu\text{g/L}$ -----	-----	Essential plant micronutrient, but excessive concentrations may inhibit plant growth.
Iron, $\mu\text{g/L}$ -----	a 300	Stains laundry and fixtures; causes discoloration and unpleasant taste in beverages. May promote growth of iron bacteria in distribution systems.
Manganese, $\mu\text{g/L}$ ----	a 50	Stains laundry and fixtures; causes discoloration and unpleasant taste in beverages.
Arsenic, $\mu\text{g/L}$ -----	b 50	Toxic to man and animals. Is eliminated very slowly from the human body.
Barium, $\mu\text{g/L}$ -----	b 1,000	Toxic to man, animals, and plants.
Cadmium, $\mu\text{g/L}$ -----	b 10	Toxic to man and animals. Cumulative in the human body.
Chromium, $\mu\text{g/L}$ -----	b 50	May be toxic to man and animals.
Copper, $\mu\text{g/L}$ -----	a 1,000	Essential nutrient for man, animals, and plants. Imparts metallic taste to water.
Lead, $\mu\text{g/L}$ -----	b 50	Toxic to man, animals, and plants. Cumulative in the human body.
Mercury, $\mu\text{g/L}$ -----	b 2	Toxic to man and animals.
Selenium, $\mu\text{g/L}$ -----	b 10	Essential micronutrient but toxic to man and animals in concentrations slightly greater than essential.
Silver, $\mu\text{g/L}$ -----	b 50	May cause skin discoloration, but not at concentrations likely in water from natural sources.
Zinc, $\mu\text{g/L}$ -----	a 5,000	Essential plant and animal nutrient. May impart a metallic taste to water.

a Secondary drinking-water regulations established by U.S. Environmental Protection Agency (1977).

b Primary drinking-water regulations established by U.S. Environmental Protection Agency (1976).

measurements may not adequately represent in-situ pH. As it is impossible to determine whether early pH measurements in WATSTORE were made in the laboratory or at the sampling site, pH data are not included. Temperature data were not included in the summary because many values included in WATSTORE do not appear to be representative of the actual in-situ water temperature.

PRINCIPAL AQUIFER GROUPINGS

Holocene-Pleistocene Aquifers

Holocene and Pleistocene deposits range in thickness from zero in small badland areas of northwestern Nebraska to about 500 feet in the Sand Hills. These deposits include alluvium, dune sand, terrace deposits, sand and gravel, loess, and glacial drift (fig. 9).

During Pleistocene time, glacial ice sheets advanced into and retreated from the northern United States several times. The ice sheets advanced into Nebraska each time; the first two times they covered most of the eastern part of the State. Successive deposits of fine-grained glacial till intermixed with pebbles and boulders derived from Precambrian and younger deposits to the north were left in place as the ice melted. Where the first glacier moved across pre-glacial valleys, sand and gravel were deposited along with till. Westward limit of glaciation was a line approximately from Knox County to Jefferson County.

As the glaciers advanced, they dammed and diverted southward across the eastward-trending drainages. These drainages deposited thick layers of sand and gravel throughout large areas of central Nebraska, including the present Big Blue and Little Blue River basins, the present central Platte River basin, and the Sand Hills.

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Following the first two glacial advances, a combination of factors led to the deposition of loess over much of southern, central, and eastern Nebraska. Several sources for the loess deposits are hypothesized, including the glacial till itself—the White River Formation, or Group where divided, of Tertiary age in South Dakota and western Nebraska, the South Dakota Badlands, the tablelands of eastern Colorado and Wyoming, the sandhills of Nebraska, and river valleys or alluvial deposits in beds of dry and intermittent streams.

The Nebraska sandhills, which are Holocene in age, cover an area of almost 20,000 square miles. Dunes 100

to 300 feet high are separated by interdune valleys in which the dune sand ranges in thickness from about 25 to 75 feet. The sandhills are eolian in origin and may have been derived from alluvium deposited by streams flowing across the region. The dune sand is underlain in the eastern part of the sandhills by sand and gravel deposited during the earliest glacial advances.

Alluvial deposits, Holocene in age, comprise the flood plains of present-day streams. These are the youngest geologic units in Nebraska.

Sources of most ground water derived from Holocene and Pleistocene deposits are sand and gravel deposits, dune sand where saturated, and alluvium. Loess, terrace lands, and till in most places are unsaturated or, if saturated, are so fine-grained that they do not provide sufficient water for wells. The Pleistocene sands and gravels in the Big Blue and Little Blue River basins, the central Platte River basin, south-central Nebraska, and the loess hills that border the sandhills on the southeast yield abundant supplies of water for irrigation, domestic, stock, and public-supply uses. More than one-half of all ground water pumped for irrigation in Nebraska comes from these Pleistocene sands and gravels. In the Nebraska sandhills, the saturated dune sand and Pleistocene sands and gravels, together with the underlying Ogallala Formation, also provide an abundance of water that is chemically suitable for all uses.

Water is less readily obtainable from Holocene and Pleistocene deposits in the Nebraska Panhandle, southwestern Nebraska, and the glaciated area of eastern Nebraska than elsewhere in the State. In much of the Panhandle, Pleistocene deposits are absent or thin so that water from them is available in small quantities only from alluvial or terrace deposits. In southwestern Nebraska water is available only from alluvial deposits. However, most of both these areas are underlain by Tertiary deposits, which provide abundant water.

Little water is available directly from the glacial till in eastern Nebraska. Here the principal sources of water are sands and gravels in ancient channels at the base of the till and from Holocene alluvial deposits along existing streams. Small quantities of water of variable quality may be found, however, in small lenses of sand within the till. These deposits generally provide water in quantities only minimally sufficient for domestic supplies.

Recharge to all water-bearing Pleistocene deposits in Nebraska is locally derived. Sources are infiltrating precipitation and water that moves from flowing streams, canals, lakes, and ponds into alluvial aquifers.

The quality of water from Holocene and Pleistocene deposits generally is variable. Water quality is affected by recharge from surface-water irrigation projects or recharge from streams where they lose water into the deposits. In some places, especially where the depth to water is shallow, the quality of ground water is affected

largely by local point sources of contamination such as feedlots, or nonpoint sources such as fertilized croplands.

Statistics

Water-quality data for specific conductance and for six principal constituents used to determine ionic balance in water and to make geochemical-equilibrium computations are summarized in table 3. Data for dissolved solids, potassium, silica, 2 nutrients, and 13 trace constituents are summarized in table 4. The constituents summarized represent only part of the total number of constituents for which analyses have been performed. Some constituents, such as pesticides, have been measured only a few times; summarizing these data by use of statistics would be meaningless. Temperature and pH data were not summarized for the reasons given in the section "Chemical constituents summarized and evaluated."

Outliers generally are significant in evaluating water-quality data because they indicate unusual hydrologic conditions. For example, of 38 wells completed in

Holocene and Pleistocene aquifers sampled in Lancaster County, specific-conductance values for 16 exceed the 90th-percentile value of 1,070 micromhos per centimeter at 25° Celsius. Some of these wells are close to the City of Lincoln landfill, and the specific conductance of water from them is the result of point-source contamination from the landfill. Some of these wells may be affected by the movement of saline water from underlying Mesozoic and (or) Paleozoic deposits into the Holocene and Pleistocene deposits or by the movement of saline water from Salt Creek into the flood plain alluvium. Sodium, chloride, and sulfate statistical data are also highly skewed as a result of very large concentrations of these constituents in water from the same 16 wells in Lancaster County.

Water-Quality Diagrams

Diagrams in figure 10 represent individual statistical parameters for the quality of water from Holocene and Pleistocene aquifers. For example, the diagram labeled

Table 3. Statistical summary of specific conductance and principal constituents in water from Holocene and Pleistocene aquifers

[N, number of measurements; μ mho, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter]

Property or constituent and unit	N	Maximum	Minimum	Mean	Standard deviation	Median	10th percentile	90th percentile
Specific conductance, μ mho-----	1,556	7,010	52	650	496	555	228	1,070
Calcium, dissolved, mg/L-----	1,265	485	1.5	82	52	76	24	130
Magnesium, dissolved, mg/L-----	1,259	160	.4	16	13	13	3.9	30
Sodium, dissolved, mg/L-----	1,445	1,310	.3	32	66	20	6.8	60
Alkalinity as CaCO ₃ , mg/L-----	1,287	689	12	213	92	214	76	326
Chloride, dissolved, mg/L-----	1,342	1,680	0	20	79	8.1	1.2	34
Sulfate, dissolved, mg/L-----	1,349	4,300	0	99	220	36	5.1	217

Table 4. Statistical summary of selected additional constituents in water from Holocene and Pleistocene aquifers

[N, number of measurements; mg/L, milligrams per liter, µg/L, micrograms per liter]

Constituent and unit	N	Maximum	Minimum	Mean	Standard deviation
Dissolved solids, residue at 180° Celsius, mg/L-----	860	3,670	56	437	341
Potassium, dissolved, mg/L-----	1,114	66	1.2	8.2	5.4
Silica, dissolved, mg/L-----	1,049	96	.6	39	13
Nitrate + nitrite as N, mg/L---	477	100	0	5.3	10
Phosphorous, dissolved, mg/L---	190	1.2	.01	.15	.15
Boron, dissolved, µg/L-----	1,005	2,500	0	89	116
Iron, dissolved, µg/L-----	560	59,000	0	322	1,865
Manganese, dissolved, µg/L-----	392	17,000	0	176	918
Arsenic, dissolved, µg/L-----	97	15	0	5.0	3.8
Barium, dissolved, µg/L-----	64	500	0	177	124
Cadmium, dissolved, µg/L-----	115	9	0	1.2	1.6
Chromium, dissolved, µg/L-----	93	90	0	8.1	13
Copper, dissolved, µg/L-----	328	400	0	7.8	28
Lead, dissolved, µg/L-----	123	46	0	3.3	6.7
Mercury, dissolved, µg/L-----	96	9.0	0	.36	.94
Selenium, dissolved, µg/L-----	162	480	0	9.8	40
Silver, dissolved, µg/L-----	59	2	0	.1	.4
Zinc, dissolved, µg/L-----	310	7,600	0	156	639

“Maximum” indicates the greatest concentration, converted to milliequivalents per liter, detected in any of the samples from these aquifers for each of the constituents for which it is constructed. Accordingly, these diagrams are composites of many analyses rather than representations of individual analyses; this represents a departure from the traditional use of this type of diagram.

Traditionally, diagrams such as these are constructed from individual analyses with the result that a balance exists between ion concentrations on the two sides of the vertical axis. The cations (calcium, magnesium, and sodium plus potassium) to the left of the axis ordinarily are balanced by the anions (bicarbonate plus carbonate, sulfate, and chloride) to the right. Units are milliequivalents per liter, which represent actual combining ratios of constituents. They are derived by dividing constituent concentration, in milligrams per liter, by a factor composed of the molecular weight of a constituent divided by its oxidation state.

The procedure used to construct these diagrams was similar to that just described, but because each diagram represents only one aspect, such as maximum, of the entire set of water-quality data, concentrations of constituents on one side of the vertical axis may not balance those on the other. Nevertheless, these diagrams provide

a useful means of examining median and percentile water-quality types, of examining the ways that outlying values affect overall water-quality types, and of examining the variability in water quality as shown by outlier values. They also may be useful in identifying aquifer source if the source is uncertain.

From the diagrams, it can be seen that water in Holocene and Pleistocene deposits is nearly always of the calcium bicarbonate type. In only a few analyses, mostly of water affected by man’s activities, do ions other than calcium and bicarbonate predominate. Specific conductance is less than 1,000 µmho/cm in nearly 90 percent of all water samples from Holocene and Pleistocene aquifers. Considering the relative abundance of calcium in soils and the ease of conversion of carbon dioxide to bicarbonate in Nebraska soils, it is reasonable that calcium bicarbonate should be the predominant chemical type of most near-surface ground water in Nebraska.

The individual water sample that had the maximum specific conductance of 7,010 µmho/cm also had the maximum sodium and sulfate concentrations. Many wells in northern Nebraska, including the well from which this sample was collected, are developed in very shallow basal sands and gravels resting directly on bedrock of the Pierre Shale. Where basal sand and gravel deposits are thin so that recharge to wells is small, wells sometimes are drilled into the shale to provide a storage reservoir. Water from the basal sand and gravel that accumulates in such reservoirs often dissolves high concentrations of soluble constituents from the shale. This combination of circumstances seems to account for high specific conductances and high concentrations of sodium and sulfate in water from several wells in Dawes and Boyd Counties.

Dissolved Solids

A well producing from Pleistocene deposits in the sandhills in Cherry County yielded water having the minimum dissolved-solids concentration of 56 milligrams per liter (mg/L). A well producing from Holocene deposits in Lancaster County, but affected by the movement of saline water from Paleozoic or Mesozoic deposits into the alluvial deposits, yielded water having the maximum dissolved-solids concentration of 3,670 mg/L.

Water having dissolved-solids concentrations more than 2,250 mg/L occurs only in part of Lancaster County (fig. 11). Water having dissolved-solids concentrations from 751 to 2,250 mg/L occurs in small areas widely distributed throughout the State. These include areas underlain by alluvium in the South Platte, central Platte, and Republican River valleys. During certain times of the year, the South Platte River carries return flow from extensively irrigated areas upstream. During these times, South Platte River water is the most mineralized

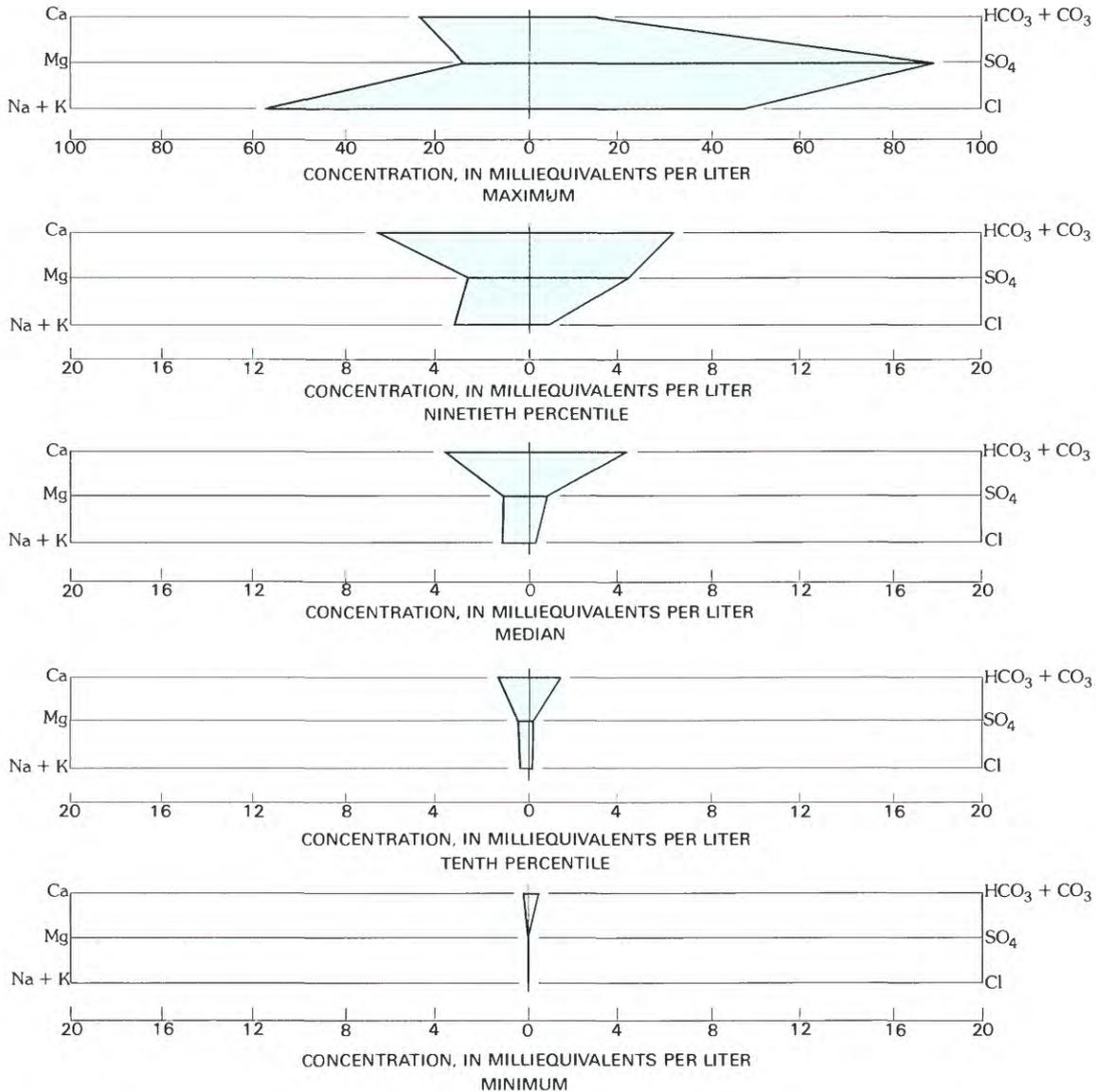


Figure 10. Diagrams of statistics on quality of water from Holocene and Pleistocene aquifers.

streamflow moving into Nebraska, averaging about 1,400 mg/L of dissolved solids at the Colorado-Nebraska border. As the water from the river is used in irrigation, it recharges the alluvial deposits. Dissolved-solids concentrations in ground water in the South Platte River flood plain, therefore, are similar to mean dissolved-solids concentrations in the South Platte River. A similar situation occurs in the central Platte Valley.

Dissolved-solids concentrations in water from saturated Holocene and Pleistocene deposits in the sandhills, with the exception of a small area in Grant and Hooker Counties, are less than 250 mg/L. Most soluble material, if ever present, in the unsaturated dune sand and soils has already been removed. Rapidly infiltrating recharge does not become very mineralized as it moves to the zone of saturation.

Although Holocene and Pleistocene deposits cover nearly the entire State, they are not used for water supplies everywhere, because in some areas they are not saturated and, therefore, are not a source of ground-water supply. In other areas, water from these deposits are used but data are insufficient to indicate what the dissolved-solids concentrations are. In eastern Nebraska, glacial till yields only small quantities of water for domestic supplies, and Pleistocene deposits that produce sufficient water for irrigation are limited to a few buried channels.

Dissolved solids is a measurement of all the dissolved chemical constituents in water. The concentrations, in milligrams per liter, of individual constituents cumulatively approximates the measured dissolved-solids concentration. Because of the ease with which specific conductance can be measured, it commonly is used to estimate

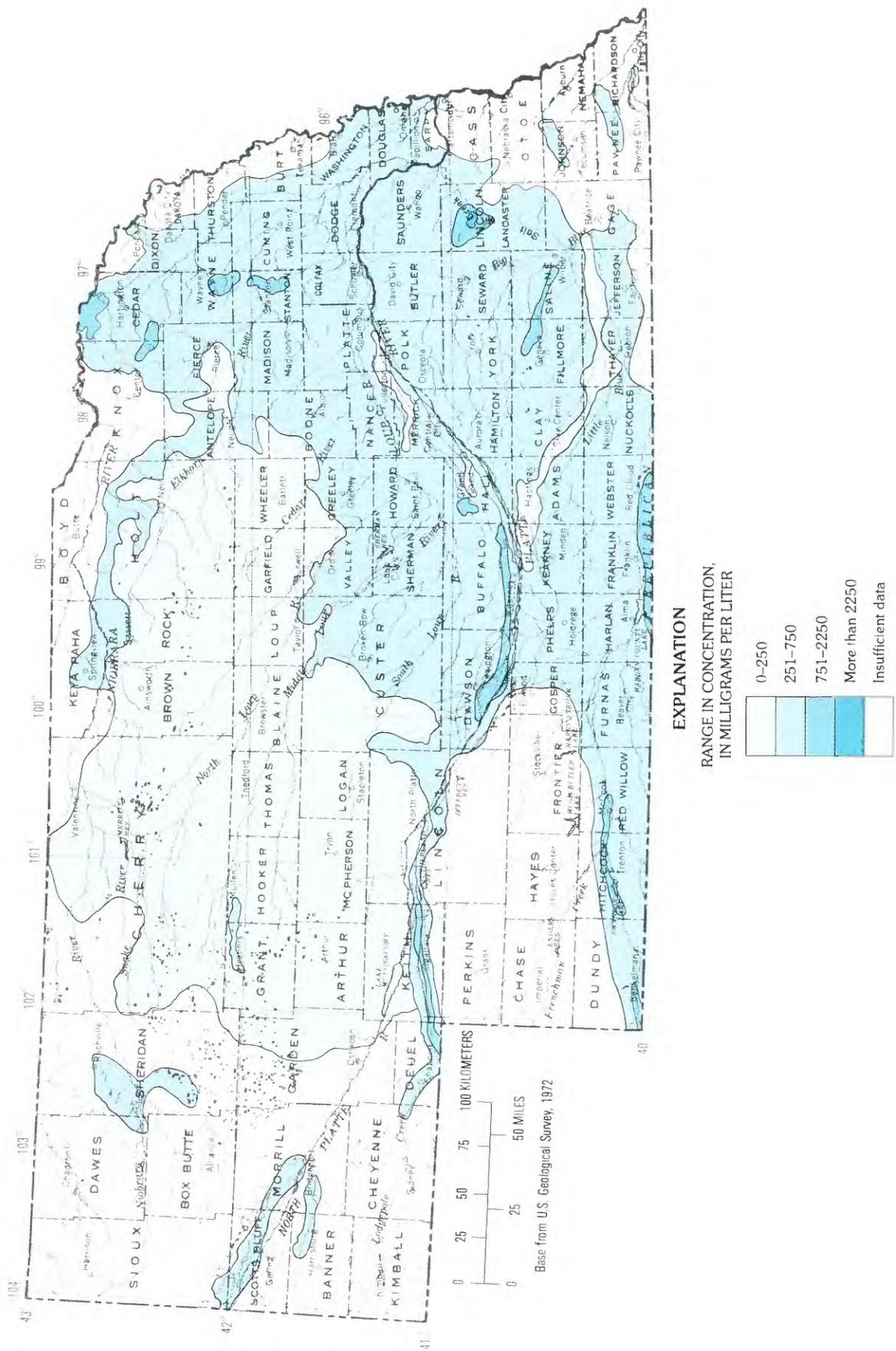


Figure 11. Map showing dissolved-solids concentrations in water from Holocene and Pleistocene aquifers.

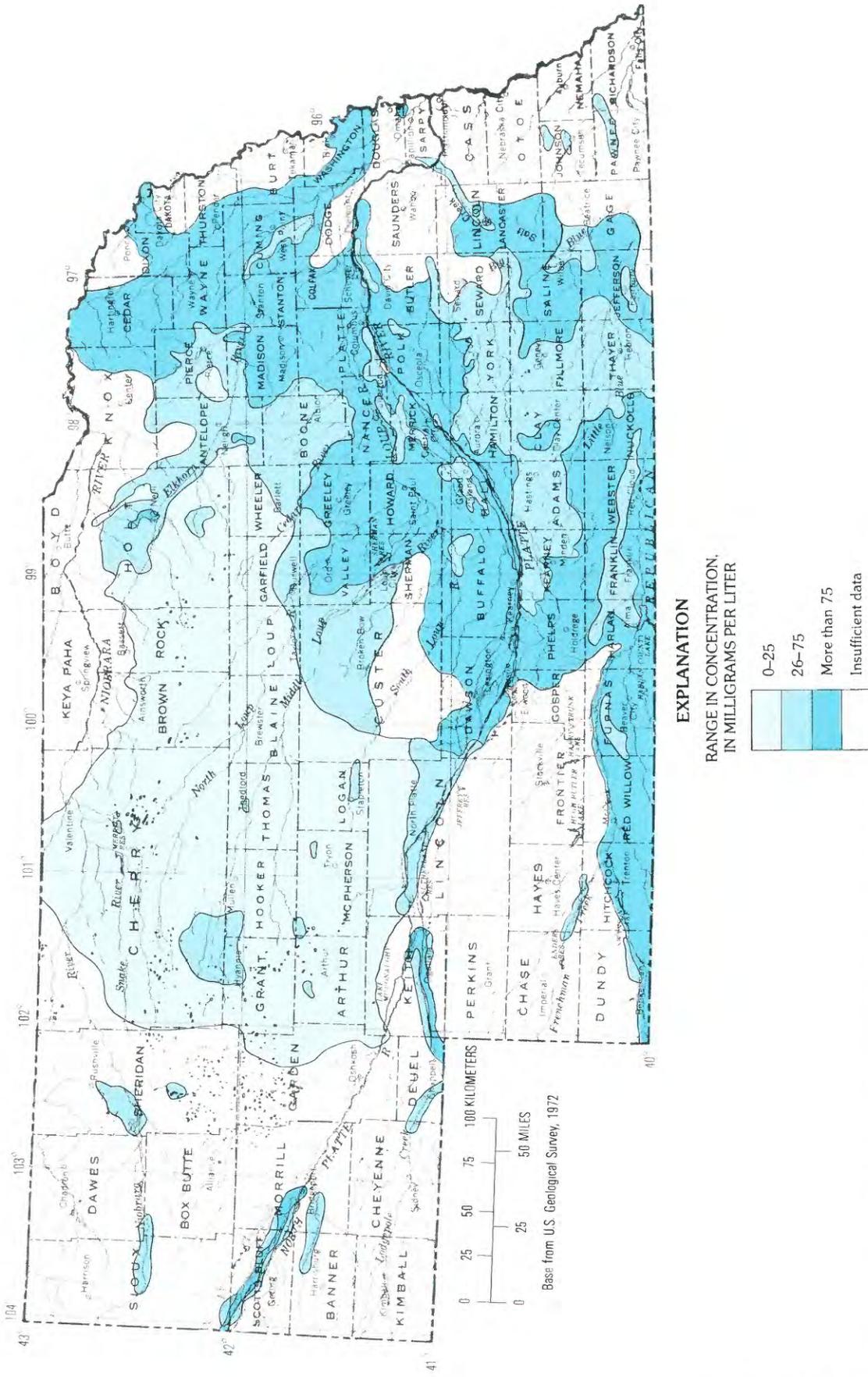


Figure 12. Map showing calcium concentrations in water from Holocene and Pleistocene aquifers.

the dissolved-solids concentration. It has been demonstrated many times that for natural water in which calcium and bicarbonate are the principal constituents, the ratio of dissolved solids, in milligrams per liter, to specific conductance, in micromhos per centimeter at 25° Celsius, ranges from 0.65 to 0.70.

Calcium

The mean calcium concentration for 1,265 samples of water derived from Holocene and Pleistocene aquifers is 82 milligrams per liter (mg/L). A maximum concentration of 485 mg/L was measured in water from a well developed in a small sand lens in glacial till in Pawnee County; a minimum concentration of 1.5 mg/L was measured in water from a well in Saline County.

In the sandhills, calcium concentrations in ground water usually are less than 25 mg/L (fig. 12). In areas bordering the sandhills on the east and south, and in part of the Big Blue River basin, calcium concentrations are variable but generally range between 26 and 75 mg/L. In most of the rest of the State where sufficient data are available, calcium concentrations are greater than 75 mg/L. Calcium probably also is the principal cation in water from Holocene and Pleistocene deposits in those areas of the State where insufficient data now exist to map concentrations.

Calcium is derived from carbonate rocks such as limestone, from evaporite deposits such as gypsum, and from calcareous cementing material in sandstone. Minerals composing soil material in most of Nebraska are enriched in calcium. Along with magnesium, calcium is a principal source of hardness in water. Calcium solubility is controlled mostly by chemical equilibria involving carbonates.

Alkalinity

Concentrations of alkalinity-causing constituents, expressed as an equivalent concentration of calcium carbonate, generally are less than 100 milligrams per liter (mg/L) in water from Pleistocene aquifers in the sandhills (fig. 13). Of the 128 wells for which alkalinity in water from the wells was less than the 90th-percentile value of 76 mg/L, all but 7 are in the sandhills. Alkalinity is less than 100 mg/L in water from a small area of sandhills in Pierce County and in water from an area of sandhills outliers on the north side of the Platte River, mostly in Merrick County. Alkalinity of more than 300 mg/L exists in ground water in southwest Nebraska along and south of the Republican River, in ground water in the central Platte River basin, and in ground water in much of the glaciated area of eastern Nebraska.

Bicarbonate ion, which is the principal cause of alkalinity in Nebraska ground water, also is the principal anion in most ground water from Holocene and Pleistocene aquifers. The chief sources of bicarbonate in Holocene and Pleistocene aquifers are atmospheric carbon dioxide and carbon dioxide formed from decaying organic matter in soils. Atmospheric carbon dioxide, dissolved in infiltrating water, reacts with basic material in the soil, such as carbonates, to form bicarbonate ion. Measurable concentrations of carbonate ion also exist in water if the pH exceeds 8.3. Other anions, such as phosphate or silicate ions, may contribute slightly to alkalinity.

Alkalinities generally are less than 100 mg/L in the sandhills area probably because of the relative lack of soluble carbonaceous materials in the soils and subsoils. In contrast, abundant carbonaceous material providing a plentiful source of alkalinity exists in the clayey soils and subsoils of the glaciated area of eastern Nebraska.

In parts of the State, data are insufficient to map alkalinity concentrations. Although Holocene and Pleistocene deposits cover nearly all of Nebraska, generally they are thin or unsaturated in most of the Panhandle, except for the North Platte River Valley. In southwestern Nebraska these deposits are thin, and in many places they are not saturated. The underlying Tertiary deposits provide water for most of the Panhandle and southwestern Nebraska. In eastern Nebraska, Holocene and Pleistocene deposits are restricted to buried channels beneath the till, stream alluvium, and small sand lenses within the till. Alkalinity data available for these areas are insufficient for delimiting areas; however, such data as exist indicate that the alkalinity of water from stream alluvium and sand lenses probably exceed 300 mg/L most places.

Sulfate

Concentrations of sulfate generally are less than 10 milligrams per liter (mg/L) in water from Holocene and Pleistocene aquifers in the sandhills because no extensive source of sulfate occurs in the area (fig. 14). Concentrations of 0.0 mg/L were reported in water from several wells in Cherry County. The maximum sulfate concentration of 4,300 mg/L was in water from a well in Dawes County.

Sulfate concentrations exceed 100 mg/L in water from alluvium of the North Platte, South Platte, Platte, and Republican River Valleys. Alluvial deposits in all these valleys are recharged by water from the rivers, canals, and reservoirs. Rivers in these areas are all used extensively for irrigation and receive irrigation return flow enriched in sulfate. Sulfate concentrations exceed 100 mg/L in water from these streams, except during periods of flood flow and snowmelt runoff.

Sulfate concentrations also exceed 100 mg/L in ground water from the Tri-County area of Gosper, Phelps, and Kearney Counties. Much of the irrigation in this area is with water diverted from the Platte River. In parts of the area, ground-water levels have risen by more than 50 feet, and the ground water has taken on quality characteristics similar to those of the diverted surface water.

Sulfate concentrations exceed 100 mg/L in some areas of northeastern Nebraska. Quality of water in alluvial and Pleistocene deposits in Cedar, Knox, and Wayne Counties is affected by contact with glacial till, which contains substantial quantities of sulfate. Some of the Pleistocene deposits may be reworked Cretaceous rocks, some of which also may be a source of sulfate.

Metallic sulfides in igneous and sedimentary rocks and gypsum or other evaporite deposits are the primary geologic sources of sulfate in ground water. Metallic sulfides are oxidized during weathering to produce sulfate. These may represent principal sources of sulfate in the ground water of Nebraska in areas other than those where sulfate is derived from streamflow or irrigation return flow.

Concentrations of sulfate ranging between 1,000 and 2,000 mg/L have been detected in ground water from several wells producing from Holocene and Pleistocene aquifers in Boyd County. However, water from nearby wells also producing from Holocene and Pleistocene aquifers contained sulfate in concentrations of less than 100 mg/L. Water having large concentrations of sulfate probably is from wells producing from thin Pleistocene sand and gravel deposited directly on bedrock of Pierre Shale of Cretaceous age. Because recharge to these wells is slow, wells are drilled deeper than otherwise necessary into the bedrock to provide a storage reservoir for the well.

The Pleistocene deposits are composed partly of shale and reworked shale rich in sulfides, which when oxidized produce sulfate. Because of contact with shale and reworked shale in the aquifer and with shale in the underlying bedrock and in the walls of the well reservoirs, water from these wells has large concentrations of sulfate. Water from nearby wells having small concentrations of sulfate probably is derived from valley alluvium neither derived from nor in direct hydrologic contact with shale. Data are insufficient for delimiting sulfate concentrations in water from Holocene and Pleistocene aquifers in Boyd County.

Tertiary Aquifers

The Ogallala Formation, the Sheep Creek Formation, the Marsland Formation, and the Arikaree Group undivided (herein called Arikaree Group) of Miocene age

and the Brule and Chadron Formations of the White River Group of Oligocene age are the principal aquifers in western and central Nebraska (fig. 15). With major exceptions of the northwestern part of the Panhandle and the Republican River Valley, the Ogallala Formation covers the western two-thirds of the State with continental water-bearing deposits of loosely cemented limestone and sandstone, gravel, ash deposits, and sand, and ranges in thickness from 0 to 400 feet (Condra and Reed, 1959). The most widespread of the Tertiary deposits in Nebraska, the Ogallala, also is the most used as a source of ground water. Probably more than one-third of all registered irrigation wells in Nebraska obtain water from the Ogallala.

The Arikaree Group, located in the northern part of the Panhandle, is composed of sand interlain with sandy silt and concretions and may be as much as 500 feet thick. The Arikaree Group supplies abundant water for irrigation in Box Butte, Sioux, southern Dawes, and northern Sheridan Counties.

The White River Group includes two water-bearing formations not differentiated in figure 15. The upper one, the Brule Formation, is composed principally of silty clays with ash deposits and some channel sandstones. Generally it supplies water in quantities sufficient only for small-yield wells such as domestic or stock wells. However, in some areas, as a result of fracturing, the Brule may yield sufficient quantities of water for irrigation. Where overlain by the Arikaree Group, water from the Brule is of similar quality to water from the Arikaree, indicating recharge of the Brule from the Arikaree. The Brule is as much as 600 feet thick in places.

Underlying the Brule Formation is the Chadron Formation. Ranging in thickness from 50 to 100 feet, the Chadron is composed of silt and clay overlying a basal sandstone. It is not developed in most areas, but in a few locations, chiefly in Sioux and Dawes Counties, it is the only source of ground water. Water in the Chadron is confined and some flowing wells exist in western Dawes County.

Statistics

Water-quality information for specific conductance and six principal chemical constituents for the Ogallala Formation, Arikaree Group, Brule and Chadron Formations, described previously, are summarized in table 5. Data for dissolved solids, potassium, silica, 2 nutrients, and 13 trace constituents, most of which have public-health significance, are summarized in table 6. Because some of the 18 constituents have been measured relatively few times, results from all four Tertiary aquifers are combined in the table.

Measurements of constituents or properties, other

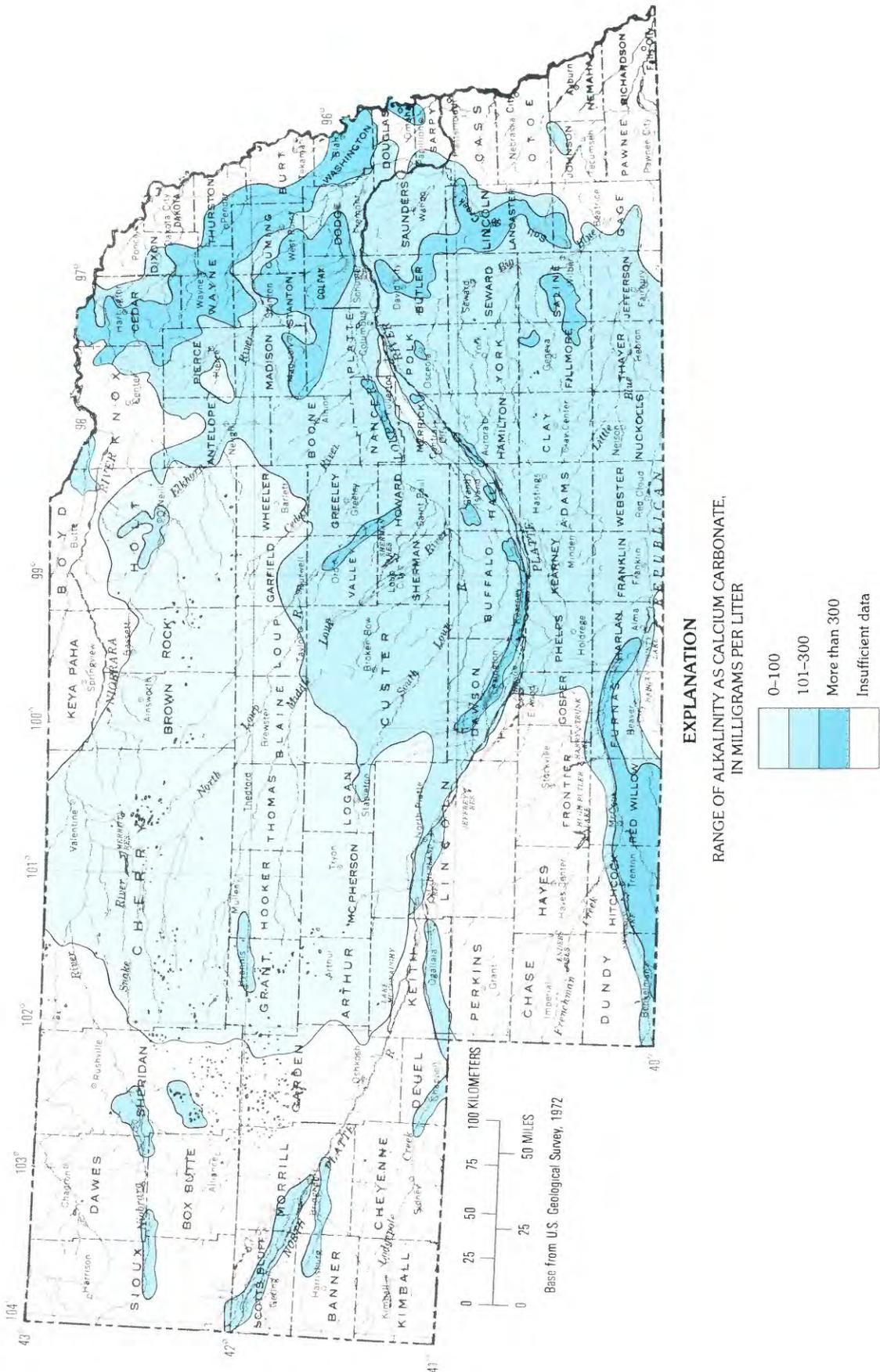


Figure 13. Map showing alkalinity of water from Holocene and Pleistocene aquifers.

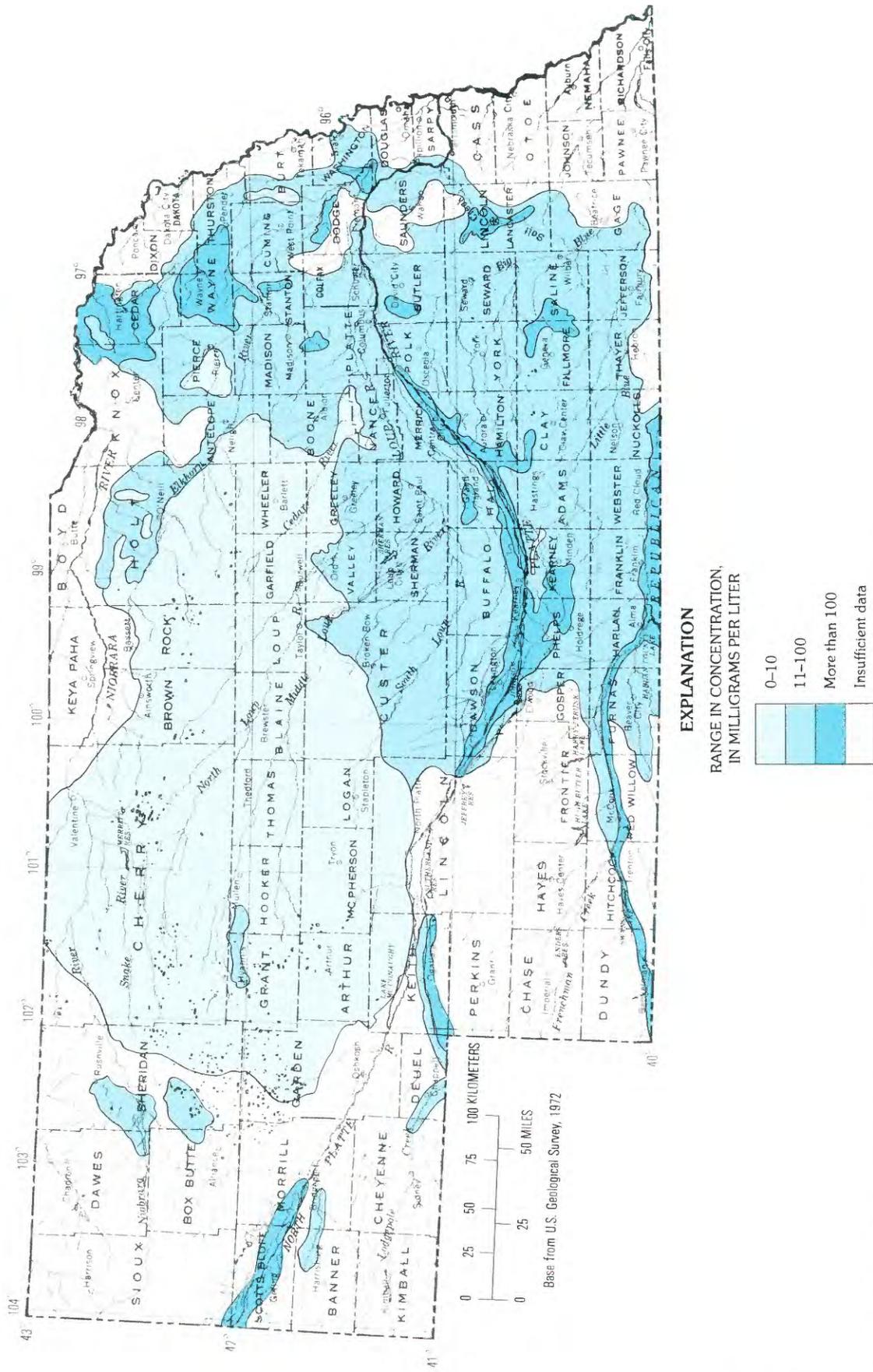


Figure 14. Map showing sulfate concentrations in water from Holocene and Pleistocene aquifers.

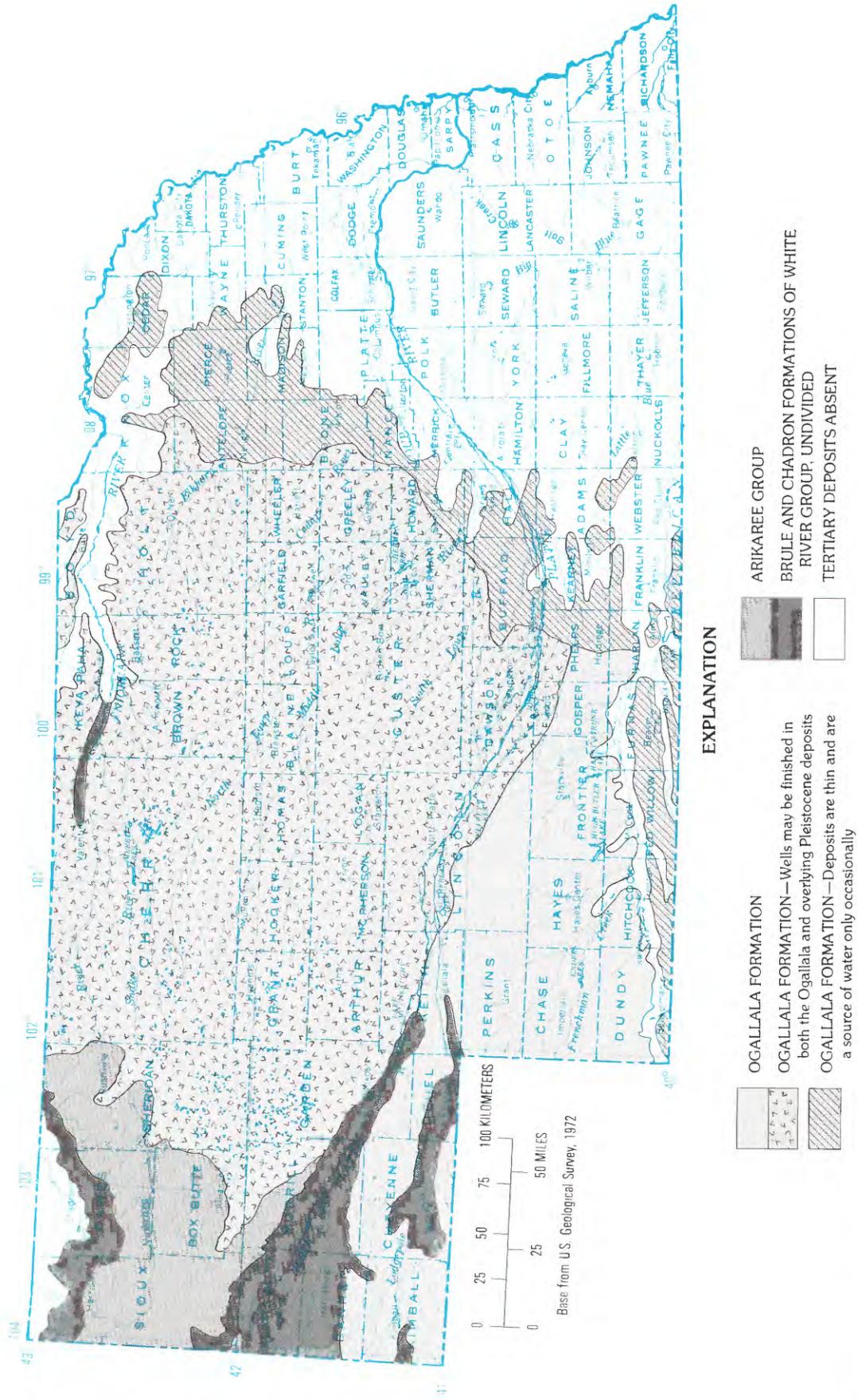


Figure 15. Map showing approximate areal distribution of aquifers in Tertiary deposits.

than those in the tables, are available but are not summarized statistically, because, in most instances, the number of measurements of a given type are too few. Temperature and pH were measured on samples from nearly all 557 wells producing from Tertiary aquifers, but are not summarized statistically for the reasons given in the section "Chemical constituents summarized and evaluated." Because most wells producing from Tertiary aquifers are only a few hundred feet deep, temperatures of water from them are expected to vary within only a few degrees. The temperatures reported, however, vary widely, probably because adequately standardized procedures of measurement were not used during much of the early period of data collection. Most of the measurements of pH were made in the laboratory a week or more after sample collection, and probably do not accurately reflect in-situ pH.

Some constituents of considerable interest have never been measured by the USGS on water samples from wells in the Tertiary. These include fecal coliform and fecal streptococci, and all pesticides.

Water-Quality Diagrams

Diagrams in figure 16 provide a visual basis for comparison of statistical data on water quality. These diagrams are constructed in the same way as those in figure 10 using statistical parameters rather than individual analyses.

Median quality of water is very similar in the Ogallala Formation, Arikaree Group, and Brule Formation. Water from aquifers in all three units is calcium bicarbonate type, and the median concentrations of the individual ions are remarkably similar. Water from the Chadron Formation differs markedly in quality from water from the other three units. At median concentrations, the Chadron aquifer produces water of the sodium bicarbonate chloride type, which is more highly mineralized than water from aquifers in the other three units. Water in the Chadron Formation is derived from a basal sandstone confined by a silt and clay layer. Artesian conditions are present in this formation and flowing wells from it occur occasionally. Recharge to the formation is derived from out-crop areas. Water in the other formations is unconfined or semiconfined and recharge is localized.

Of water from the four units, that from the Arikaree Group is the least variable and that from the Chadron Formation is the most variable, according to ranges in constituent concentrations. For the Ogallala Formation, a striking difference is observed between diagrams of maximum and 90th percentile. The influence on maximums or outlier values is evident from the high concentrations of sodium and chloride on the "maximum" diagram. The water from wells in which high concentra-

tions of these constituents were observed is affected by local recharge of water derived from surface-water irrigation projects.

Another striking difference is the overall increase in mineralization between medians and maximums for the Brule Formation. This difference is evident for sodium and for all three anions. Leakage of more highly mineralized water into the Brule Formation from the underlying Chadron Formation, in some areas, may cause the difference. Alternatively, poor circulation of water in parts of the Brule Formation that are only slightly fractured may be the cause.

Water represented by either the maximum or the minimum diagrams does not occur in any of the formations. These diagrams are merely representations of the observed extremes in all samples analyzed. The percentile and median diagrams, however, may closely approximate certain individual analyses of water from the respective formations.

Dissolved Solids

A well producing from the Ogallala Formation in the sandhills yielded water having the minimum dissolved-solids concentration of 61 milligrams per liter (mg/L), and one producing from the Chadron Formation in Deuel County yielded water having the maximum dissolved-solids concentration of 1,190 mg/L.

An area with water having more than 750 mg/L of dissolved solids exists in Deuel County (fig. 17). Similar areas may exist elsewhere in the Panhandle where the Chadron Formation exists. However, because most of the water used in these areas is derived from the Arikaree Group or Brule Formation, data on the quality of water from the Chadron are too few to be able to delimit them in the figure.

Water derived from the Ogallala Formation in southwestern Nebraska and in the loess hills of central Nebraska is somewhat more mineralized than water derived from the Ogallala in the sandhills. The soils and dune sand of the sandhills contain little soluble material, and rapidly infiltrating recharge does not become very mineralized as it moves to the zone of saturation.

The areas where concentrations of dissolved solids are 251 to 750 mg/L in Box Butte and Sheridan Counties coincide approximately with the area of a large-scale irrigation development. The same is true for the area where concentrations are within that range in Holt County.

Although the Ogallala Formation is present south of the Republican River in southwestern Nebraska, no information is available concerning the quality of water in this area. Likewise, the Ogallala Formation thins out in northeastern Nebraska and either is not considered an aquifer or no information regarding the quality of water

Table 5. Statistical summary of specific conductance and principal constituents in water from Tertiary aquifers[N, number of measurements; μ mho, micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter]

Property or constituent and unit	N	Maximum	Minimum	Mean	Standard deviation	Median	10th percentile	90th percentile
Ogallala Formation								
Specific conductance, μ mho-----	457	1,380	84	422	190	440	181	652
Calcium, dissolved, mg/L-----	411	160	7.8	56	29	60	22	99
Magnesium, dissolved, mg/L-----	411	62	.8	11	6.2	12	3.3	17
Sodium, dissolved, mg/L-----	431	186	3.1	13	14	10	6	18
Alkalinity as CaCO ₃ , mg/L-----	373	434	21	170	77	183	66	290
Chloride, dissolved, mg/L-----	390	340	.3	8.3	23	4.0	1.0	14
Sulfate, dissolved, mg/L-----	389	311	.3	25	40	17	4.0	43
Arikaree Group								
Specific conductance, μ mho-----	31	495	273	371	65	367	299	465
Calcium, dissolved, mg/L-----	37	72	28	47	10	46	36	59
Magnesium, dissolved, mg/L-----	37	20	4.7	10	3.5	9.8	7.4	15
Sodium, dissolved, mg/L-----	32	54	5.0	17	12	13	7.1	33
Alkalinity as CaCO ₃ , mg/L-----	37	267	120	161	30	156	130	200
Chloride, dissolved, mg/L-----	42	31	1.1	6.2	5.9	4.7	2.0	12
Sulfate, dissolved, mg/L-----	42	91	3.0	21	18	15	5.2	43

Table 5. Statistical summary of specific conductance and principal constituents in water from Tertiary aquifers—Continued

Property or constituent and unit	N	Maximum	Minimum	Mean	Standard deviation	Median	10th percentile	90th percentile
Brule Formation								
Specific conductance, μmho -----	28	1,030	245	463	187	427	313	612
Calcium, dissolved, mg/L-----	46	100	2.0	43	22	49	24	66
Magnesium, dissolved, mg/L-----	31	20	.2	9.9	4.8	11	5.3	14
Sodium, dissolved, mg/L-----	26	129	5.5	37	30	24	14	74
Alkalinity as CaCO_3 , mg/L-----	31	602	99	200	90	189	146	232
Chloride, dissolved, mg/L-----	46	195	1.1	21	34	9	5	29
Sulfate, dissolved, mg/L-----	46	400	1.8	69	78	17	10	140
Chadron Formation								
Specific conductance, μmho -----	10	2,000	764	1,374	504	1,410	781	1,752
Calcium, dissolved, mg/L-----	9	27	5.2	14	9	12	5.3	26
Magnesium, dissolved, mg/L-----	9	8.9	1.5	3.4	2.2	2.6	1.5	6.6
Sodium, dissolved, mg/L-----	11	422	89	267	128	293	110	376
Alkalinity as CaCO_3 , mg/L-----	12	494	148	322	99	343	199	395
Chloride, dissolved, mg/L-----	11	420	14	172	139	182	23	308
Sulfate, dissolved, mg/L-----	12	197	1.0	72	64	61	9.0	150

Table 6. Statistical summary of selected additional constituents in water from Tertiary aquifers [N, number of measurements; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent and unit	N	Maximum	Minimum	Mean	Standard deviation
Dissolved solids, residue at 180° Celsius, mg/L-----	278	1,190	61	301	155
Potassium, dissolved, mg/L-----	437	38	.5	8.3	3.9
Nitrate + nitrite as N, mg/L----	321	76	.01	3.2	6.4
Phosphorus, dissolved, mg/L----	103	.28	.01	.07	.06
Silica, dissolved, mg/L-----	433	76	5.1	53	11
Boron, dissolved, µg/L-----	390	2,200	.0	110	232
Iron, dissolved, µg/L-----	221	3,100	.0	78	260
Manganese, dissolved, µg/L-----	206	1,000	.0	39	110
Arsenic, dissolved, µg/L-----	107	27	1.0	6.6	3.9
Barium, dissolved, µg/L-----	27	500	100	211	128
Cadmium, dissolved, µg/L-----	91	3.0	.0	.7	1.0
Chromium, dissolved, µg/L-----	106	20	.0	8.1	9.9
Copper, dissolved, µg/L-----	147	75	.0	4.1	9.4
Lead, dissolved, µg/L-----	107	23	.0	1.7	3.9
Mercury, dissolved, µg/L-----	107	1.3	.0	.2	.2
Selenium, dissolved, µg/L-----	145	25	1.0	2.0	2.7
Silver, dissolved, µg/L-----	18	.0	.0	0	0
Zinc, dissolved, µg/L-----	148	.0	.0	82	451

is available. Further study of Tertiary deposits in Nebraska needs to include studies of the water quality of these deposits.

Calcium

Calcium concentrations greater than 100 milligrams per liter (mg/L) have been detected only in a small area near the North Loup River in Valley and Greeley Counties and in an even smaller area in Nance County. Concentrations are less than 25 mg/L in water from Tertiary aquifers throughout the sandhills. Elsewhere they range from 25 to 100 mg/L.

Calcium, a principal cause of hardness in water, is common in igneous and sedimentary rocks. Limestone is an important source of calcium, as are the calcareous sands and sandstones in the Ogallala Formation. Concentrations of calcium in ground water are regulated strictly by mineral solubility and chemical equilibria. Calcium is thought to be the principal cation in those areas labeled "Insufficient data" in figure 18.

Alkalinity

Alkalinity, expressed as an equivalent concentration of calcium carbonate, generally is significantly less than 100 milligrams per liter (mg/L) in ground water of the Sand Hills Region (fig. 19). Alkalinity greater than 300

mg/L is found in water from the Ogallala Formation in Greeley, Howard, and Valley Counties and in water from the Chadron and Brule Formations in Dawes, Deuel, Sheridan, and Sioux Counties.

Bicarbonate ion, the principal source of alkalinity, is the principal anion in water from all four Tertiary aquifers, although sulfate occurs in nearly equal milliequivalent concentrations in water from the Chadron Formation. Bicarbonate in water from aquifers of Tertiary age is formed by the reaction of carbon dioxide dissolved in infiltrating water with basic material in the soil and by the solution of carbonaceous material from the formation from which the water is derived. Other anions derived from the solution of weak acids may contribute to alkalinity, but their contributions usually are very small compared to that of bicarbonate. When the pH of water is greater than 8.3, measurable concentrations of carbonate exist in solution in equilibrium with bicarbonate.

Small amounts of alkalinity in water from the Ogallala Formation in the Sand Hills Region probably reflect the lack of soluble carbonaceous material in the siliceous soils and subsoils of the region. Large amounts of alkalinity in water from the Chadron Formation in Dawes, Deuel, Sheridan, and Sioux Counties are related to low calcium concentrations. Calcium concentrations tend to control the amount of alkalinity in water by controlling concentrations of bicarbonate and carbonate that can exist in solution under equilibrium conditions. Because calcium concentrations are small in water from the Chadron Formation compared to those in water from the other Tertiary aquifers, alkalinities tend to be greater.

Data available are insufficient to map alkalinity in Tertiary deposits in the Republican River basin in southwestern Nebraska and along most of the eastern boundary of the deposits.

Sulfate

Concentrations of sulfate generally are less than 10 milligrams per liter (mg/L) (fig. 20) in ground water of the Sand Hills Region because no extensive source of sulfate exists in this area. Concentrations of sulfate exceeding 100 mg/L occur in water from Tertiary aquifers in the upper North Platte River Valley and in the Platte River Valley east of the confluence of the North Platte and South Platte Rivers. Although data available are insufficient to map sulfate concentrations in the lower North Platte and the South Platte River Valleys, concentrations of sulfate in water from Tertiary aquifers underlying these areas probably exceed 100 mg/L also. Wells throughout the Platte River valley produce water from aquifers and receive recharge from the river system, canals, and reservoirs. Concentrations of sulfate in the Platte River system exceed 100 mg/L during all periods except floods.

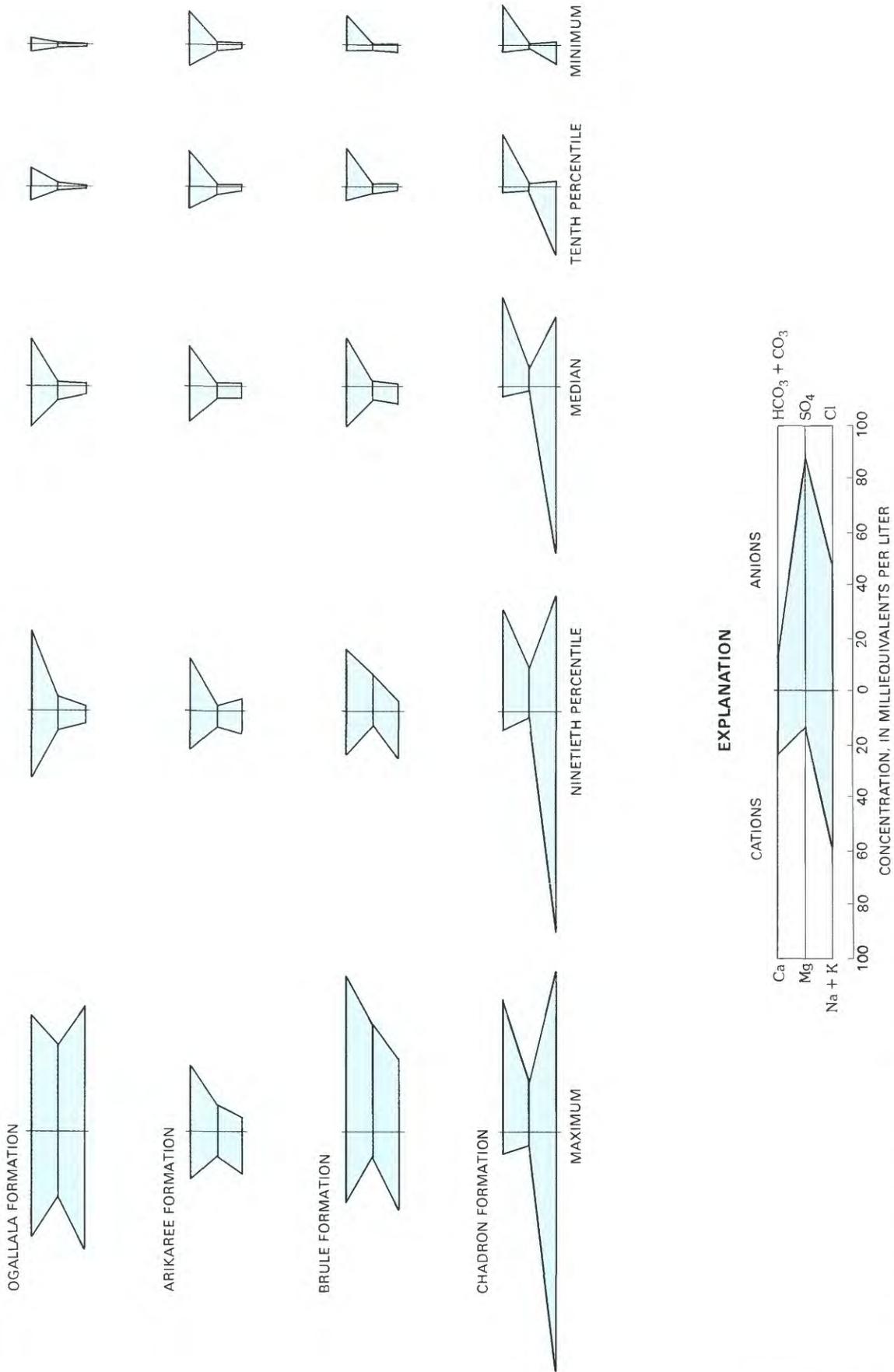


Figure 16. Diagrams of statistics on quality of water from Tertiary aquifers.

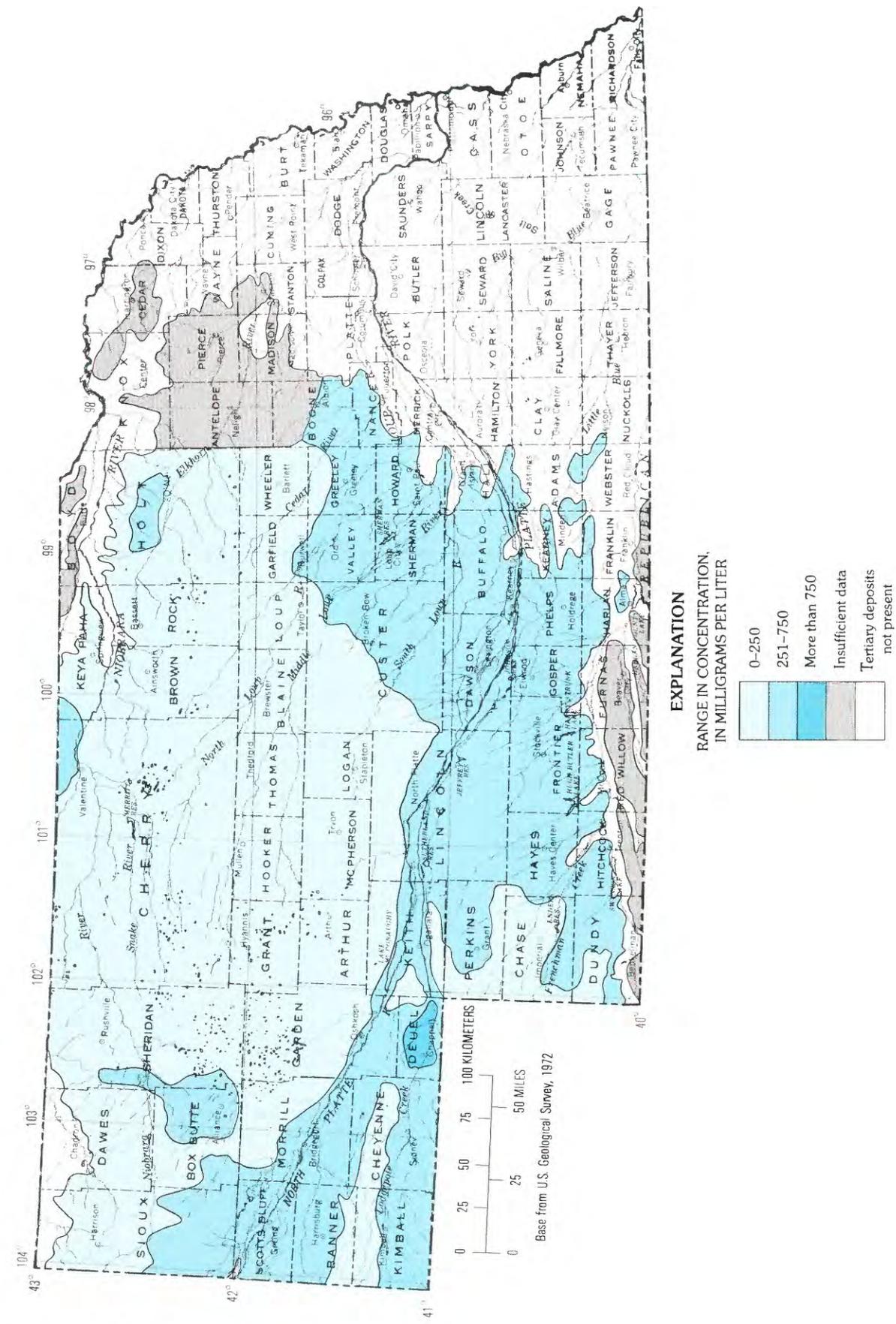


Figure 17. Map showing dissolved-solids concentrations in water from Tertiary aquifers.

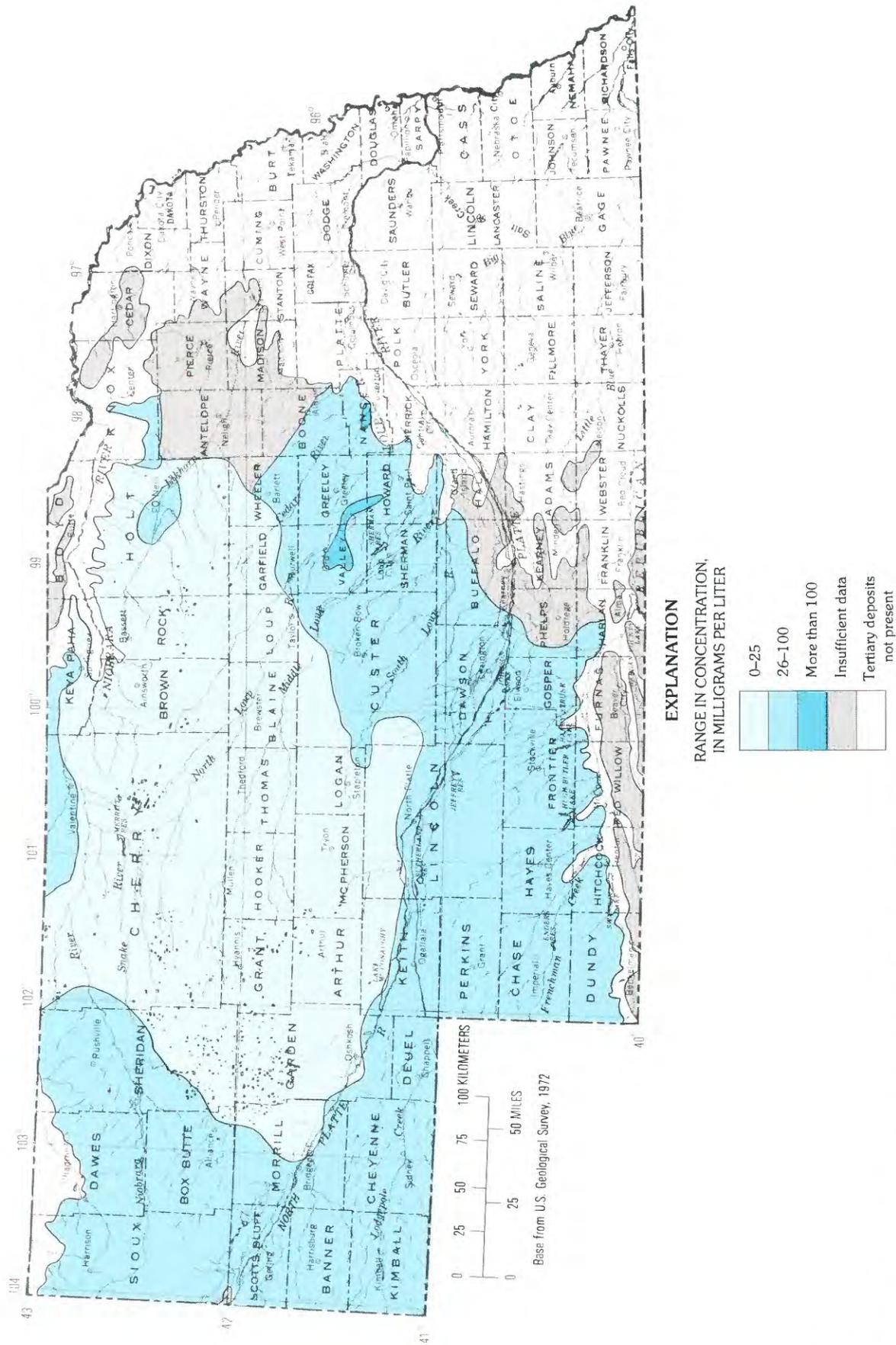


Figure 18. Map showing calcium concentrations in water from Tertiary aquifers.

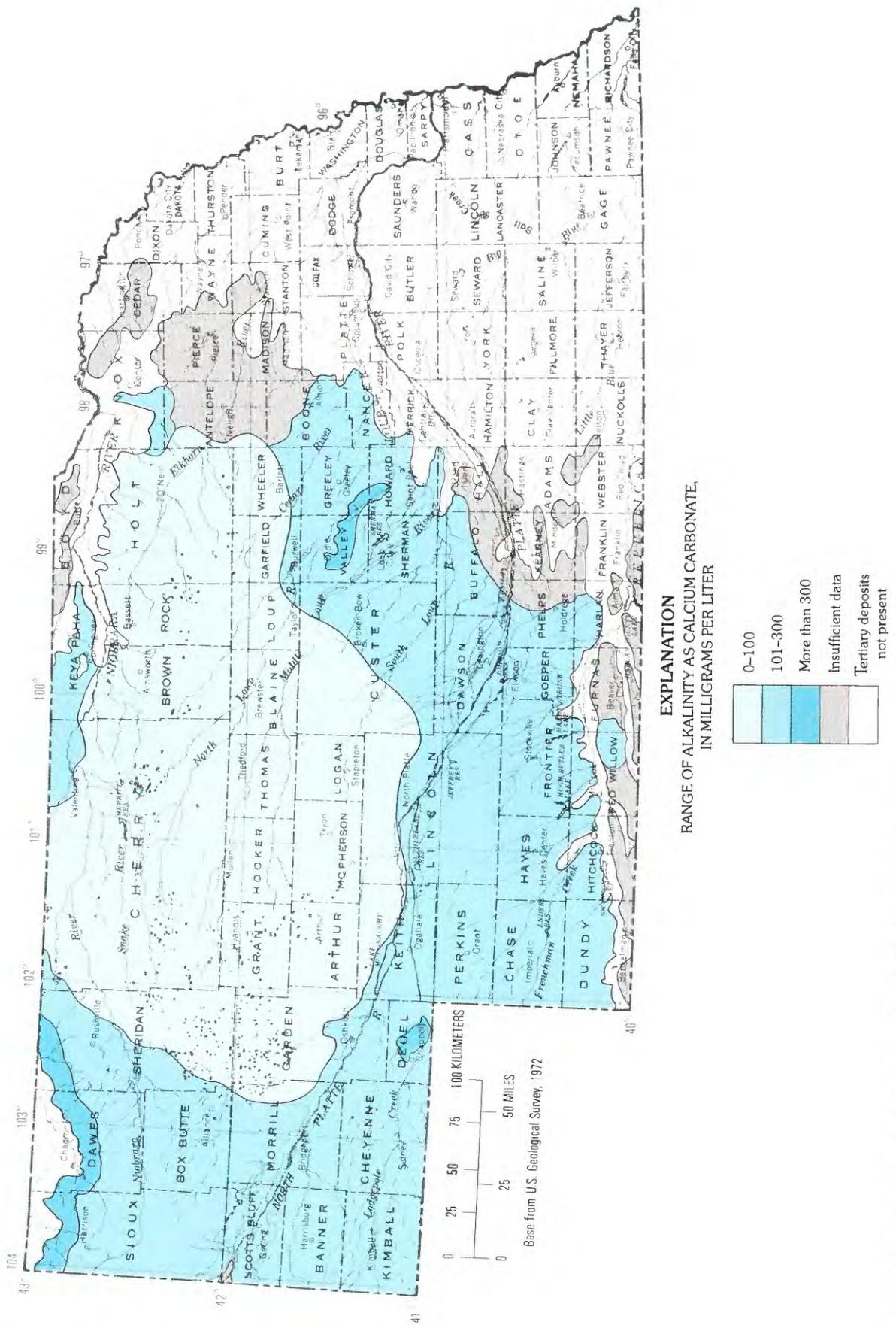


Figure 19. Map showing alkalinity of water from Tertiary aquifers.

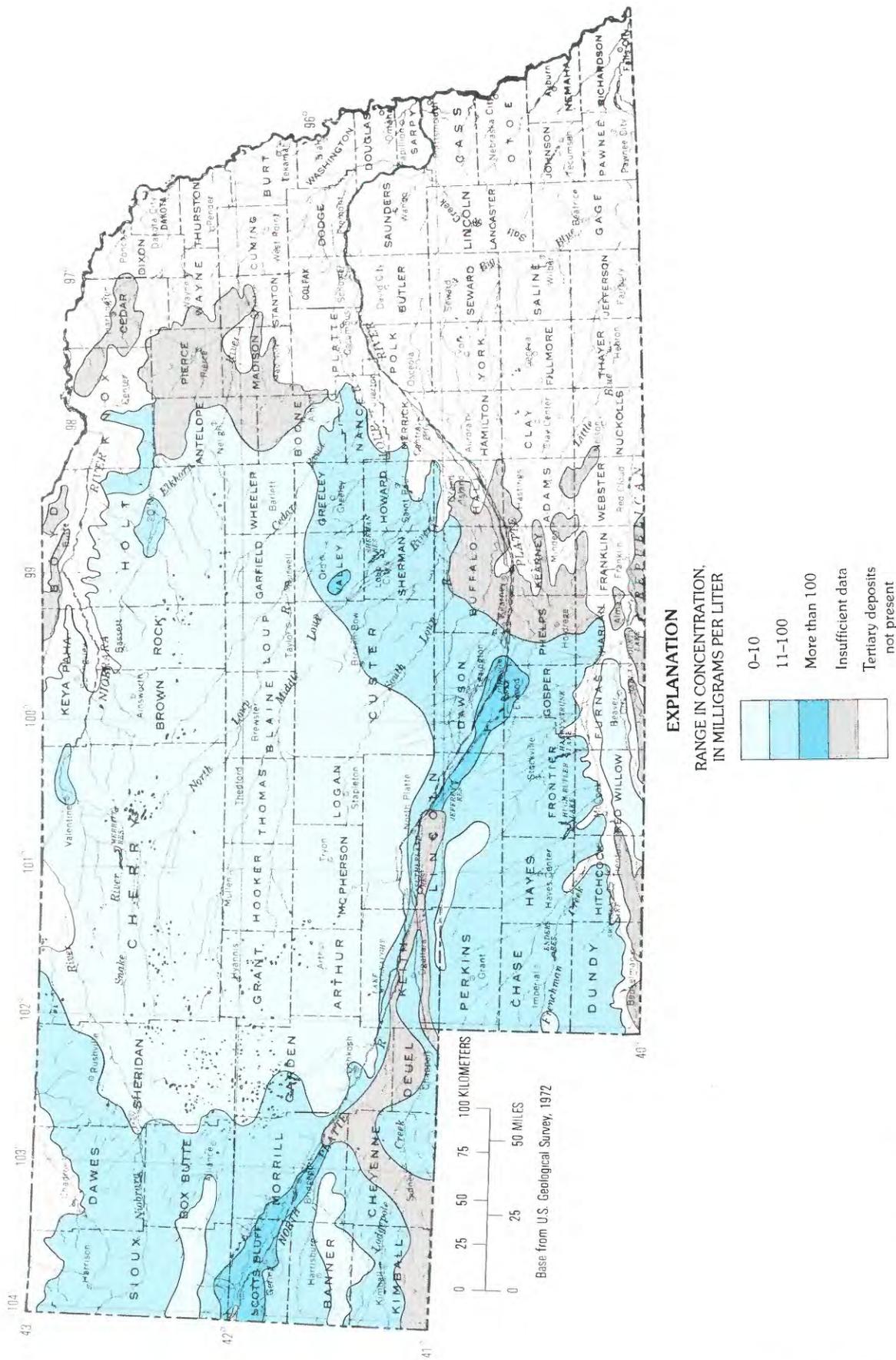


Figure 20. Map showing sulfate concentrations in water from Tertiary aquifers.

Principal geologic sources of sulfate are metallic sulfides in sedimentary or igneous rocks, which during weathering are oxidized to produce soluble sulfates. Carbonaceous deposits also may contain sulfides, which are readily oxidized to sulfate. Certain evaporite deposits contain sulfate, but probably the relatively small concentrations of sulfate in water from Tertiary aquifers in Nebraska are derived from the carbonaceous deposits, as few evaporite deposits or metallic sulfides are thought to be present in deposits composing these aquifers.

Mesozoic Aquifers

Formations of Cretaceous age compose the principal Mesozoic deposits in Nebraska, including all those that provide ground water (fig. 21). Some Triassic and Jurassic deposits occur at great depth in western Nebraska.

The youngest Cretaceous deposits in Nebraska are the Lance Formation and Fox Hills Sandstone, which occur in parts of Banner, Kimball, Scotts Bluff, and Sioux Counties. The Lance Formation, composed of sand and sandstone, is a source of water for stock and domestic wells in two of these counties—Banner and Scotts Bluff—if none is available from overlying Tertiary deposits or if such deposits are absent. The Fox Hills Sandstone is used only sparingly for water supplies.

The Pierre Shale underlies the Lance Formation and the Fox Hills Sandstone. Ranging in thickness from less than 100 feet in its eastern outcrops, westward to more than 5,000 feet in Kimball County, the Pierre generally is not considered to be a source of water for wells in Nebraska. However, in a water-poor area in Boyd County, quality of water in sand and gravel of Pleistocene age directly overlying the Pierre may be affected adversely by contact with the Pierre.

The Niobrara Formation underlies the Pierre Shale. Ranging from 0 to 300 feet in thickness, the Niobrara is composed of shaley chalk and limestone deposits. Although not considered an aquifer for much of its areal extent, the Niobrara may produce large volumes of water in certain areas where secondary porosity has developed as a result of fractures and solution channels. Irrigation and public-supply wells that yield about 1,000 gallons per minute have been developed in the Niobrara Formation in Cedar and Madison Counties along with domestic and stock wells. Some public-supply, domestic, and stock wells are developed in the Niobrara Formation in Clay, Nuckolls, and Webster Counties in south-central Nebraska.

The Niobrara Formation is underlain consecutively by the Carlile Shale, the Greenhorn Limestone, and the Graneros Shale. With the exception of the Codell Sandstone Member, which occurs in the upper part of the Car-

lile, none of these formations yield significant quantities of water to wells. The Codell, a fine-grained sandstone only 10 to 20 feet thick, is used for domestic and stock supplies in a small area of Boyd and Knox Counties.

The oldest Cretaceous Formation, the Dakota Sandstone, crops out in many places in eastern and southeastern Nebraska near its eastern extremity but is deeply buried throughout most of the State. The base of the Dakota is nearly 8,000 feet beneath land surface in Kimball County in the Panhandle. Data from petroleum exploration indicate that the Dakota is more than 800 feet thick in north-central Nebraska. In eastern Nebraska, where the Dakota is near land surface or in some places within 1,500 feet of land surface, it is used for water supplies if other sources are not available. West of the 99th Meridian in Nebraska, with but few exceptions, the Dakota presently is not used because abundant supplies of water chemically suitable for most uses are available from overlying Tertiary and Quaternary deposits.

The Dakota Sandstone provides water for public supply for at least one community in each of nine counties in eastern Nebraska and for numerous domestic and stock wells. In addition, it provides water for more than 100 registered irrigation wells in 11 counties. The quality of water from the Dakota is quite variable, depending on whether deposits from which it is produced are recharged locally, whether the deposits previously have been leached, whether the pumped water has been in the aquifer for a long time, and other factors.

The "D" and "J" sands, which correlate with the upper part of the Dakota Sandstone, are a source of petroleum in the Denver basin in western Nebraska, including the counties of Banner, Cheyenne, Deuel, Garden, Kimball, Morrill, and Scotts Bluff. Ground water associated with petroleum is extremely variable in quality, ranging from freshwater to water that is more mineralized than sea water.

Statistics

Water-quality information for specific conductance and six principal chemical constituents for each of the Cretaceous aquifers is summarized in table 7. Data for water from the Lance Formation and Fox Hills Sandstone are combined because of the limited areal extent of each formation, because only one analysis of water from a well identified as producing from Fox Hills exists in the record, and because that analysis is very similar to analyses of water from the Lance.

Data for 18 additional constituents are summarized in table 8. In this table, only one set of statistical data is presented for all Cretaceous aquifers rather than a set for each formation because of the limited number of analytical measurements available for many of the con-

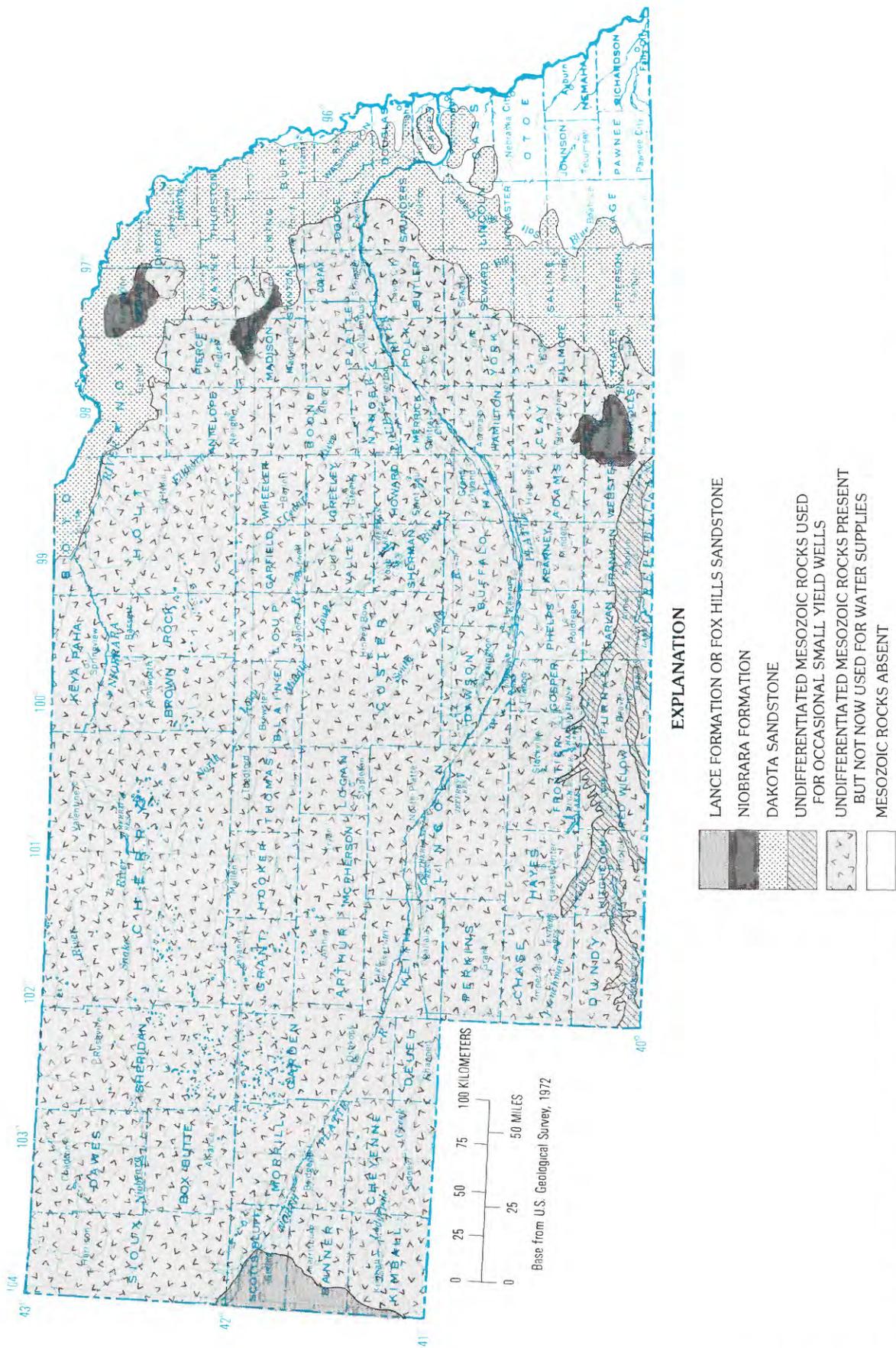


Figure 21. Map showing approximate areal distribution of Mesozoic rocks and those areas currently (1982) used for water supplies.

Table 7. Statistical summary of specific conductance and principal constituents of water from Cretaceous aquifers[N, number of measurements; μmho , micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter]

Property or constituent and unit	N	Maximum	Minimum	Mean	Standard deviation	Median	10th percentile	90th percentile
<u>Lance Formation and Fox Hills Sandstone</u>								
Specific conductance, μmho	9	2,640	541	1,457	674	1,430	-----	2,160
Calcium, dissolved, mg/L	13	32	.1	9.5	9.0	6.5	2.4	19
Magnesium, dissolved, mg/L	9	17	.5	4.3	5.0	3.8	1.1	7.7
Sodium, dissolved, mg/L	9	548	74	327	164	295	109	496
Alkalinity as CaCO_3 , mg/L	9	787	198	512	196	545	259	733
Chloride, dissolved, mg/L	13	611	6.0	129	177	59	7.0	260
Sulfate, dissolved, mg/L	12	63	.0	16	19	5.0	2.1	38
<u>Niobrara Formation</u>								
Specific conductance, μmho	20	2,250	576	1,075	559	720	593	1,984
Calcium, dissolved, mg/L	19	480	87	173	126	95	88	370
Magnesium, dissolved, mg/L	19	49	12	23	9.0	22	12	29
Sodium, dissolved, mg/L	18	53	14	23	8.7	20	18	31
Alkalinity as CaCO_3 , mg/L	18	527	238	319	73	287	241	412
Chloride, dissolved, mg/L	19	49	2.1	14	13	9.4	2.9	32
Sulfate, dissolved, mg/L	19	970	25	228	281	96	27	623
<u>Dakota Sandstone</u>								
Specific conductance, μmho	87	62,700	346	4,226	11,200	1,080	517	2,230
Calcium, dissolved, mg/L	86	415	2.2	142	86	130	40	240
Magnesium, dissolved, mg/L	86	205	.4	38	34	31	9.6	54
Sodium, dissolved, mg/L	86	16,600	13	881	2,930	59	23	329
Alkalinity as CaCO_3 , mg/L	72	627	68	233	114	216	108	339
Chloride, dissolved, mg/L	86	24,400	.9	1,197	4,220	41	3	200
Sulfate, dissolved, mg/L	86	3,150	5.0	491	633	290	28	840

stituents. Included are dissolved solids, potassium, silica, 2 nutrients, and 13 trace constituents, most of which have public-health significance.

Some constituents, such as pesticides, have never been measured on water from Mesozoic aquifers. Other constituents such as vanadium and strontium have been measured so few times in water from wells in Mesozoic aquifers that statistics on them would be meaningless. Temperature and pH data for water from Mesozoic aquifers are not included in the tables for the reasons given

in the section "Chemical constituents summarized and evaluated."

Quality of water in the Dakota Sandstone is quite variable. Ninety percent of the 87 specific conductances for water from the Dakota are 2,230 micromhos (μmho) per centimeter at 25° Celsius or less, whereas the maximum value is 62,700 μmho . The standard deviation is large and the mean is greater than the 90th percentile, indicating a highly skewed frequency distribution. In this situation, the median is a much better statistic than the

Table 8. Statistical summary of selected additional constituents in water from Cretaceous aquifers

[N, number of measurements; mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent and unit	N	Maximum	Minimum	Mean	Standard deviation
Dissolved solids, residue at 180° Celsius, mg/L-----	105	43,800	269	2,571	7,117
Potassium, dissolved, mg/L----	121	118	1.2	14	16
Silica, dissolved, mg/L-----	98	67	4.0	22	13
Nitrate + nitrite as N, mg/L--	39	51	.0	2.6	8.3
Phosphorus, dissolved, mg/L--	16	.69	.01	.11	.16
Boron, dissolved, µg/L-----	114	5,500	30	594	1,046
Iron, dissolved, µg/L-----	64	12,000	.0	1,473	2,156
Manganese, dissolved, µg/L----	21	470	1.0	78	110
Arsenic, dissolved, µg/L-----	17	9.0	.0	1.8	2.2
Barium, dissolved, µg/L-----	24	200	.0	25	53
Cadmium, dissolved, µg/L-----	20	2.0	.0	.2	.6
Chromium, dissolved, µg/L-----	5	20	.0	-----	-----
Copper, dissolved, µg/L-----	51	110	.0	6.2	20
Lead, dissolved, µg/L-----	20	3.0	.0	.55	1.0
Mercury, dissolved, µg/L-----	9	.5	.0	.37	.21
Selenium, dissolved, µg/L-----	25	14	.00	.51	4.4
Silver, dissolved, µg/L-----	15	1.0	.0	.07	.3
Zinc, dissolved, µg/L-----	44	2,500	.0	597	237

mean for indicating distribution of specific conductance in water from the Dakota. Highly mineralized water that was either structurally trapped in the Dakota at the time of deposition or that migrates into the Dakota, possibly from underlying Pennsylvanian rocks, is found in the Dakota Sandstone in parts of Lancaster County. The maximum specific conductance and several other specific-conductance values of similar magnitude were for samples of water from the Dakota in Lancaster County.

Water-Quality Diagrams

Water-quality diagrams provide a visual means of examining water-quality variation within and between aquifers. Because of the wide variation in concentrations associated with water samples from Cretaceous aquifers and because of the limited number of analyses, it is impractical to present diagrams based on maximums, minimums, and means such as those in figures 10 and 16. Instead, diagrams in figure 22 are presented for representative analyses of water from different locations within Cretaceous aquifers from a variety of locations and for a variety of conditions. Diagrams in this figure were prepared by the traditional procedure described in the section "Holocene-Pleistocene aquifers—Water-quality diagrams"

and, therefore, are not comparable to the diagrams in figures 10 and 16.

Seven diagrams indicate similarities and differences in the quality of water from the developed part of the Dakota Sandstone in Nebraska. Diagrams 1 and 5 represent water from two wells, one in Jefferson County and one in Sarpy County, in outcrop areas where the Dakota receives local recharge. These diagrams are similar in shape to those representing calcium bicarbonate type water from nearby wells producing from Pleistocene deposits. In contrast, diagram 7 represents saline water of the sodium chloride type from a well in Saline County. Water quality in the vicinity of this well (see location 7 on the index map), and in part of Lancaster County, probably is affected by the migration of saline water into the Dakota from underlying Pennsylvanian rocks or was structurally trapped in place at the time of deposition. Diagrams 3 and 6 represent calcium sulfate type water from wells 500 to 1,000 feet deep that receive little or no local recharge. Diagrams 2 and 4 represent water from wells 200 to 400 feet deep; these diagrams are similar to diagrams 3 and 6, except that the water they represent seems to be diluted somewhat by localized recharge.

Diagrams 8, 9, and 10 represent water from the Niobrara Formation. Localized recharge probably accounts for the predominance of calcium and bicarbonate in the water from this formation in Nuckolls County (diagram 8). The increasingly greater proportions of sulfate indicated by diagrams 9 and 10, which represent water from the formation in Cedar County, show the effects of recharge through overlying sulfate-enriched glacial till.

Water from a well finished in the Codell Sandstone Member of the Carlile Shale is represented by diagram 11. This water is of the sodium sulfate bicarbonate type and is very soft (hardness less than 60 mg/L).

Water from the Lance Formation in Banner and Scotts Bluff Counties is represented by diagrams 12 and 13; whereas, water from a well completed in the Fox Hills Sandstone is represented by diagram 14. Although water from both formations is of the sodium bicarbonate type, that from the Lance contains a greater proportion of chloride than that from the Fox Hills.

Dissolved Solids

Although about 93 percent of Nebraska is underlain by Mesozoic rocks, these rocks are used for water supplies in only about one-sixth of the State. Even for this one-sixth of the State, data are sufficient only in a few places to describe areal distribution of dissolved solids (fig. 23).

The maximum dissolved-solids concentration detected in water from Mesozoic aquifers was 43,800 milligrams per liter (mg/L). The well from which this water

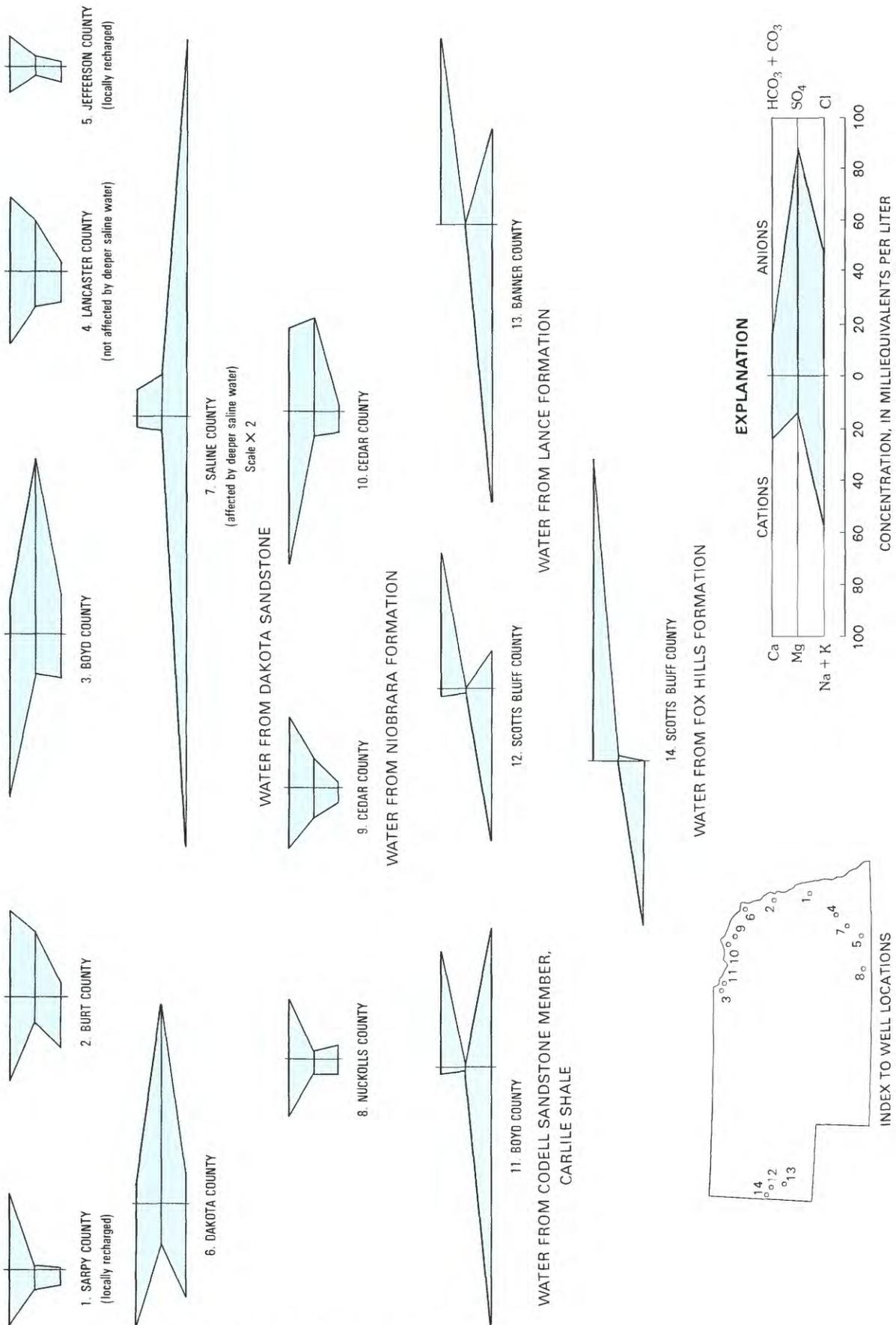


Figure 22. Water-quality diagrams of representative analyses of water from Mesozoic aquifers showing variations within and between water-bearing formations.

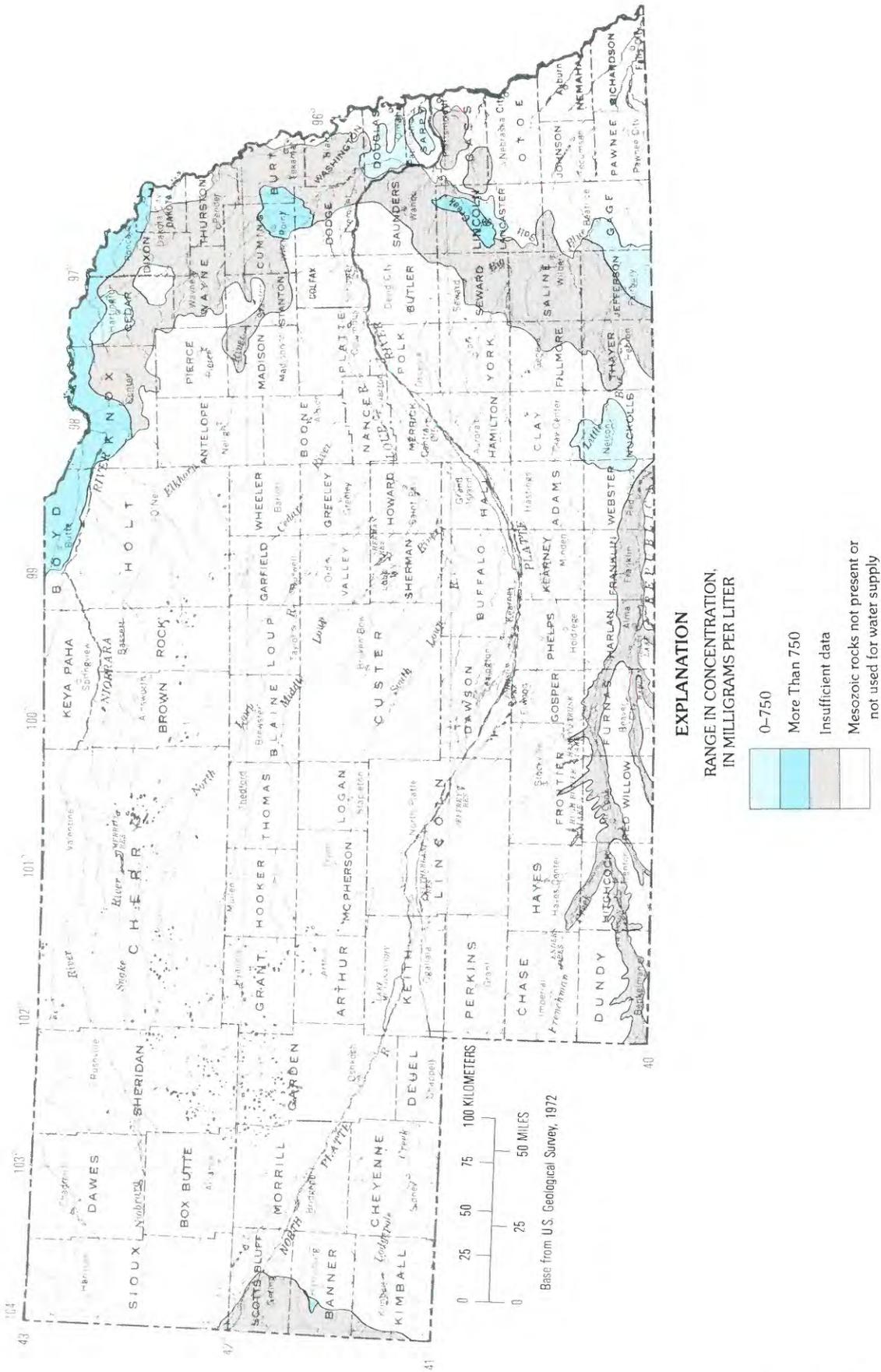


Figure 23. Map showing dissolved-solids concentrations in water from Mesozoic aquifers.

came produces from Dakota Sandstone and is located in a part of Lancaster County where saline water either moves upward into the Dakota from underlying deposits or was structurally trapped in the Dakota at the time of its deposition. Less than 10 miles away, another well producing from the Dakota yielded water having the minimum detected dissolved-solids concentration of 269 mg/L. This well is shallow and produces from a part of the aquifer that is recharged regularly by freshwater from local precipitation.

Three areas of eastern Nebraska have been mapped in which dissolved-solids concentrations are known to exceed 750 mg/L (fig. 23). One is an area in northeastern Nebraska paralleling the Missouri River, one is in Lancaster County, and one is in parts of Burt, Cuming, and Dodge Counties. In these areas the water is from Dakota Sandstone. One area in western Nebraska has been mapped in which dissolved solids are known to exceed 750 mg/L. This area is in Banner and Morrill Counties, and the water is from the Lance Formation.

In two areas where concentrations of dissolved solids in water have been mapped as ranging from 0 to 750 mg/L, the water is from the Niobrara Formation; one is mostly in Nuckolls County and the other is in Cedar County. In the several other small areas, all in eastern Nebraska where the map indicates concentrations ranging from 0 to 750 mg/L, the water is from Dakota Sandstone. In most of these small areas, the Dakota is recharged locally

Data are insufficient to map the areal distribution of dissolved solids in the Republican River Valley near the southern border of Nebraska, even though many domestic and stock wells obtain water from Mesozoic aquifers.

Calcium

Areas of similar calcium concentrations are delimited in figure 24. Concentrations generally are considerably less than 25 milligrams per liter (mg/L) in water from the Lance Formation in western Nebraska, and the water is very soft (hardness generally less than 60 mg/L). This also is true for water from the Codell Sandstone Member of the Carlile Shale where it is used for water supplies in Boyd County.

Concentrations of calcium exceed 100 mg/L in three areas of eastern Nebraska where water from Mesozoic aquifers is derived from Dakota Sandstone. In several other areas of eastern Nebraska where data are sufficient to be mapped, concentrations in water from the Dakota range between 26 and 100 mg/L. Water quality in the Dakota in each of the areas having small concentrations of calcium is affected by local recharge.

Calcium concentrations in water from the Niobrara Formation in Cedar County are variable; they exceed 100 mg/L in water from some wells and are less than 100 mg/L in water from others. Generally, wells producing water from the Niobrara with calcium concentrations exceeding 100 mg/L are in northern Cedar County. Here the quality of water in the Niobrara appears to be affected by recharge that has moved through glacial till.

Data available are not sufficient to permit mapping of calcium concentrations in much of the area where Mesozoic rocks are used for ground-water supply. Where concentrations have been mapped, 10th- and 90th-percentile limits were used to determine areal boundaries, and outlying values were given little weight.

Limestone, calcareous sandstones, and soils derived from them, are important sources of calcium in water from Mesozoic aquifers. Concentrations of calcium in ground water are controlled by chemical solubility equilibria or by ion exchange. Calcium may be exchanged for sodium or clay minerals in the Lance Formation.

Alkalinity

Alkalinity, expressed as an equivalent concentration of calcium carbonate, generally is more than 300 milligrams per liter (mg/L) in water from the Lance Formation in western Nebraska, but with few exceptions ranges from 101 to 300 mg/L in water from Dakota Sandstone and from the Niobrara Formation in eastern Nebraska (fig. 25). Only in small areas of Boyd and Knox Counties, Cedar County, and Lancaster County does alkalinity exceed 300 mg/L in water from the Dakota or the Niobrara. Alkalinity less than 100 mg/L was detected in water from the Dakota in only a small area of Knox County.

Bicarbonate is the principal source of alkalinity in water from Mesozoic aquifers and is the principal anion in water from both the Lance and Niobrara Formations. Other anions derived from the solution of weak acids may contribute to alkalinity, but they usually are insignificant compared to bicarbonate. Sulfate generally is the principal anion in water from Dakota Sandstone. However, near outcrop areas where water in the Dakota is largely local recharge, bicarbonate is the principal anion. This probably results from the reaction of carbon dioxide in the infiltrating water with basic material in the soil or from the reaction of the carbon dioxide charged water with carbonate minerals in the rocks.

Calcium concentrations tend to control the concentrations of carbonate and bicarbonate in water and thus to control the amount of alkalinity. If calcium concentrations are low, alkalinity tends to be greater than if calcium concentrations are high. Accordingly, because calcium concentrations are low in water from the Lance Formation, alkalinity of water from the Lance is high.

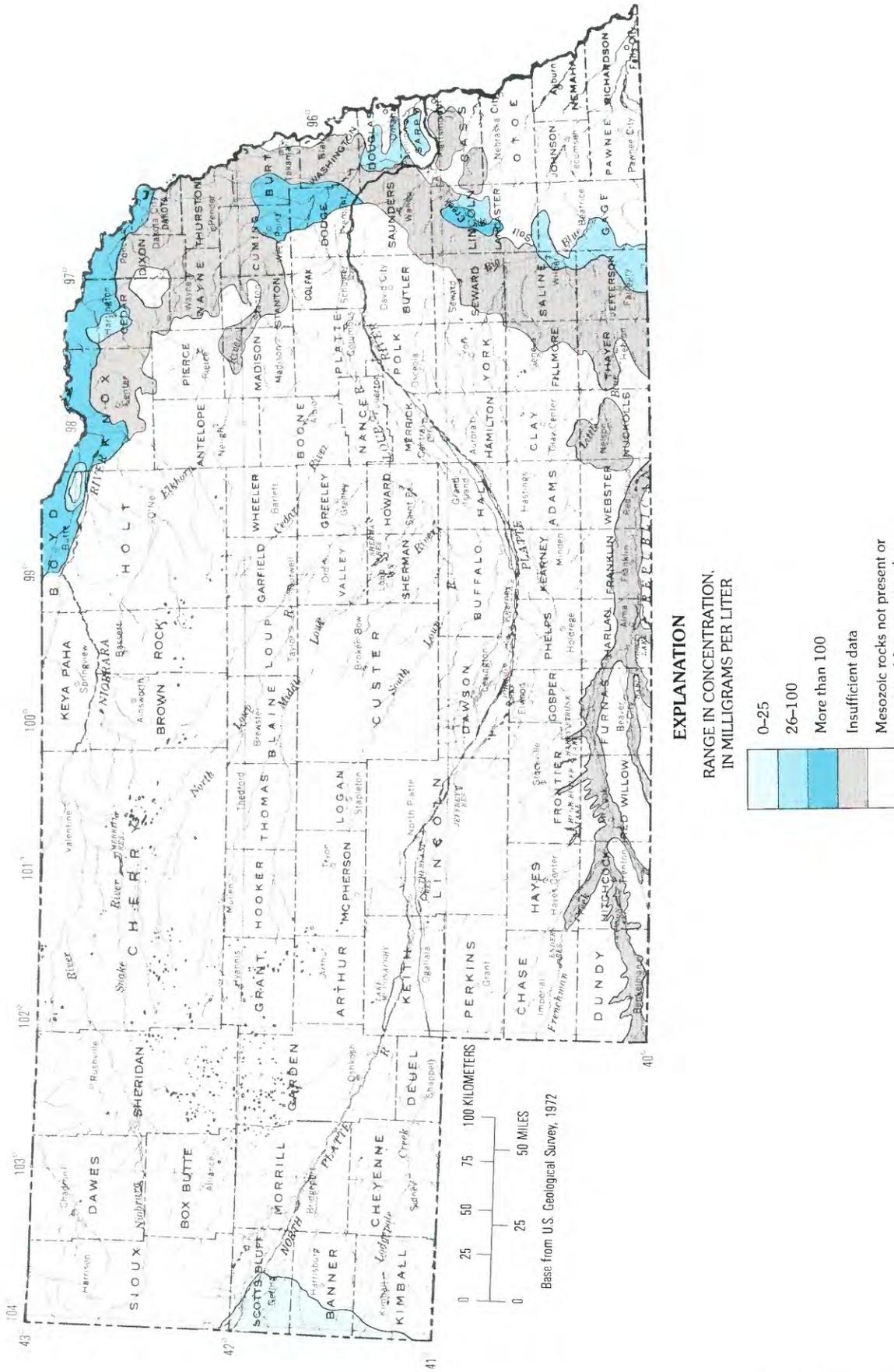


Figure 24. Map showing calcium concentrations in water from Mesozoic aquifers.

Data available are insufficient to map alkalinity of water from Mesozoic aquifers in the Republican River basin and in much of eastern Nebraska, even though these deposits are used for water supplies.

Sulfate

Concentrations of sulfate generally are less than 10 milligrams per liter (mg/L) in water from the Lance Formation in western Nebraska. They exceed 100 mg/L in water from those parts of the Dakota Sandstone that are not affected significantly by local recharge. The maximum concentration of sulfate (3,150 mg/L) was detected in water from the Dakota in Lancaster County, at a site where saline water from deeper formations moves into the Dakota. Concentrations of sulfate in water from Mesozoic aquifers are shown in figure 26.

Principal geologic sources of sulfate include metallic sulfides in sedimentary rocks that are oxidized during weathering to produce sulfates. Some evaporite deposits are rich in sulfate, and some carbonaceous deposits also are a source of sulfate. Each of these possible sources probably contributes sulfate to water from Dakota Sandstone. Few of these sources, however, are known to exist extensively where water supplies are derived from the Lance Formation in western Nebraska.

Data available are insufficient to map sulfate concentrations in water from Mesozoic aquifers in the Republican River valley or in much of eastern Nebraska.

Paleozoic Aquifers

Paleozoic rocks, ranging in thickness from about 1,000 to 4,000 feet, underlie all of Nebraska except a small area in Boyd, Cedar, and Knox Counties along the northern edge of the State (fig. 27). Because they lie at a depth of several thousand feet in western and central Nebraska, and because petroleum explorations indicate that water in the deposits is saline, these deposits are not now, and may never be, developed for water supplies unless further exploration determines that freshwater exists in some horizons.

The geology of Paleozoic rocks is complex, and Paleozoic systems that underlie Nebraska are made up of over 100 units. Wells completed in Paleozoic aquifers in eastern and southeastern Nebraska are classified only by the system or systems from which water is produced. These systems and their generalized lithologies and thicknesses are given in the following table. The Pennsylvanian is the only system that is present under the entire area for which Paleozoic rocks are used for water supplies.

System	Lithology	Thickness (feet)
Permian	Interbedded limestone and shale.	0-500
Pennsylvanian	Interbedded limestone and shale, grading into shale and sandstone at base.	400-2,000
Mississippian	Dolomitic limestone and dolomite with basal siltstone and shale.	0-250
Devonian	Shale overlying dolomite, shaly dolomite, and limestone.	0-500
Silurian	Dolomite.	0-500
Ordovician	Shaly dolomite and dolomite underlain by shale, limestone and sandstone on basal dolomite.	0-700
Cambrian	Sandstone underlain by dolomite on basal sandstone.	0-150

Permian and Pennsylvanian rocks of Paleozoic age outcrop in southeastern Nebraska, or are covered by glacial drift less than 200 feet thick. They thin northward, and although they may be present, they do not supply much water to wells in counties north of Otoe and Lancaster. Because glacial drift is a meager source of water, and because buried channels containing Pleistocene sand or gravel deposits occur in few places in southeastern Nebraska, water from Permian and Pennsylvanian rocks are used for domestic and stock supplies in upland areas in several counties, including Gage, Johnson, Nemaha, Pawnee, Richardson, and parts of Otoe and Lancaster. Additionally, a few small communities in these counties use water from these deposits for public supplies.

Some deep wells in Cass, Douglas, Sarpy, and Washington Counties are developed in deposits older than Permian or Pennsylvanian. Wells producing only from dolomite deposits of Devonian age have been developed in Cass County. Generally, however, the procedure in deep-well construction in these counties is to case nonproducing deposits and screen or leave open those deposits that produce water. The result is that water from many deep wells is a mixture derived from formations ranging in age from Mississippian to Cambrian. For example, several wells in eastern Douglas County that are approximately 2,100 feet deep and that produce water at 300 to 500 gallons per minute do so from virtually the entire Paleozoic section present at their locations. Although analyses of water from individual producing horizons are not available, it seems that more saline water from Devonian rocks mixes with fresher water from Ordovician and Cambrian rocks to

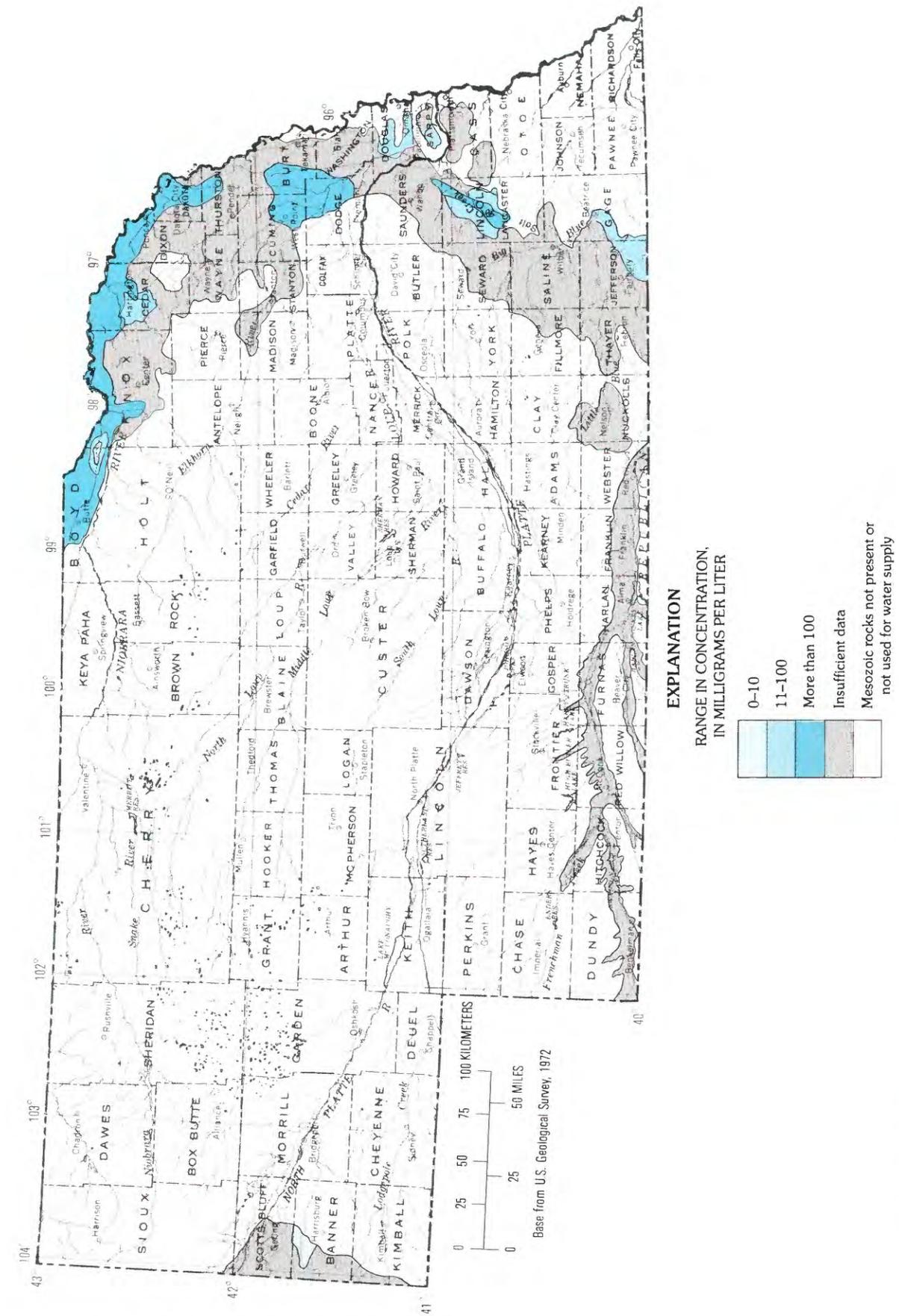


Figure 26. Map showing sulfate concentrations in water from Mesozoic aquifers.

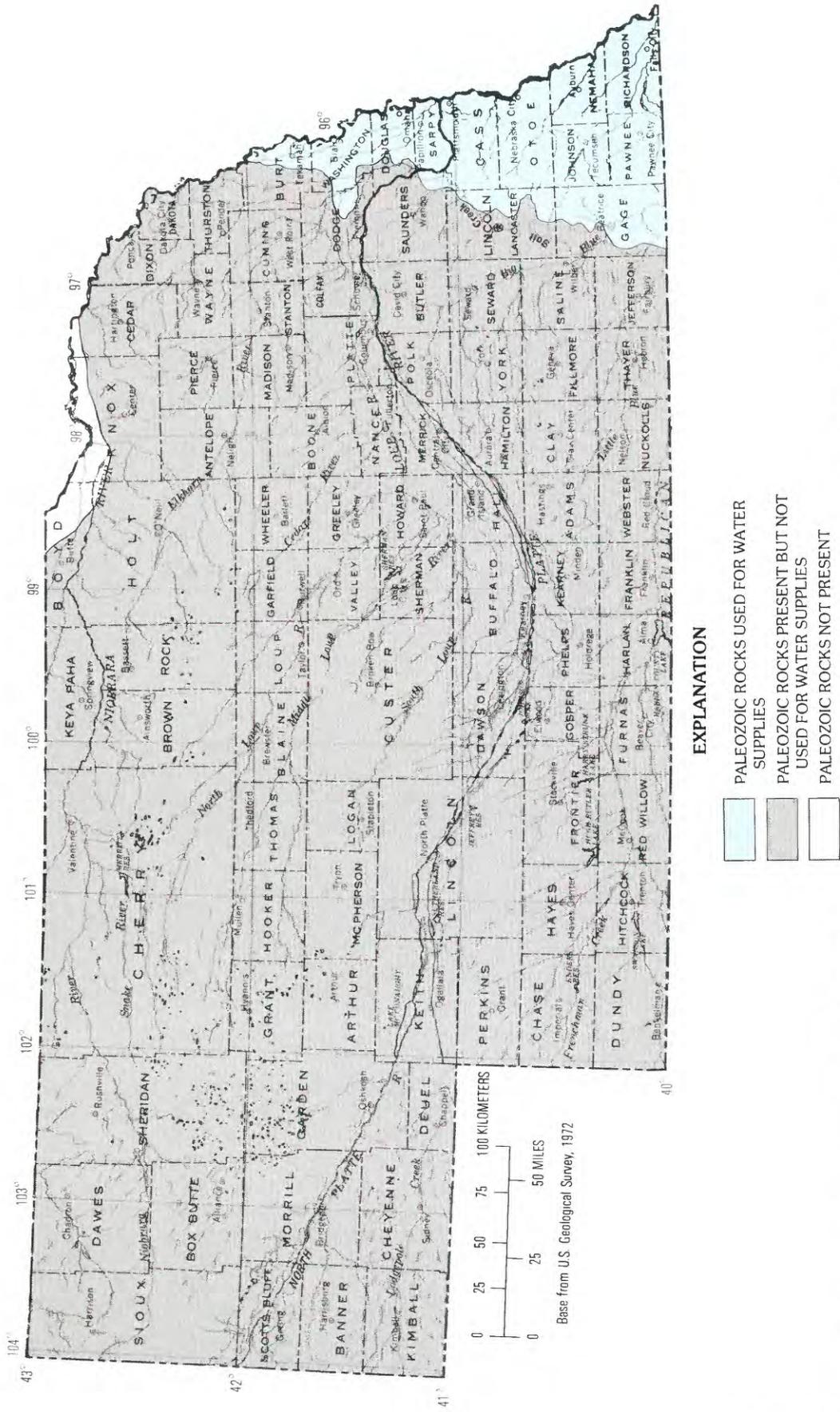


Figure 27. Map showing approximate areal distribution of Paleozoic rocks and those areas currently (1982) used for water supplies.

yield water of the sodium sulfate type having dissolved-solids concentrations of about 1,500 milligrams per liter.

Probably no more than 20 to 25 of these deep water wells now exist in eastern Nebraska because shallower Holocene, Pleistocene, and Cretaceous deposits are present and provide a more easily obtainable water supply.

Statistics

Water-quality data for specific conductance, dissolved solids, principal constituents, nutrients, and trace constituents are summarized in tables 9 and 10.

The broad distribution of specific-conductance values and constituent concentrations in the tables is related to the fact that analyses of water from several bedrock aquifers have been used in computing data for the tables. So few analyses are available of water from individual aquifers that statistical data from them, individually, is impossible. This is compounded by the fact that near-surface Pennsylvanian and Permian rocks are recharged in outcrop areas with precipitation and runoff that may remain in residence only for short periods.

The data on trace constituents, though few, indicate that probably none of these constituents occur in potentially dangerous concentrations. However, the need for more analyses of trace constituents to define their ranges of occurrence more adequately is apparent, as most have been analyzed fewer than 10 times.

Water-Quality Diagrams

The variability in chemical composition of water from Paleozoic aquifers is apparent from figure 28. The four diagrams were prepared from analyses of those individual water samples regarded as most representative of the several analyses from their respective water-bearing units.

Comparison of the diagram for water from Devonian aquifers with that for water from all Paleozoic aquifers combined indicates that water from the well producing from the Devonian aquifer is considerably more mineralized than water from the combination of Paleozoic aquifers. Conversely, this indicates that water from Ordovician and Cambrian aquifers, at least in the vicinity of these wells, is less mineralized than water from the overlying Devonian.

A comparison also can be made between the diagram for water from Pennsylvanian aquifers that receives recharge locally and one of greater depth that does not. Water from the aquifer receiving local recharge is similar in quality to water from nearby Pleistocene channel deposits.

Table 9. Statistical summary of specific conductance and principal constituents in water from Paleozoic aquifers

[N, number of measurements; μmho , micromhos per centimeter at 25° Celsius; mg/L, milligrams per liter]

Property or constituent and unit	N	Maximum	Minimum	Mean	Standard deviation
Specific conductance, μmho	54	5,537	442	1,999	3,310
Calcium, dissolved, mg/L	53	508	9.0	129	132
Magnesium, dissolved, mg/L	53	268	6.4	54	61
Sodium, dissolved, mg/L	52	2,000	14	282	431
Alkalinity as CaCO_3 , mg/L	53	804	43	256	133
Chloride, dissolved, mg/L	53	1,990	.0	190	397
Sulfate, dissolved, mg/L	53	2,250	2.3	593	608

Table 10. Statistical summary of selected additional constituents in water from Paleozoic aquifers

[N, number of measurements; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter]

Constituent and unit	N	Maximum	Minimum	Mean	Standard deviation
Dissolved solids, residue at 180° Celsius, mg/L-----	50	5,620	189	1,482	1,351
Potassium, dissolved, mg/L-----	59	39	1.2	12	11
Silica, dissolved, mg/L-----	49	36	3.6	19	9.2
Nitrate + nitrite as N, mg/L---	0	-----	-----	-----	-----
Phosphorus, dissolved, mg/L----	0	-----	-----	-----	-----
Boron, dissolved, mg/L-----	46	4,100	20	857	938
Iron, dissolved, $\mu\text{g/L}$ -----	42	24,000	.0	2,126	4,378
Manganese, dissolved, $\mu\text{g/L}$ ----	2	80	10	-----	-----
Arsenic, dissolved, $\mu\text{g/L}$ -----	3	3.0	.0	-----	-----
Barium, dissolved, $\mu\text{g/L}$ -----	6	.0	.0	-----	-----
Cadmium, dissolved, $\mu\text{g/L}$ -----	9	.0	.0	.0	.0
Chromium, dissolved, $\mu\text{g/L}$ -----	0	-----	-----	-----	-----
Copper, dissolved, $\mu\text{g/L}$ -----	42	190	.0	12	35
Lead, dissolved, $\mu\text{g/L}$ -----	9	.0	.0	.0	.0
Mercury, dissolved, $\mu\text{g/L}$ -----	0	-----	-----	-----	-----
Selenium, dissolved, $\mu\text{g/L}$ -----	3	10	2.4	-----	-----
Silver, dissolved, $\mu\text{g/L}$ -----	9	1.0	.0	.2	.4
Zinc, dissolved, $\mu\text{g/L}$ -----	26	1,800	.0	329	547

The few data available severely limit our understanding of the quality of water from Paleozoic aquifers. Future studies to obtain more detailed information on the quality of water in Paleozoic aquifers in Nebraska clearly are needed.

PROBLEM AREAS

Areas where there are, or have been, problems with ground-water quality and where there is potential for such problems are shown in figure 29. Problems related to ground-water quality in Nebraska are predominantly caused by man's activities and are divided into those caused by point-source contamination and those caused by nonpoint-source contamination. Typical point sources of contamination are human and animal waste sources and municipal or industrial waste discharges; typical nonpoint sources are fields to which fertilizers or pesticides are applied.

Problems of contamination from point sources commonly are restricted to relatively small areas but may nonetheless be serious. Past or present problems are divided in figure 29 into those in which the contaminant was an organic chemical and those in which it was nitrate-nitrogen. Organic chemicals, including pesticides or petroleum products, from spills or leaks contaminating ground-water supplies in small areas have forced the abandonment of some public-supply wells. The presence of nitrate-nitrogen in concentrations greater than 10 milligrams per liter (mg/L)—the limit for public supplies established by the U.S. Environmental Protection Agency (1976)—for which, in most cases, point sources have been identified, has caused many communities to replace or deepen existing wells. Well-location data were provided by the Nebraska Department of Health (Owen Goodenkauf, written communication, 1982).

Problems of contamination from nonpoint sources potentially are more serious than those from point sources because they commonly involve larger areas. Nonpoint sources of contamination in Nebraska include, but are not limited to, the leaching of livestock waste in ranching areas and the leaching of fertilizer and other agricultural chemicals in irrigated farmland. Existing problem areas derived from nonpoint sources are given in the following table and coded by number to figure 29.

Nitrate-nitrogen concentrations in ground water presently exceed the drinking-water standard of 10 mg/L in part of the central Platte River Valley from Buffalo County to Platte County and in the north-central part of Holt County. Shallow water tables and sandy soils characterize these areas of intensive irrigation development. Fertilizer nitrogen is the principal source of greater concentrations of nitrate-nitrogen in these areas, but point sources such as barnyard and feedlot waste and leachate from individual septic systems may contribute.

Nitrate-nitrogen concentrations in ground water presently exceed the drinking-water standard of 10 mg/L in part of the central Platte River Valley from Buffalo County to Platte County and in the north-central part of Holt County. Shallow water tables and sandy soils characterize these areas of intensive irrigation development. Fertilizer nitrogen is the principal source of greater concentrations of nitrate-nitrogen in these areas, but point sources such as barnyard and feedlot waste and leachate from individual septic systems may contribute.

Selenium concentrations exceeding the drinking-water standard of 10 micrograms per liter ($\mu\text{g/L}$), established by the U.S. Environmental Protection Agency (1976), occur in ground water in Boyd County. A maximum value of 480 $\mu\text{g/L}$ was detected in water from one well. Shallow wells in the area are developed in Pleistocene sands and gravels immediately overlying a seleniferous member of the Pierre Shale. Some of the aquifer material also is composed of reworked Pierre Shale. The large selenium concentrations in the ground water are derived from these sources.

Based on water-level rises or declines, recent economic discoveries, new methods for irrigation developments, increased use of agricultural chemicals, and other reasons, several areas of the State are considered possible future problem areas for nonpoint-source contamination. These areas, keyed by number to figure 29, are given in table on page 52.

Nitrate-nitrogen and pesticide contaminations in ground water may increase to problem concentrations in

Code no.	Area	Problem	Source
1	Central Platte River valley	Nitrate-nitrogen concentrations ranging from 10 to 30 milligrams per liter.	Fertilizer nitrogen; barnyard and feedlot waste; septic systems.
2	Holt County	---do-----	Fertilizer nitrogen from extensive irrigation development.
3	Boyd County	Selenium concentrations greater than 10 micrograms per liter.	Water from Pleistocene deposits composed of reworked Pierre Shale or in contact with seleniferous member of Pierre Shale.

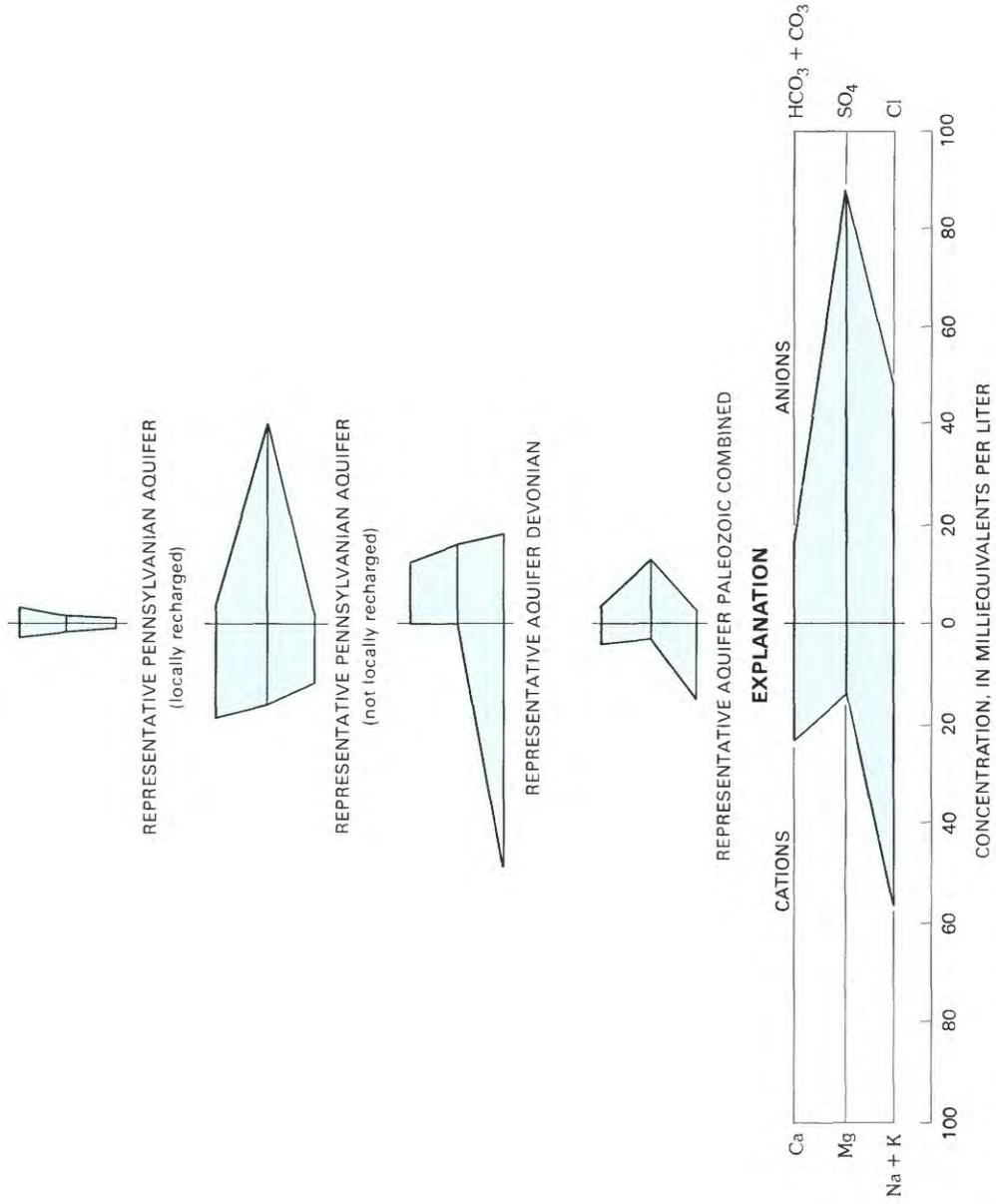


Figure 28. Diagrams showing variations in chemical composition of water from Paleozoic aquifers.

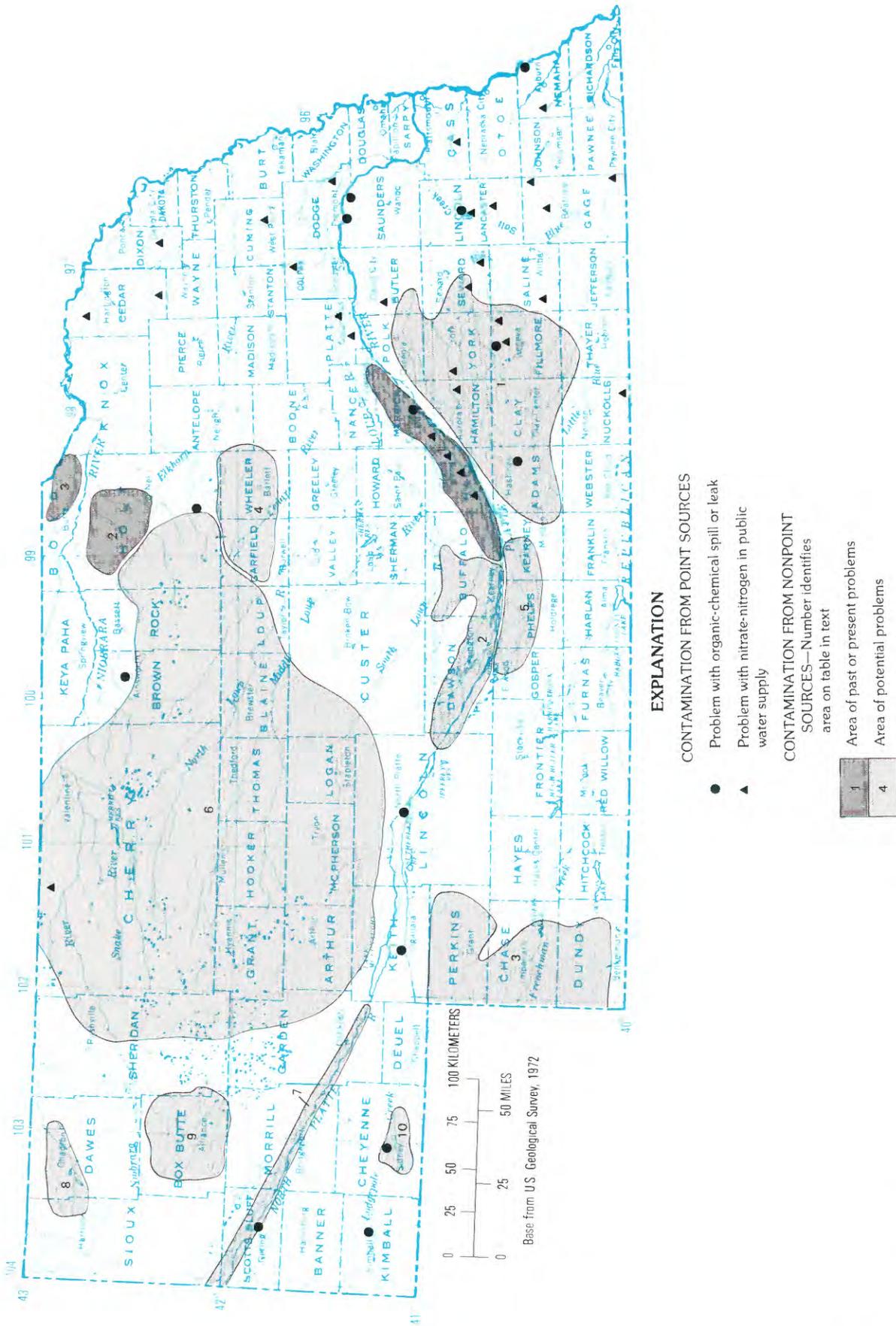


Figure 29. Map showing areas of past, present, and potential problems of ground-water quality.

Code number	Area	Possible problem	Possible source or reason
1	Big Blue River basin.	Nitrate-nitrogen, pesticides in ground water.	Agricultural chemicals; area has had water-level declines.
2	Parts of Buffalo, Dawson, and Lincoln Counties.	Nitrate-nitrogen, pesticides in ground water; increased salinity.	Agricultural chemicals; adjacent area to central Platte valley. Area in Buffalo County has had water-level declines. Extensive development of irrigation in Dawson County.
3	Upper Republican River basin.	-----do-----	Agricultural chemicals; possible importing of surface water to supplement ground water. Area has had water-level declines.
4	Parts of Garfield and Wheeler Counties.	Nitrate-nitrogen, pesticides in ground water.	Agricultural chemicals; sandy soil in area being developed on large scale for center-pivot irrigation.
5	Parts of Gosper, Kearney, and Phelps Counties.	Nitrate-nitrogen, pesticides in ground water; increased salinity.	Agricultural chemicals; area has had rising water levels as a result of recharge of aquifer with diverted surface water from irrigation.
6	Sand Hills	Nitrate-nitrogen, pesticides in ground water.	Agricultural chemicals; potential agricultural development.
7	North Platte River valley.	Nitrate-nitrogen, pesticides in ground water; increased salinity.	Agricultural chemicals; aquifer is recharged with diverted surface water from irrigation projects.
8	Parts of Dawes and Sioux Counties.	Radioactive constituents in ground water.	In-situ mining of extensive uranium deposits.
9	Most of Box Butte County.	Nitrate-nitrogen, pesticides in ground water.	Agricultural chemicals; area has had large water-level declines.
10	Part of Cheyenne County.	-----do-----	Agricultural chemicals; area has had water-level declines.

areas 1, 2, 3, 9, and 10 in the future. These areas all have large-scale development of ground water for irrigation and all have had water-level declines as a result of the development. Recharge derived locally and enriched

in agricultural chemicals probably will cause gradual increases of these constituents in ground water to problem concentrations.

Nitrate-nitrogen and pesticide concentrations in

ground water may increase to problem concentrations in areas 5 and 7. In both areas, surface water is used extensively for irrigation. Water levels have risen to within a few feet of the land surface in parts of these areas, and native ground water has been replaced or mixed with recharge water of increased salinity. Agricultural chemicals can move rapidly into the ground-water reservoir in areas of shallow water tables such as these, and concentrations of these constituents, or their derivatives, may increase in the ground water.

Use of the agricultural chemicals may increase rapidly in areas 4 and 6 as irrigation development proceeds. Both are areas of very sandy soils, and recharge infiltrates rapidly to the water table. Extensive irrigation development is underway in area 4, but development is proceeding slowly in area 6.

Radioactive constituents pose potential threats to the ground water in area 8. Extensive deposits of uranium recently were discovered in the area. The possible development of in-situ mining of uranium increases the possibility of contamination of ground water by other radiochemical constituents associated in trace quantities with the uranium.

FUTURE DATA NEEDS

Although many analyses already have been made of ground water in Nebraska, most have been made for specific projects with limited areas and objectives. Consequently, a lack of data exists for other areas of the State and for certain geologic units. For example, because the Mesozoic and Paleozoic aquifers previously have been used only sparingly, little has been done to evaluate the quality and quantity of water in these units. Future water requirements may necessitate detailed evaluation of these units as possible sources of irrigation or industrial water supply or as possible places for disposal of liquid wastes.

Little or no pesticide data for ground water presently have been collected. Likewise, no bacteriological data, except for that collected routinely for health considerations of public supplies, exist. Virtually no information is available on radionuclides in the ground water. Future studies need to address these data needs.

Studies also are needed that address the relationship of the hydrology of aquifer systems to the water quality in the systems. Although it is impossible to determine the quality of water at every point in an aquifer, a thorough understanding of the hydrologic system, of which the aquifer is a part, may lead to a better understanding of how water quality can change within the system.

The following matrix identifies, by aquifer grouping, major data needs for planning future ground-water quality projects in Nebraska:

Data needs	Aquifer			
	Holocene and Pleistocene	Tertiary	Mesozoic	Paleozoic
Areally distributed data-----	---	---	X	X
Major chemical constituents-----	---	---	X	X
Trace constituents-----	X	X	X	X
Bacteriological constituents-----	X	X	X	X
Radionuclides-----	X	X	X	X
Quality of water in the unsaturated zone-----	X	X	---	---
Relation of ground-water quality to surface-water quality-----	X	X	X	---
Relation of ground-water quality to regional flow systems-----	---	X	X	X
Pesticides-----	X	X	X	X

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