GROUND-WATER QUALITY IN NORTH DAKOTA, SOUTH DAKOTA, NEBRASKA, KANSAS AND OKLAHOMA

By

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CHAPTER I

INTRODUCTION

General Overview

Ground water has been an important water resource throughout the ages. Approximately half of our Nation's water supply is obtained from aquifers. One important role of the water scientists is to assess the quality of water supplies and provide information useful in assisting resource managers and policy makers in making wise decisions. The quality of ground water is affected by physical, chemical, biological, and human activities. The natural quality of ground water is determined largely by the types of rocks with which the water comes in contact. The interrelationship between surface and ground water also has a significant effect on the water quality.

The majority of ground-water samples collected for chemical analysis are obtained for site specific investigations. This information generally is studied and analyzed to address a concern that is of a local scale. The regional study described here relies on data that were collected by others; most probably were collected as a part of smaller scale studies focused on local problems. The fundamental working assumption is that a regional investigation provides a broader view and understanding of our overall ground-water system.

Purpose and Scope

The purpose of this study is to develop a computer-based method of mapping ground-water quality on a regional scale, and to use this method to map selected ground-water constituents in North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma (Figure 1). The chemical constituents used in this study include total dissolved solids, hardness, chloride, nitrate, and sulfate. The representation of ground-water quality can be done in a variety of fashions, and various types of graphical representation are discussed in the following section. Chemical constituents in this investigation will be displayed by range of concentration and by geographic location. This information can be used for general assessment of ground-water quality conditions at a specific location. It does not necessarily depict current conditions at a specific aquifer. The vast majority of samples were drawn from the major aquifer in the area.

Chemical Constituents

Introduction. Five chemical constituents were examined during this investigation. These included total dissolved solids, hardness, chloride, sulfate, and nitrate. These were selected because they are common constituents found in all ground water. Water samples are often analyzed for common chemical constituents.

Total Dissolved Solids. Total dissolved solids expresses the total concentration of dissolved minerals in water. The measurement is determined by the weight of residue remaining from a sample after evaporation at 180 degrees Celsius. The solid residue invariably consists of inorganic constituents and very small amounts of organic matter (Freeze and

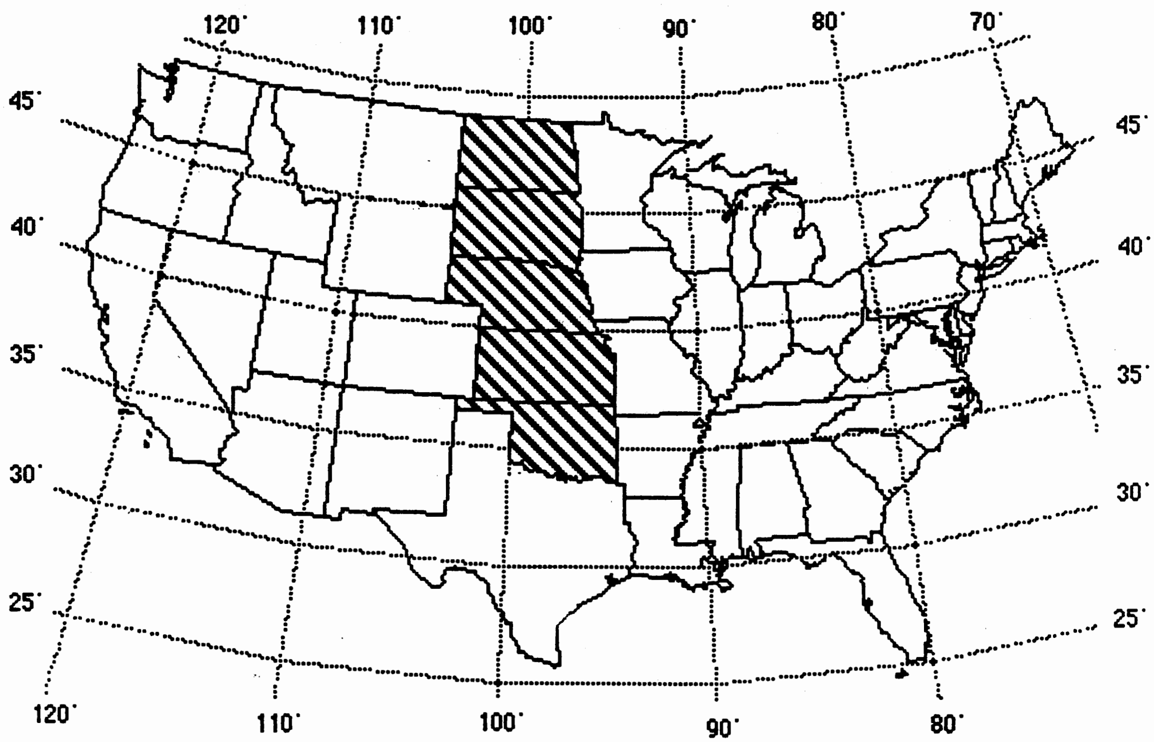


Figure 1. Location of the Study Area

Cherry, 1979). This measurement is commonly used in the general classification scheme presented in Table 1.

Hardness. Hardness is a term used to describe a property of water. It has no established limit for public supplies, however, it is an important constituent because even moderate concentrations lead to the build up of scale. Hardness is commonly expressed as the total concentration of calcium and magnesium as milligrams per liter equivalent of calcium carbonate. Total hardness is the sum of temporary hardness and permanent hardness. Temporary or carbonate hardness is calcium and magnesium carbonates that would be removed by boiling which precipitates calcium carbonate. Permanent or noncarbonate hardness is the calcium and magnesium that would exist as sulfates that would not be removed by boiling (Hounslow, 1991). Hard water requires more soap to produce suds, leaves an insoluble residue when combined with soap, and precipitates excessive scale formations when used in boilers. The terms "hard" and "soft" are inexact and have meaning only in the relative sense. Table 2 summarizes three hardness classifications.

Chloride. Waters with chloride concentrations in excess of 250 mg/l may exhibit objectionable taste characteristics. Most shallow natural ground water generally contains relatively low levels of chloride. Chloride occurs as the predominate anion in sea water where the average concentration is about 19,000 mg/l (Driscoll, 1987). Rain water in coastal regions generally contains higher concentrations of chloride than noncoastal regions. Common sources for chloride are precipitation, thermal waters, halite, saltwater intrusion, sewage leachate, oil-field brine, and road deicing salts.

TABLE 1

SIMPLE GROUNDWATER CLASSIFICATION
BASED ON TOTAL DISSOVLED SOLIDS

Category	Total Dissolved Solids (mg/l)
Fresh water	0 - 1000
Brackish water	1000 - 10,000
Saline water	10,000 - 100,000
Brine water	More than 100,000

Freeze and Cherry, 1979.

TABLE 2

SELECTED HARDNESS CLASSIFICATIONS

Hardness range (mg/l of $CaCO_3$)	Description
Classification 1	
0 - 60	Soft
61 - 120	Moderately Hard
121 - 180	Hard
Greater than 180	Very Hard
Classification 2	
0 - 60	Soft
Greater than 60 - 80	Excessive scale formation
Greater than 80 - 120	Common community practice to soften water
Greater than 150	Very Hard
Classification 3	
0 - 50	Soft
50 - 150	Acceptable for most uses
100 - 150	Scale formation
Greater than 150	Quite noticable scale formation and staining

Classification 1 modified from Hem, 1989.
Classification 2 modified from Freeze and Cherry, 1979.
Classification 3 modified from Driscoll, 1987.

Sulfate. The recommended limit of sulfate in public water supplies is 250 mg/l. Waters with high levels of sulfate may impart a bitter taste. For people not accustomed to elevated sulfate concentrations, these waters may act as a laxative. Common sources are gypsum, anhydrite, pyrite, thermal waters, from the combustion of fossil fuels and smelting of ores.

Nitrate. Nitrate-nitrogen (NO3-N) concentrations above 10 mg/l are cause for concern due to its toxic effect on infant children and some animals. It can cause methemoglobinemia or blue babies in infants. Cattle experience loss of milk production and aborted calves. Unlike most other elements in ground water, nitrate is not derived primarily from earth materials. Nitrate enters ground water from the nitrogen cycle in the earth's hydrosphere and biosphere. It is generally expressed as nitrate as NO3, or nitrate as N (1 mg/l N equals 4.5 mg/l NO3). Nitrate can not be removed by boiling. Common sources of nitrate are barnyards, sewage lagoons, and agricultural chemicals.

Drinking Water Standards

The Environmental Protection Agency (E.P.A.) established drinking water standards by direction of the Safe Drinking Water Act. Primary maximum contaminant levels (MCLs) were established for materials that propose a health risk, such as nitrate. Secondary maximum contaminant levels govern substances that can affect the aesthetic quality of water by adverse taste, color, odor, or by staining. The E.P.A. also established recommended concentration limits for dissolved solids and nitrate relative for use as crop irrigation and livestock production. Table 3 outlines drinking water standards as they apply to this investigation.

TABLE 3

SELECTED WATER QUALITY STANDARDS

Drinking Water

Constituent	Standard: Primary MCL (mg/l)	Standard: Secondary MCL (mg/l)
TDS	-	500*
Chloride	-	250
Sulfate	-	250
Nitrate as N	10	-

Crop and Livestock

Constituent	Recommended concentration limit (mg/l): Livestock	Recommended concentration limit (mg/l): Irrigation Crop
TDS		700
Small Animals	3000	-
Poultry	5000	-
Other Animals	7000	-
Nitrate as N	10	-

TDS - Total dissolved solids
MCL - Maximum contaminant level
* Concentrations of 1000 mg/l are acceptable where levels below 500 mg/l can not be obtained.

Modified from Driscoll, 1987 and Freeze and Cherry, 1979.

Previous Investigations

Studies that address ground-water quality on a national, regional, or state scale are relatively few compared to some of the other geologic subdisciplines. One of the most complete works was published by the U.S. Geological Survey (1988). This nationwide study describes the ground-water quality of the major aquifers in each state. Analyses were obtained from the data base, WATSTORE, the U.S. Geological Survey's National Water Data Storage and Retrieval System. Chemical constituents evaluated include dissolved solids and hardness. Other constituents evaluated varied from common major ions to radionuclides. The analyses were grouped by major aquifers and graphically displayed as statistical percentiles (Figure 2).

In 1979 Pettyjohn and others published a ground-water atlas of the Nation. The purpose of this study was to develop a series of general maps for each state that showed the chemical quality of drinking water that was obtained from aquifers in rural America. Rural America was defined as population centers of less than 10,000 people. The primary data source was ground water quality records obtained from the U.S. Geological Survey in the form of magnetic tapes. Some published state and federal water analyses also were used. Chemical variables mapped were: (1) total dissolved solids, (2) hardness, (3) chloride, (4) sulfate, (5) calcium plus magnesium and (6) sodium plus potassium. Data were displayed with two chemical variables per map; one variable represented by contour intervals and the other by a range of concentration (Figure 3). Statistics used in the evaluation were maximum, minimum, mean, and standard deviation for each chemical variable.

In 1986 Congress appropriated funds to the U.S. Geological Survey to test and refine concepts for a national water-quality assessment (NAQWA)

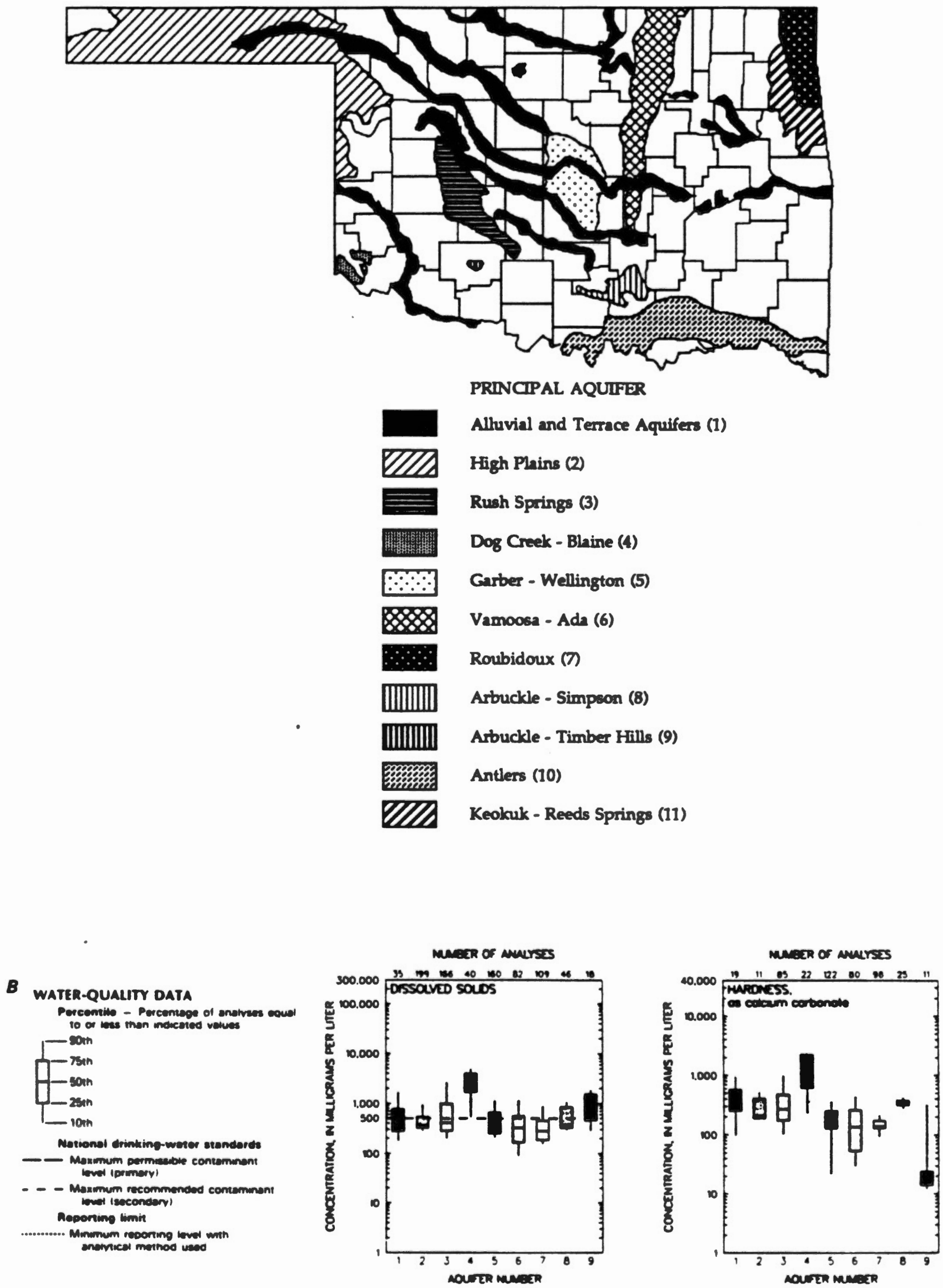


Figure 2. Box-and-Whisker Plots, Principle Aquifers of Oklahoma (Modified from U.S.G.S., 1988)

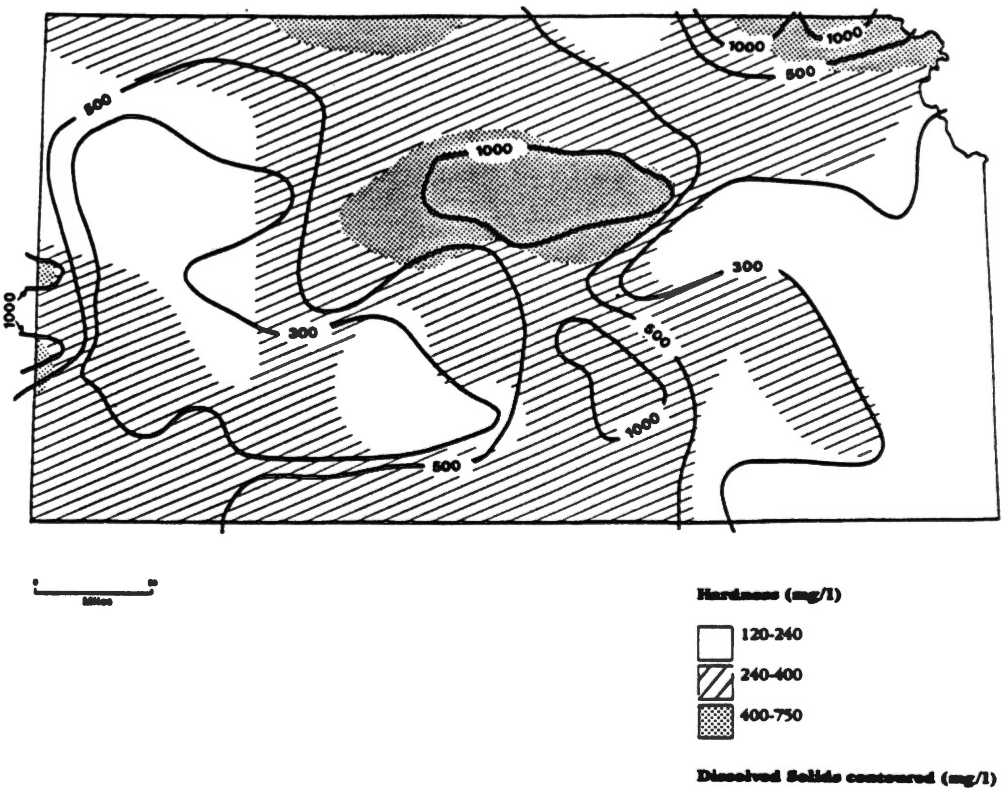


Figure 3. Data Represented by Contours and by Range of Concentration (Pettyjohn and Others, 1979)

program. The programs goals were: (1) provide a nationally consistent description of the water-quality conditions for a large part of the Nation's water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends (Parkhurst and others, 1989). Three ground-water and four-surface water pilot studies were conducted to refine water-quality assessment and to determine the need for a full scale program. One of the ground-water pilot studies was conducted by Parkhurst and others (1989). This study described the Central Oklahoma Aquifer. Water-quality data for the aquifer was obtained from the following local, state and federal agencies: (1) Association of Central Oklahoma Governments, (2) Oklahoma State Department of Health, (3) Oklahoma Water Resources Board, (4) U.S. Department of Defense, (5) U.S. Department of Energy, and (6) U.S. Geological Survey. Analyses that could be associated with specific geographical location and the U.S.G.S. well inventory procedure were mapped. Chemical constituents investigated were inorganic compounds, organic compounds and radionuclides. Figure 4 depicts the method of data mapping.

Sprinkle and others (1983) conducted a ground-water quality study for the state of Kentucky. Although this report does not lie within the present study area, their methods of investigating ground-water quality on a regional scale warrant review. The primary objectives of the Sprinkle study were to examine the computer files of the U.S. Geological Survey and (1) determine if the data needed to describe the ground-water quality of Kentucky were available, (2) identify errors and deficiencies in the data, and (3) to the extent possible, use the available data to describe ground-water quality by major geohydrologic units. The data used included analyses collected from wells

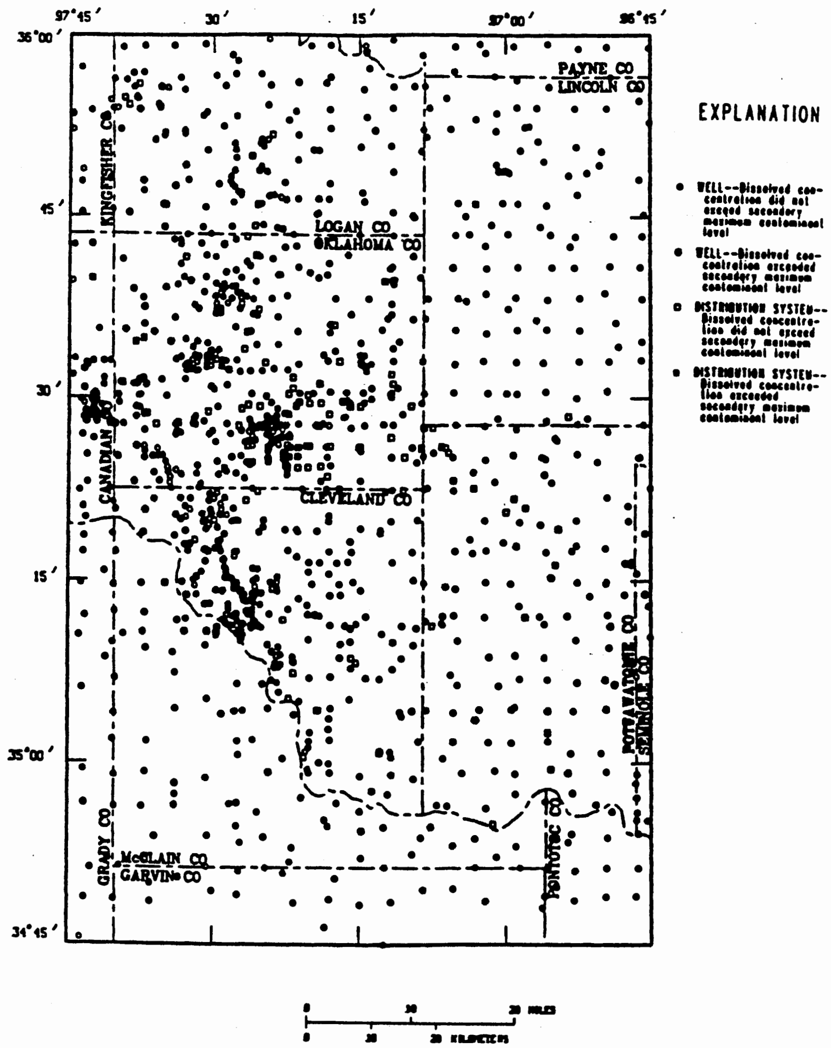


Figure 4. Locations of Wells Where Ground Water Was Above and Below Secondary Contaminant Levels, Central Oklahoma Aquifer (Parkhurst and Others, 1989)

and springs before October 1981 that were accessed from the WATSTORE database. The water was analyzed for physical properties, such as temperature and color, as well as chemical properties such as major inorganic ions, nutrients, trace elements, radionuclides, and organic chemicals. Principle water-bearing formations were combined into 10 retrieval groups based on geological age. For each retrieval group dissolved solids were mapped by means of color code by range of concentration. Analyses that were considered to be complete and ionically balanced were plotted on quadrilinear diagrams (Figure 5). The statistical parameters selected to characterize the major dissolved constituents and physical properties were: (1) maximum, (2) minimum, (3) median, and (4) the 75 percent and 25 percent quartiles. Frequency bar graphs of dissolved solids, chloride, sulfate, and hardness were prepared for each retrieval group.

Durfor and Becker (1962) prepared the hydrologic investigation atlas of the United States and Puerto Rico. This study addresses the selected quality of water supplies for population centers exceeding 2,500 residents. The data used were obtained from district offices of the U.S. Geological Survey, as well as from published and unpublished data from local, county, and state agencies. The findings are shown on eight maps that depict the dissolved solids, sodium, fluoride, and hardness of untreated and finished water supplies of 1,596 municipal water systems (Figure 6). Also included is a table summarizing the population served by the municipal systems, number of systems surveyed, and a trend of hardness concentration from 1922 to 1962.

Feth and others (1965) investigated dissolved solids concentrations and their depth. This study was conducted on a national scale. Two maps of scale 1: 3,168,000 summarizes the data, which was collected by the U.S. Geological Survey in cooperation with state, local, and federal agencies. The Depth and

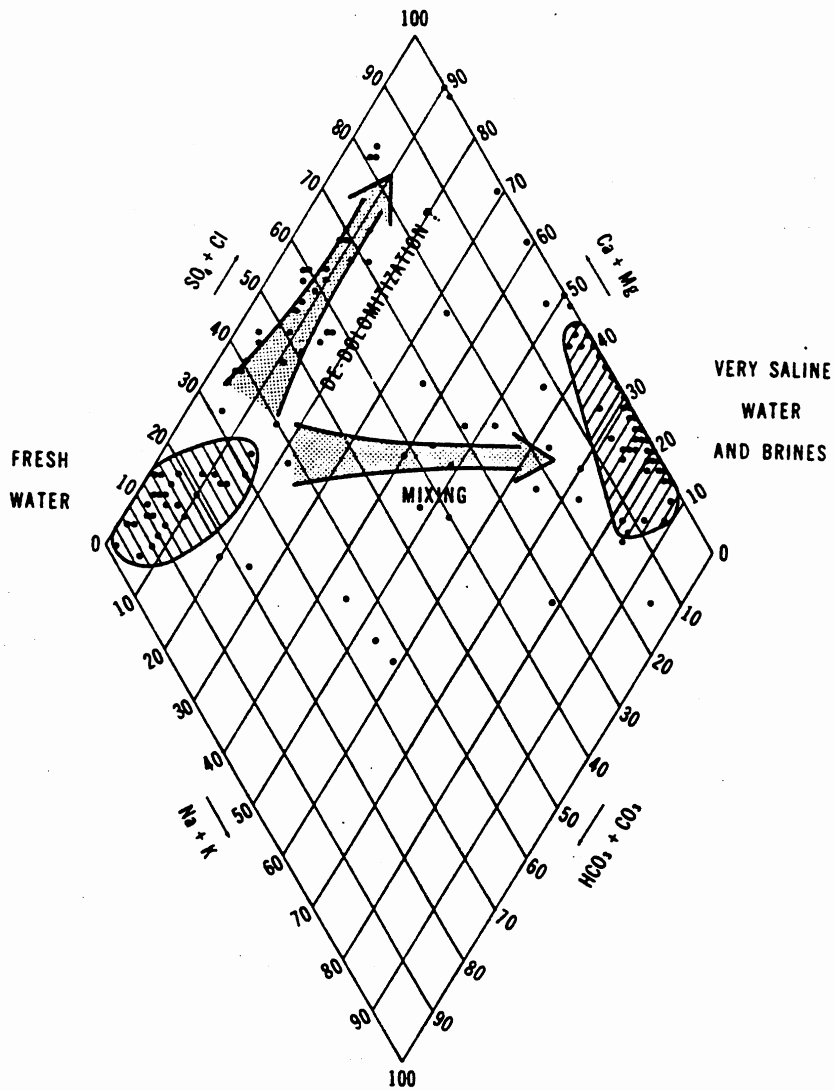


Figure 5. Data Represented on a Quadrilinear Diagram (Sprinkle and others, 1983)

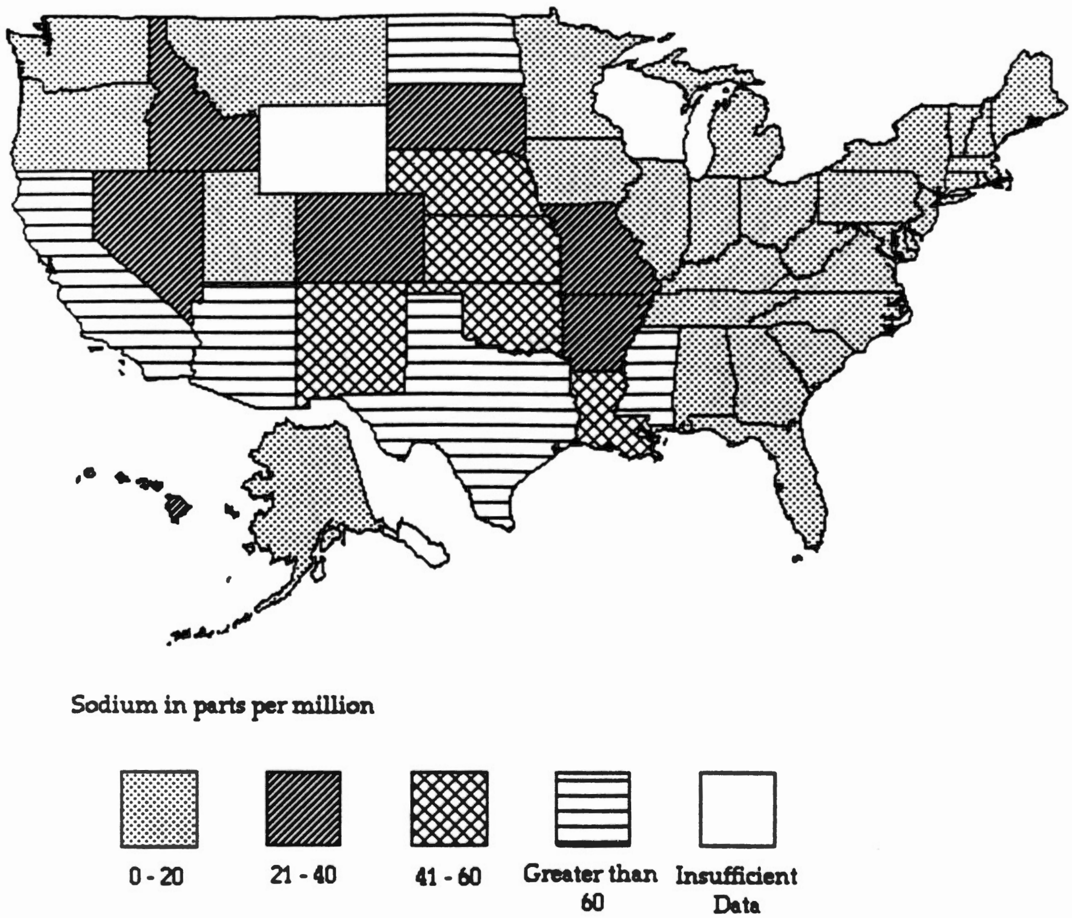
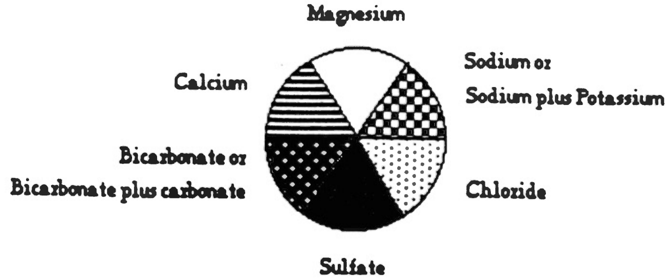


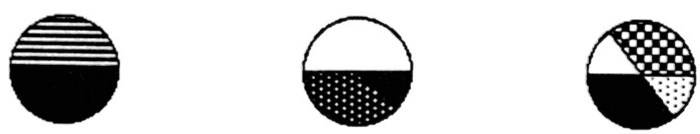
Figure 6. Data Represented in Concentration Average Weighted by Population Served (Modified by Durfor and Becker, 1962)

Distribution of Mineralized Water map shows dissolved-solid concentration by color coded-ranges. Depth to shallowest zone that contains mineralized water is shown by patterned depth ranges. The Chemical Types of Water map uses pie diagrams to represent graphically major ions found in water. Figure 7 diagrams the example used from the study.



1) The size of the pie represents concentration ranges of dissolved solids.
2) The subdivisions in the top half of the pie represent percentage compositions of the following positive ions: (1) calcium, (2) magnesium, and (3) sodium or sodium plus potassium. The sum of equivalents of these positive ions was assumed to be 100 percent and the percentage of each was calculated from that base. The bottom half of the pie represents percentage compositions of the following negative ions: (1) bicarbonate or bicarbonate plus carbonate, (2) sulfate, and (3) chloride. Similarly, the sum of equivalents of negative ions was taken to be 100 percent and the percentage of each was calculated from that base.
3) Where one constituent makes up 51 percent or more of the total cations (calcium = 68 % in example 1) and one makes up 51 percent or more of the total anions (sulfate = 75 % in example 1), the major cation and major anion give their names to the water type - calcium sulfate in example 1.
4) Where no constituent makes up as much as 50 percent of the cations or none makes up 50 percent of the anions, the constituent making up the largest percentage is named first; the second largest follows as a subsidary term (examples 2 and 3). The subdivisions of the hemisphere is diagrammatic, the dominated cation or anion occupying two-thirds of the hemisphere and the second highest one third, regardless of the actual proportions between them. Rarely, all three major cations (or three anions) are virtually equal in percentage.

Examples



	Example 1 %	Example 2 %	Example 3 %
<u>Cations</u>			
Calcium	68	5	21
Magnesium	11	21	35
Sodium	21	74	46
<u>Anions</u>			
Bicarbonate	22	40	15
Sulfate	75	35	48
Chloride	3	25	37
	Calcium sulfate type water	magnesium bicarbonate sulfate type water	Sodium magnesium sulfate chloride type water

Figure 7. Data Represented by Pie Diagram with Explanation (Modified From Feth and Others, 1965)

CHAPTER II

DESCRIPTION OF THE STUDY AREA

Location and Physiography

The study area includes North Dakota, South Dakota, Nebraska, Kansas, and Oklahoma in the central United States. With the exception of far eastern Oklahoma the area lies within the Great Plains and Central Lowlands physiographic provinces (Figure 8). The Great Plains province is characterized by flat upland plains and valleys that are broad, shallow and steep-sided. Low rolling hills and dissected till plains shape the landscape of the Central Lowland province. In Oklahoma's eastern margin low mountains with subparallel ridges and valleys form the Ozark Plateaus and Ouichita provinces. Gently sloping plains make up the Coastal Plains physiographic province in southeastern Oklahoma.

Generalized Geology of the Region

The study area principally occupies parts of the Nonglaciated Central, Glaciated Central, High Plains and Alluvial Valleys ground-water regions (Figure 9). Small areas in North Dakota and South Dakota lie in the Northeast and Superior Uplands region and Western Mountain Ranges region, respectively. Both the Glaciated and Nonglaciated Central regions are underlain by gently dipping Paleozoic to Tertiary age bedrock that consists primarily of sandstone, shale, and limestone. The Glacial region is mantled

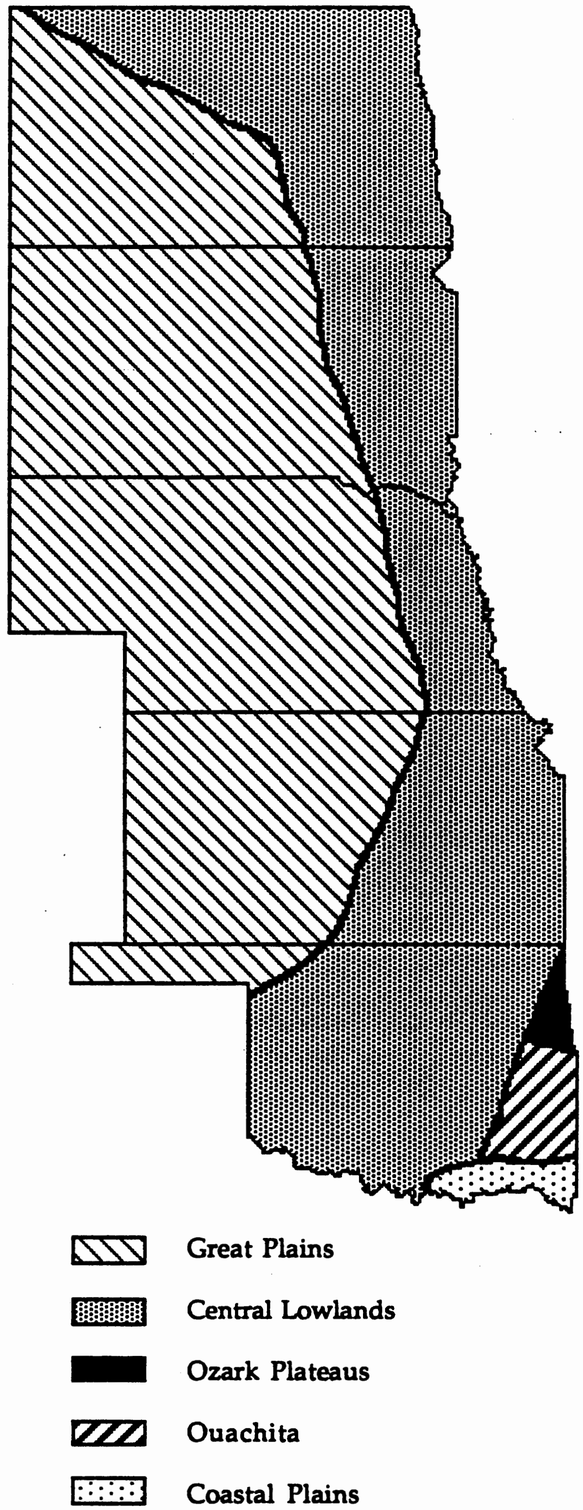


Figure 8. Physiographic Provinces of the Study Area
(Modified from Hunt, 1967)

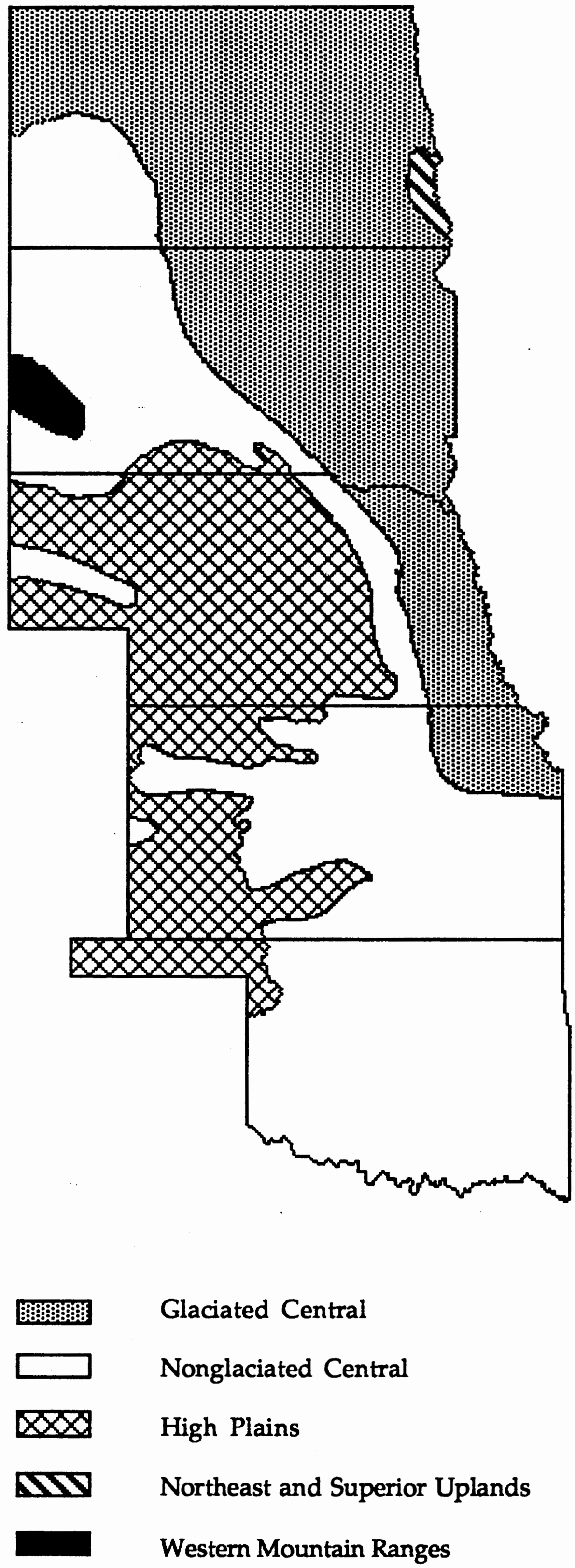


Figure 9. Ground-Water Regions of the Study Area (Modified From Heath, 1984)

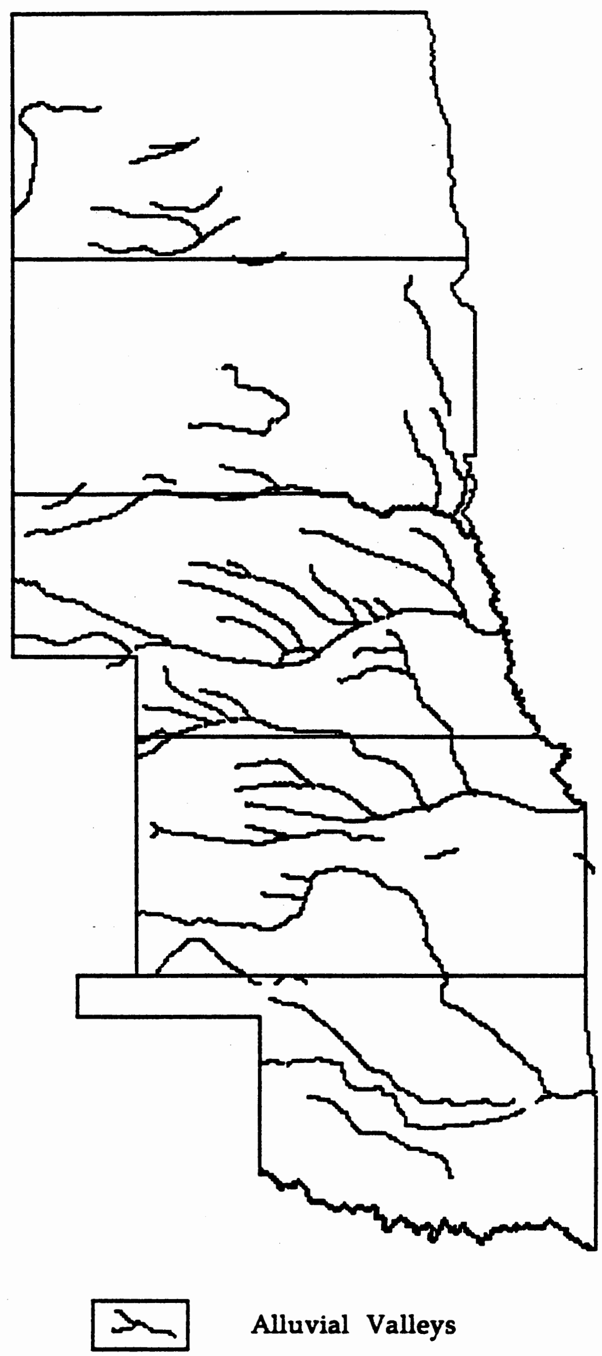


Figure 9. Continued

by till, loess, and outwash sediments deposited during Pliestocene age glacial episodes. The High Plains region is underlain by Permian to Cretaceous age sedimentary rock that dips gently to the east. Overlying these strata is an alluvial apron deposited by streams that flowed eastward from the Rocky Mountains. These Tertiary deposits consist of unconsolidated to semiconsolidated gravel, sand, silt, and clay known as the Ogallala Formation. Recent deposits of eolian dune sands overlie the Ogallala in parts of Nebraska, Kansas and Oklahoma. The Alluvial Valley region is not one of geographic continuity, but rather one of geologic origin. Alluvial valleys are occupied by thick sand and gravel deposits that are in hydraulic contact with a perennial stream. These channel deposits generally do not extend beyond the floodplain and adjacent alluvial terraces.

Regional Precipitation Pattern

Precipitation varies greatly in the study area (Figure 10). Average annual precipitation ranges from less than 16 inches in the western margin to over 52 inches in southeastern Oklahoma. Contour lines representing precipitation amounts trend generally in a north-south lineation and increases from west to east in the region. The amount of precipitation has a significant effect on ground-water recharge, quality, and streamflow.

Occurrence of Ground Water in the Area

This region, consisting of approximately 377,000 square miles, is quite diverse in geology and water resources. The glaciated area contains ground water in surficial and buried deposits of sand and gravel, as well as in extensive pre- and interglacial valleys. Commonly, these aquifers provide

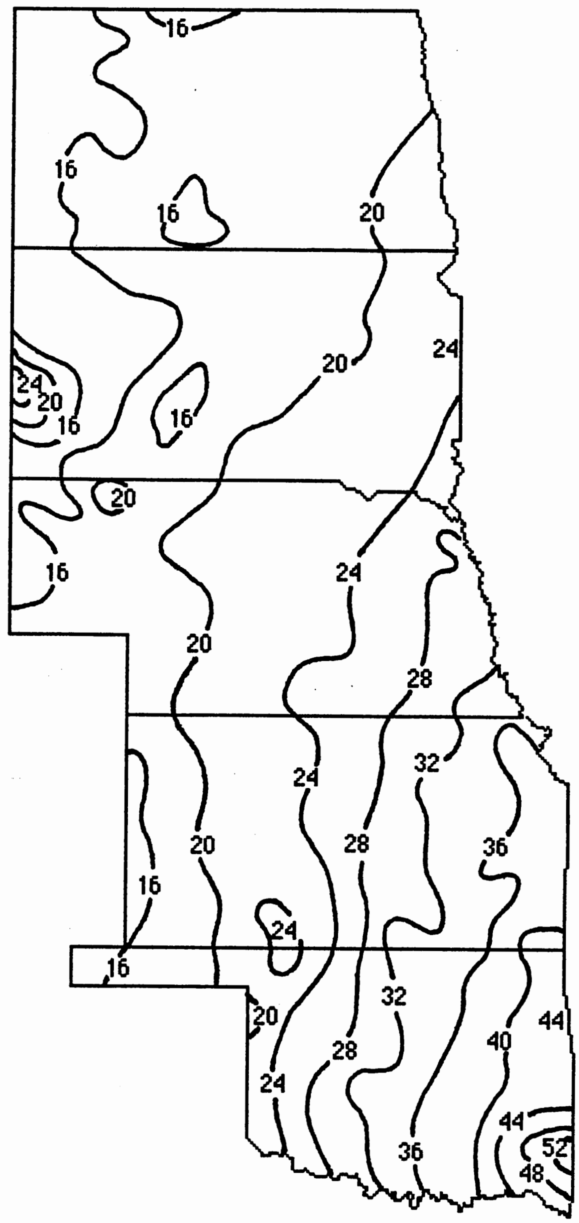


Figure 10. Average Annual Precipitation in the Study Area

large quantities of water to wells. The chemical quality of the ground water although generally very hard, is useful for domestic, municipal, industrial supplies, as well as irrigation. Ground water obtained from wells tapping glacial till is generally highly mineralized and well yields usually range from less than one to several gallons per minute.

The Non-glaciated Central Region contains ground water in sedimentary bedrock aquifers that range from Tertiary age in North Dakota to middle Paleozoic age in Kansas and Oklahoma. These aquifers consist generally of sandstone and siltstone with some limestone and gypsum. The Tertiary age aquifers in North and South Dakota generally contain water that is soft and has high levels of sulfate. This water is suitable for most purposes except irrigation.

The Cretaceous age aquifers in Kansas and Oklahoma yields up to several hundreds of gallons per minute of water to wells. The water is generally suitable for most uses but is considered hard and highly mineralized in some areas.

Paleozoic age aquifers occupy southeast Kansas and much of Oklahoma. The water is considered suitable for domestic, industrial, municipal, and irrigation use. Water from these aquifers generally ranges from hard to very hard. Well yields commonly range from a few tens to several hundreds of gallons per minute.

Ground water in the High Plains Region occurs in unconsolidated to semiconsolidated Tertiary age deposits. These deposits consist of gravel, sand, silt, and clay. The saturated thickness of the aquifer ranges from a few feet to over 500 feet in some areas (U.S.G.S., 1988). The water is generally suitable for public supply, although some areas contain high levels of chloride and sulfate. Well yields commonly range from 100 to 1000 gallons per minute.

Alluvial valley aquifers occur throughout the study area and are a major source of ground water. Fluvial and terrace deposits consist of gravel, sand, silt, and clay. This water is used for both public supply and irrigation use. The water obtained from alluvial aquifers is considered hard and locally contains high levels of dissolved solids, chloride, and sulfate. Wells that tap these aquifers may yield several hundreds of gallons per minute.

CHAPTER III

METHODOLOGY

Description of the Data Base

This study evaluates ground-water quality using data stored on compact disks, which were prepared by EarthInfo, Inc. The associated program, Hydrodata QW, accesses WATSTORE data via personal computer. The entire file contains about 15,000,000 measurements from about 200,000 sampling stations throughout the United States. The data file contains analyses that were collected for a variety of purposes. Most of the data was collected by the U.S. Geological Survey to meet the objectives of site-specific or subregional investigations. Some water samples do not represent natural conditions since they were collected during or after episodes of contamination. To conserve funds, these studies restricted the analyses of ground water samples to major inorganic constituents. Relatively few samples were analyzed for organic chemicals or trace elements.

The Hydrodata QW program was operated on a 386-type personal computer with compact disc optical drive. Selected chemical analyses were obtained by filtering the data through location, analysis type, and parameter criteria. The data used for this investigation were taken from only ground water samples in each state.

Computer Hardware

The computer hardware used in this investigation is as follows: (1) 386 IBM compatible personal computer with 40 megabyte hardrive and an optical disk (CD-ROM) drive by Hitachi, (2) Macintosh IIci desktop computer by Apple with a removable hardrive by SyQuest, and (3) Laser Writer II printer, also by Apple.

Computer Software

Computer software was an essential part of the gathering, organizing, and mapping the water-quality data. The computer programs used on the personal computer or PC include: (1) Hydrodata QW by EarthInfo, (2) Wordstar by MicroPro, and (3) SEP100 by Kelly Goff. Programs used on the Macintosh are: (1) Atlas MapMaker 4.5 by Strategic Mapping, (2) Apple File Exchange 1.1.1 by Apple, (3) Microsoft Word 4.0 by Microsoft, (4) Microsoft Excel by Microsoft, and (5) SuperPaint 1.1 by Bill Snider.

CHAPTER IV

PROCEDURE

Data Base Search

The analyses were obtained from Hydrodata QW by specifying a distinct search path or query. One query was run for each of the five states. Each query consisted of the state, all samples that were drawn only from a well, and the 20 constituents (the Hydro QW program labels constituents as parameters) listed on Table 4. Once the search was complete the analyses were saved to the hardrive as a state file. Complete computer steps and commands are listed in the Appendix.

Analyses Editing

Each sample analysis contains concentrations of selected constituents and a station location identification code. The identification code is a 14 digit number representing latitude and longitude in degrees, minutes and seconds, as well as a sequence positioning code. To map the location of the well and express a measurement on MapMaker the data must be put in a specific format. Latitude and longitude can only be read from a file in decimal form. Every sample was not tested for all parameters requested. For example, some samples were only tested for hardness and chloride, while others were tested for all 20 parameters. Again, due to the requirements of MapMaker, each parameter must be listed in the file in a specific position or category. Each

TABLE 4

PARAMETERS SEARCHED IN THE DATA BASE

Parameter	Units
Total dissolved solids	mg/l
Hardness	mg/l
Chloride	mg/l
Sulfate	mg/l
Nitrate as N	mg/l
Temperature	celcius
Specific Conductance	micromhos
Bicarbonate	mg/l
pH	standard units
Calcium	mg/l
Magnesium	mg/l
Sodium	mg/l
Potassium	mg/l
Fluoride	mg/l
Silica	mg/l
Boron	ug/l
Iron	ug/l
Nitrate as NO3	mg/l
Depth of well	feet
Depth to water	feet

state file was run through SEP100 in order to create a decimal form location file and a data file with parameters in the appropriate categories. The location and data files were then edited in Wordstar to remove unwanted spaces between data. Once the data were edited, the files were of a manageable size, containing approximately 800 kilobytes, that could be transferred to a high density 3.5 inch floppy disk. A disk was prepared for each state, placed into the Macintosh and then run through the Apple File Exchange program. This process allows the Macintosh to read a file that was created on a PC.

Mapping

The MapMaker program contains a variety of boundary files such as the outline of a state. One also can combine several boundary files to make a map. The imported latitude-longitude file was converted to a boundary file and then combined with the state outline boundary file. The combined file was used to create a map showing the locations of all sampling stations in that state. Once this map was created, the data file containing the measurements for each of the 20 chemical parameters was imported into each map file. The maps shown in this investigation were created by selecting a state, a chemical parameter, and a specific range of concentration.

CHAPTER V

GROUND-WATER QUALITY BY STATE

North Dakota

General Setting

North Dakota contains approximately 71,000 square miles. Annual average precipitation ranges from less than 14 inches in the western part of the state to about 20 inches in the southeast. Western North Dakota is principally drained by southeastern flowing Missouri River network. The eastern part of the state is drained by the north flowing Red River of the North and its tributaries.

North Dakota is underlain by Paleozoic to Tertiary age clastic and carbonate rock. The bedrock dips gently westward into the Williston Basin in the western part of the state. These units thin to the east and primarily consist of shale, sandstone, and limestone. All but the southwest part of North Dakota is overlain by unconsolidated glaciofluvial, glaciolacustrine and glacial till deposits of Quaternary age.

Discussion

Table 5 exhibits the number of analyses measured, percentage of samples that exceed E.P.A. drinking water standards, and percentage in each range of concentration. A map of the major aquifers in North Dakota and their descriptions is depicted in Figures 11 and 12. Maps illustrating the location of wells and selected ground water quality in North Dakota are shown in Figures 13-43.

Eighty five percent of the ground-water samples tested for total dissolved solids in North Dakota exceed the recommended limit of 500 mg/l, and 57 percent of those sampled exceed 1000 mg/l. The high concentrations appear to be rather evenly distributed throughout the state, without regard to major aquifers present (Figure 15 and 16). Data in Table 5 suggests that much of the dissolved solids concentration is related to the presence of sulfate. The sulfate may have been derived from gypsum, which is widely distributed throughout the state.

More than 7700 samples have been analyzed for hardness in North Dakota. About 68 percent of those samples exceed 180 mg/l, which is considered very hard water. This reflects the wide spread distribution of carbonate material and gypsum, particularly the glacial till. About 18 percent of the samples contain water that would by considered soft, that is, less than 60 mg/l of hardness. Ground water in the Tertiary strata is characteristically soft, owing to the abundance of sodium and the lack of calcium in the water. Soft water appears to be most abundant in the southwestern part of the state where Tertiary strata crop out. Elsewhere the strata is covered by glacial till, which contains hard water.

Over 8700 samples were analyzed for chloride in the state. 81 percent contain water which measured less than 125 mg/l of chloride, and is distributed somewhat evenly throughout the state. Figures 27 and 28 indicate that waters with higher concentrations are located in the north-central and eastern parts of the state. Although some of the higher chloride concentrations may be the result of contamination, perhaps caused by oil-field activities, the elevated values present in the eastern third of the state are probably related to upward leakage from the Dakota Sandstone and other bedrock aquifers.

Only 4 percent of the samples analyzed for nitrate as N and nitrate as NO3 exceed the recommended levels. Maps of wells where nitrate was measured indicate a fairly even distribution throughout the state. High concentrations may be related to poor well construction, which allows nitrate-rich waters, such as barnyard wastes, to infiltrate around the well bore. In some cases nitrate concentrations may be related to agricultural practices. In other cases high values are the result of leaching of decaying organic matter from the millions of potholes, which are naturally occuring undrained depressions, which are characteristic of the glaciated regions.

TABLE 5

NORTH DAKOTA: NUMERICAL SUMMARIES OF WATER ANALYSES

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
TDS		500*	85	•
All Samples	7632		•	•
0 - 500	1184		•	16
501 - 1000	2103		•	28
Greater than 1000	4345		•	57
Equal to or Greater Than			•	•
the 90th Percentile	646		•	8
Hardness		None	•	•
All Samples	7815		•	•
0 - 60	1432		•	18
61 - 120	546		•	7
121 - 180	509		•	7
Greater than 180	5328		•	68
Equal to or Greater Than			•	•
the 90th Percentile	793		•	10
Chloride		250	13	•
All Samples	8736		•	•
0 - 125	7058		•	81
126 - 250	564		•	6
Greater than 250	1106		•	13
Equal to or Greater Than			•	•
the 90th Percentile	871		•	10
Sulfate		250	49	•
All Samples	8402		•	•
0 - 125	2602		•	31
126 - 250	1682		•	20
Greater than 250	4118		•	49
Equal to or Greater Than			•	•
the 90th Percentile	846		•	10

TABLE 5 (continued)

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
Nitrate as N		10	4	•
All Samples	5365		•	•
0 - 5	5069		•	95
6 - 10	92		•	2
Greater than 10	204		•	4
Equal to or Greater Than			•	•
the 90th Percentile	539		•	10
Nitrate as NO3		45	4	•
All Samples	6715		•	•
0 - 25	6301		•	94
26 - 45	115		•	2
Greater than 45	299		•	4
Equal to or Greater Than			•	•
the 90th Percentile	682		•	10

EXPLANATION

Principle Unconsolidated Aquifers

Fort Union Aquifer System

Hell Creek - Fox Hills Aquifer System

Great Plains (Dakota) Aquifer System

Ordovician and Precambrian Rocks

Madison Group Aquifer (Not Shown)

Figure 11. North Dakota: Map of Major Aquifers (Modified from U.S.G.S., 1985)

[Gal/min = gallons per minute; ft = feet; mg/L = milligrams per liter; Sources: geologic and hydrologic reports of the U.S. Geological Survey and the North Dakota State Water Commission]

Aquifer name and description	Well characteristics			Remarks
	Depth (ft)	Yield (gal/min)		
	Common range	Common range	May exceed	
Unconsolidated aquifers:				
Englevale: Sand, gravel, silt, and silty clay. Confined and unconfined.	0 - 80	1 - 1,000	1,500	Water hard to very hard. Large concentrations of iron (mean concentration of 1.9 mg/L) and manganese (mean concentration of 0.4 mg/L). Suitable for irrigation.
Oakes: Sand, gravel, silt, and silty clay. Confined and unconfined.	0 - 100	1 - 500	700	Water moderately hard to very hard. Locally large concentrations of iron (0.1-10 mg/L). Suitable for irrigation.
Page: Sand and gravel. Confined and unconfined.	10 - 180	1 - 300	500	Water very hard. Locally large concentrations of iron (0.01-0.4 mg/L). Suitable for irrigation.
Spiritwood: Sand and gravel interbedded with silt and clay. Confined and unconfined.	0 - 300	1 - 1,000	1,500	Water mostly hard. Locally large concentrations of iron (0.4-9.1 mg/L). Suitable for irrigation.
Sundre: Sand and gravel. Confined and unconfined.	50 - 300	1 - 500	1,000	Water mostly hard. Generally large concentrations of iron (generally greater than 2 mg/L). Suitable for public supply or irrigation.
West Fargo: Sand, gravel boulders, and clay lenses. Confined.	100 - 250	10 - 1,000	1,300	Water hard to very hard. Suitable for public supply and selected industry.
Consolidated aquifers:				
Fort Union aquifer system: Sandstone, siltstone, claystone, and lignite.	0 - 900	1 - 100	150	Water generally soft. Sodium sulfate bicarbonate water. Locally large concentrations of sulfate (50-9,600 mg/L) and iron (0.01-42 mg/L). Generally not suitable for irrigation.
Hell Creek-Fox Hills aquifer system: Sandstone, siltstone, claystone, and shale.	0 - 2,000	1 - 150	300	Water soft. Sodium bicarbonate sulfate water. Generally not suitable for irrigation.
Great Plains aquifer system: Sandstone, siltstone, and shale.	500 - 5,500	10 - 60	1,000	Water salinity (mean dissolved-solids concentration 7,300 mg/L) limits use to oil recovery in western part of State and stock watering in eastern part of State.
Madison Group aquifer: Limestone, some sandstone and shale.	200 - 6,000	-	-	Highly saline (mean dissolved-solids concentration 19,000 mg/L). Undeveloped in State.

Figure 12. North Dakota: Major Aquifer Descriptions and Well Characteristics (Modified from U.S.G.S., 1985)

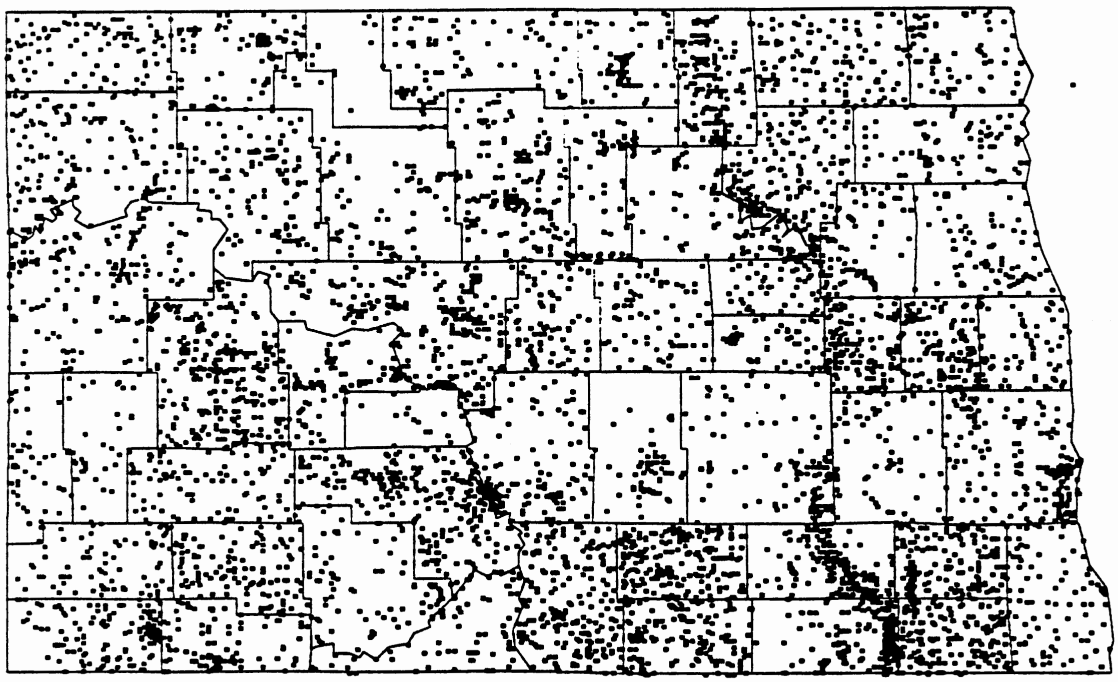


Figure 13. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Total Dissolved Solids

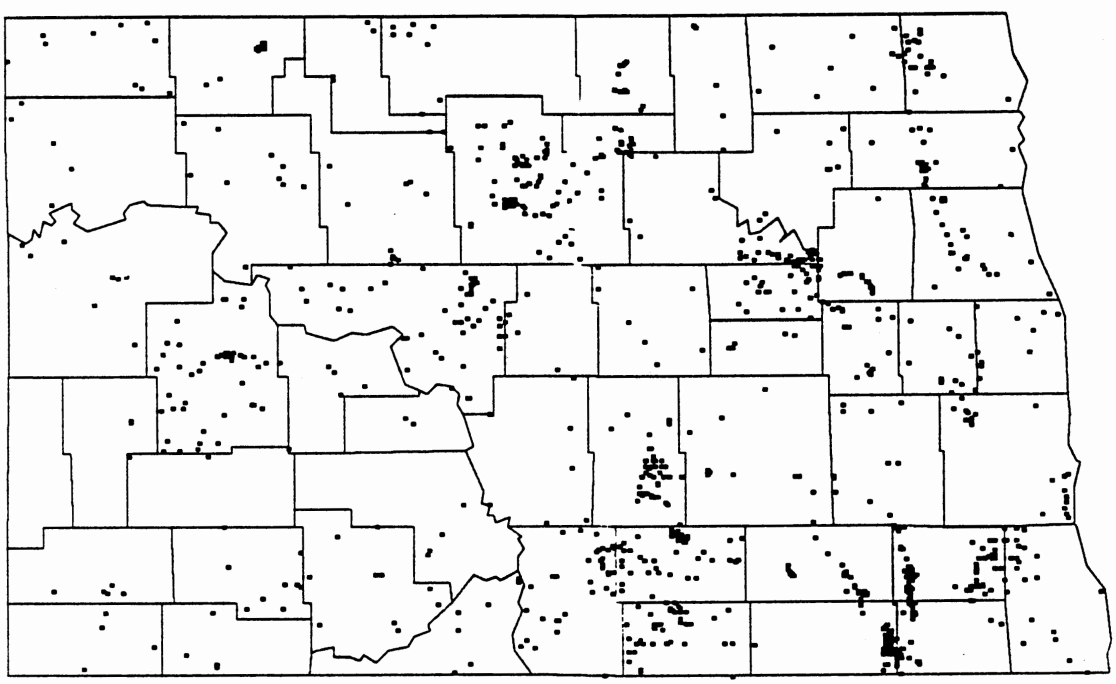


Figure 14. North Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Less Than or Equal to 500 mg/l

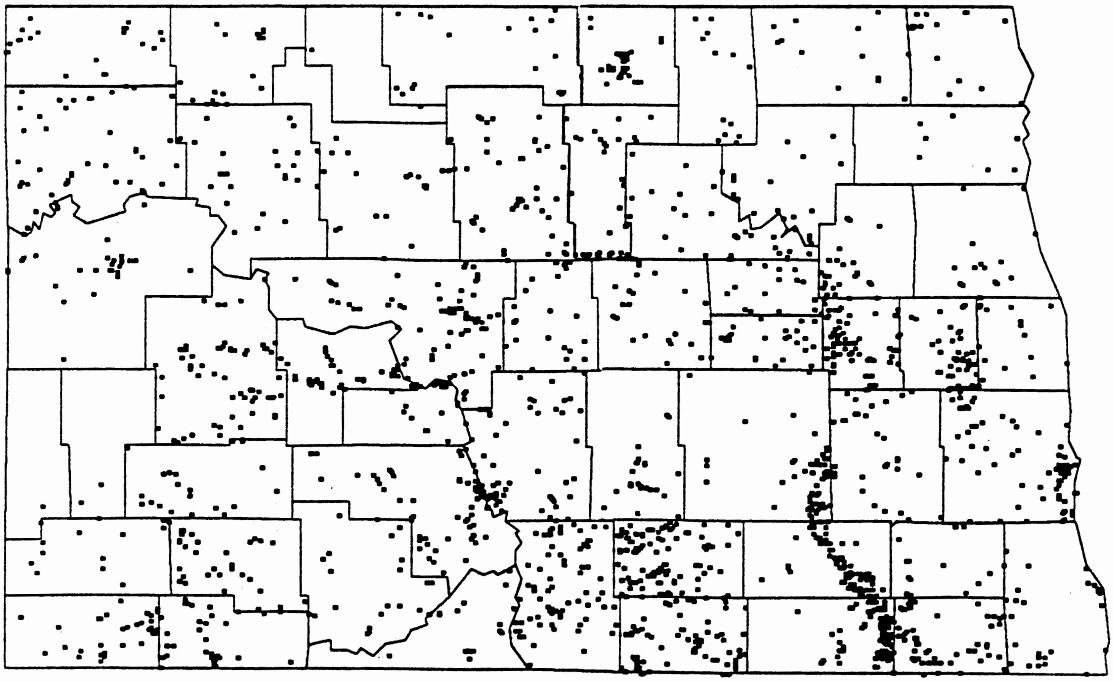


Figure 15. North Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 500 mg/l but Less Than or Equal to 1000 mg/l

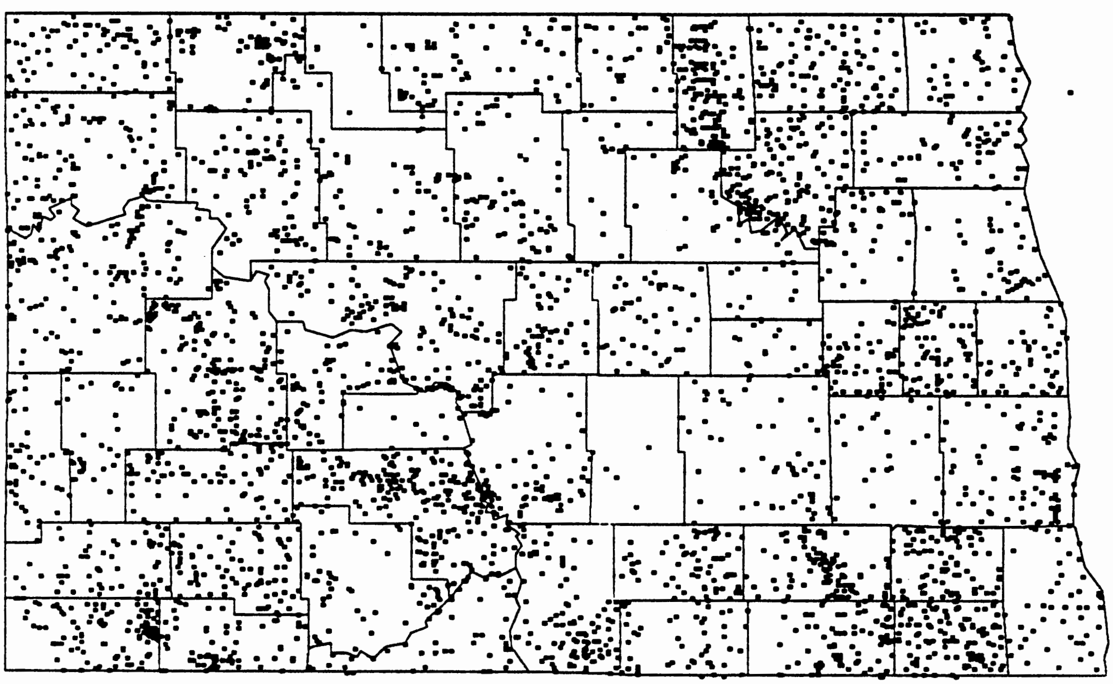


Figure 16. North Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 1000 mg/l

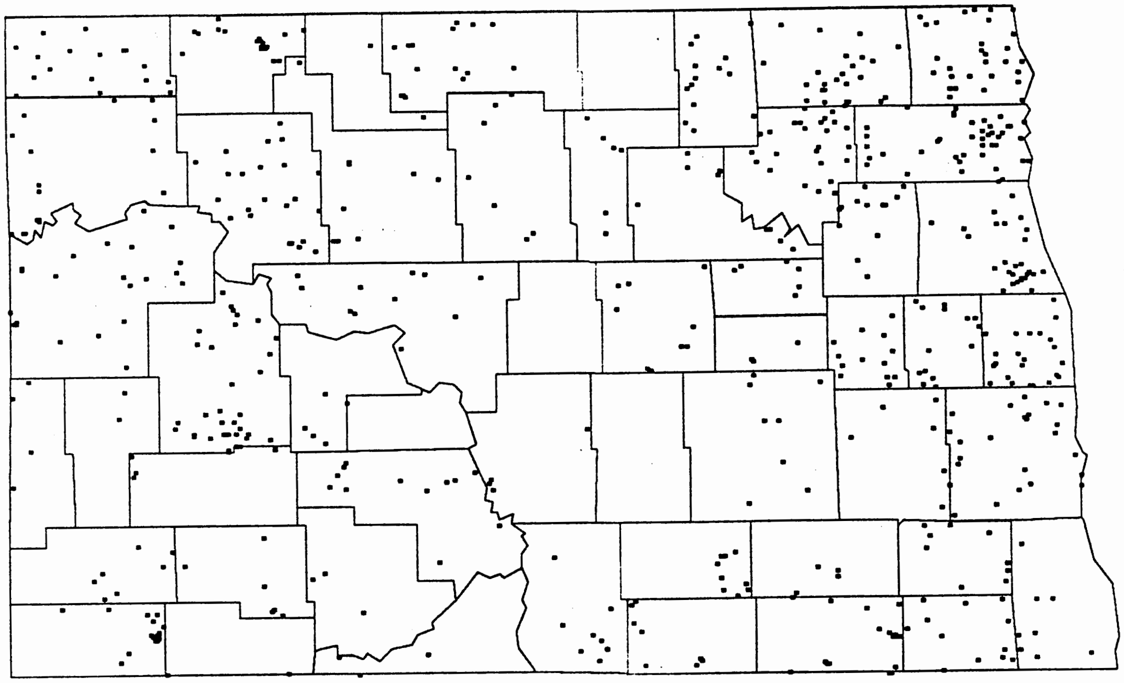


Figure 17. North Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Equal to or Greater Than the 90th Percentile

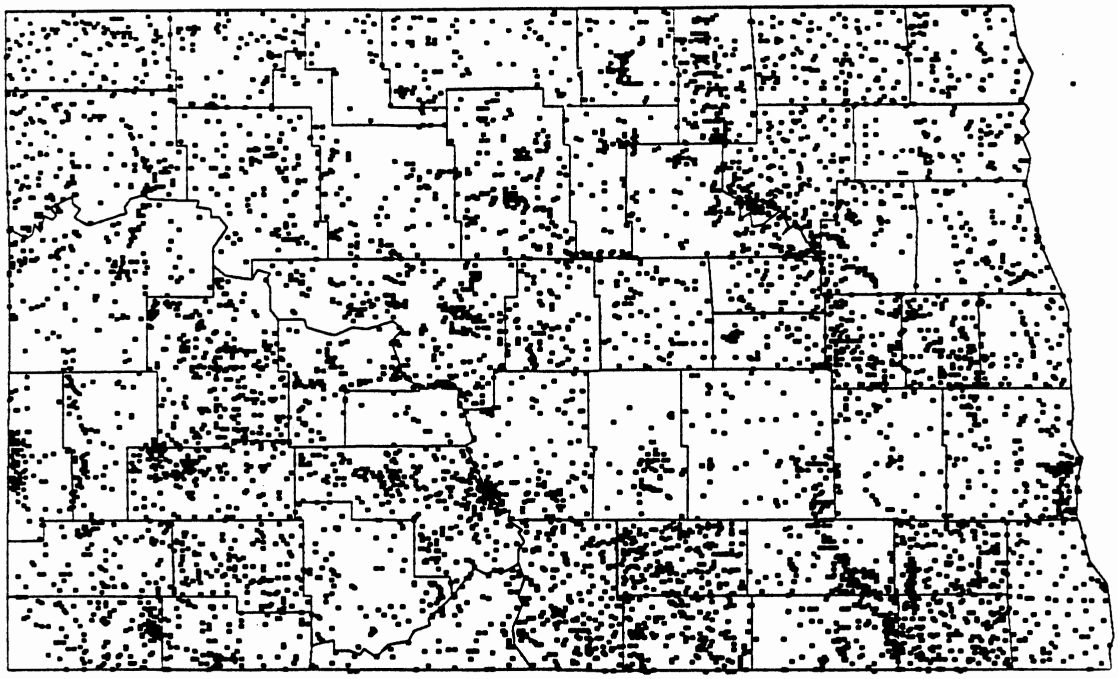


Figure 18. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Hardness

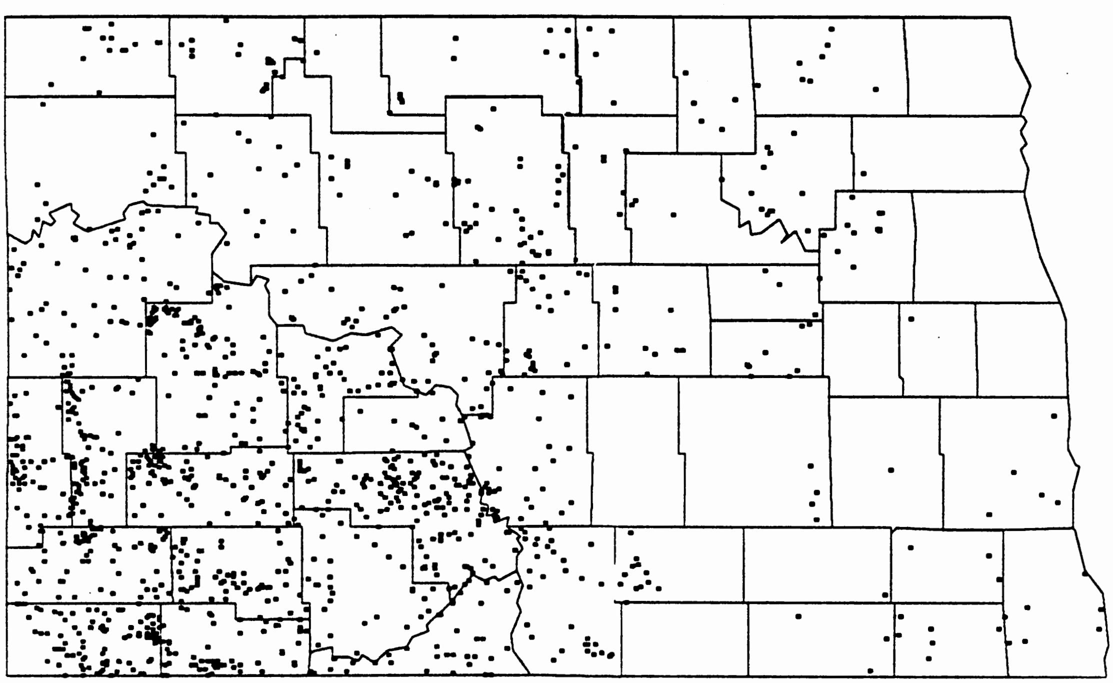


Figure 19. North Dakota: Locations of Wells Where Water Contained Hardness Concentrations Less Than or Equal to 60 mg/l

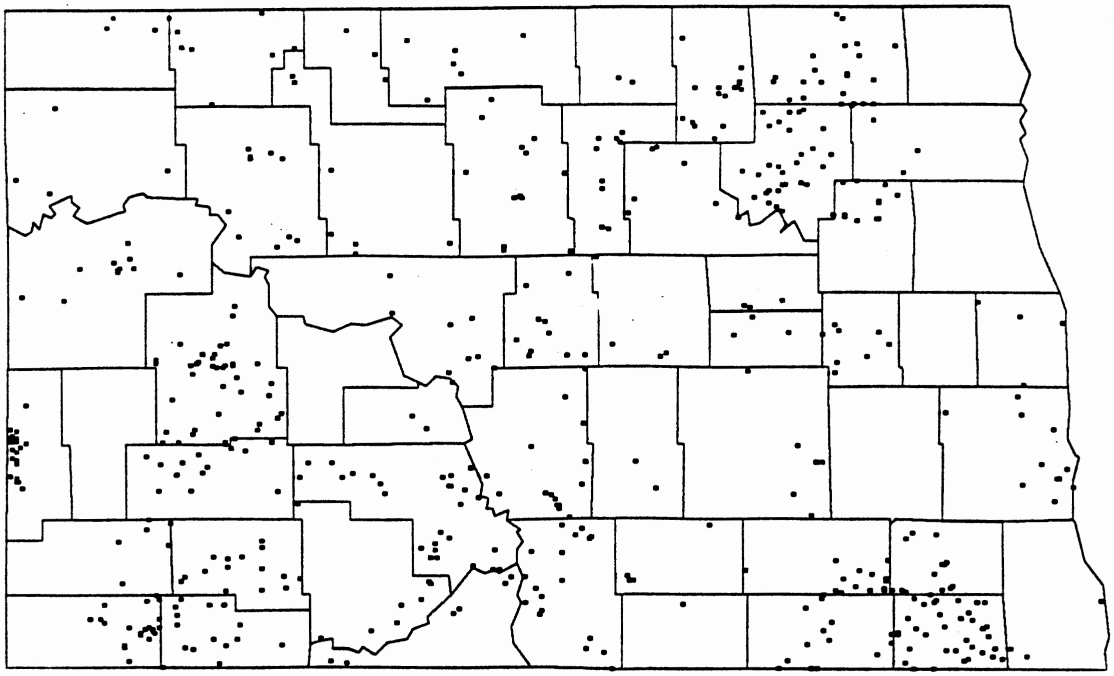


Figure 20. North Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 60 mg/l but Less Than or Equal to 120 mg/l

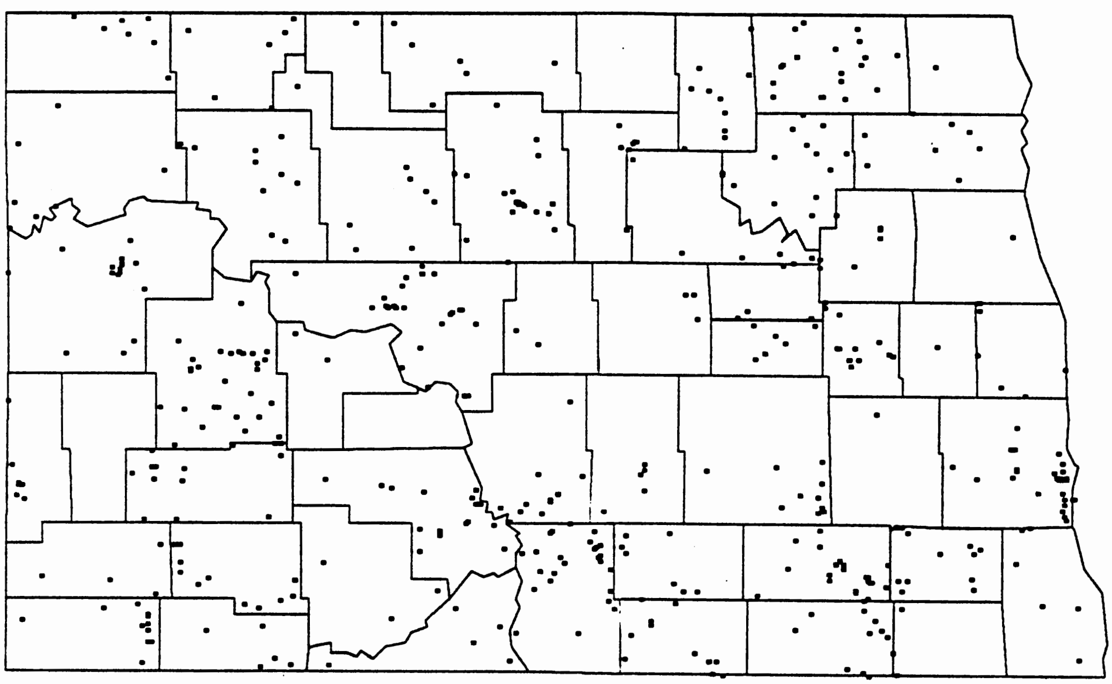


Figure 21. North Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 120 mg/l but Less Than or Equal to 180 mg/l

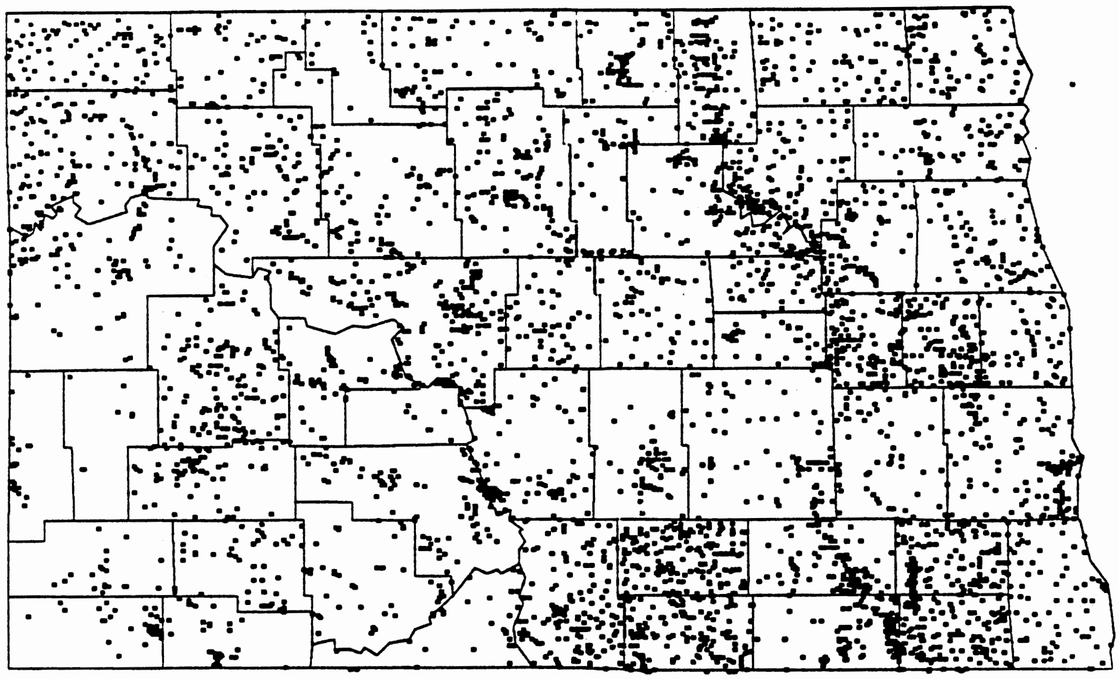


Figure 22. North Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 180 mg/l

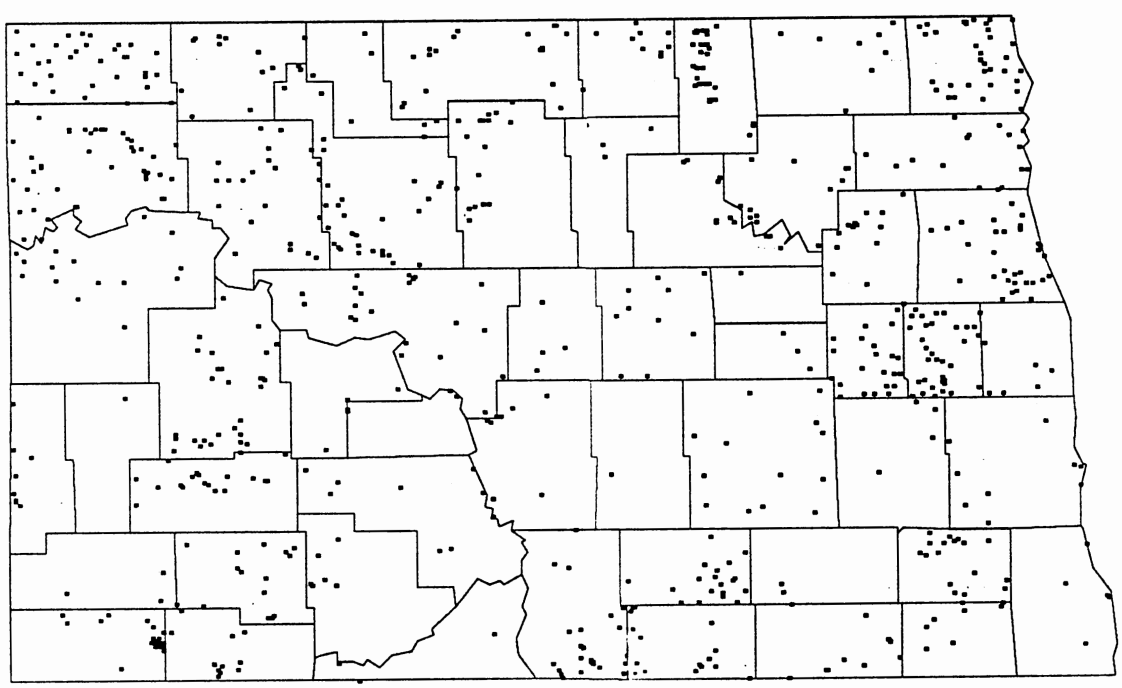


Figure 23. North Dakota: Locations of Wells Where Water Contained Hardness Concentrations Equal to or Greater Than the 90th Percentile

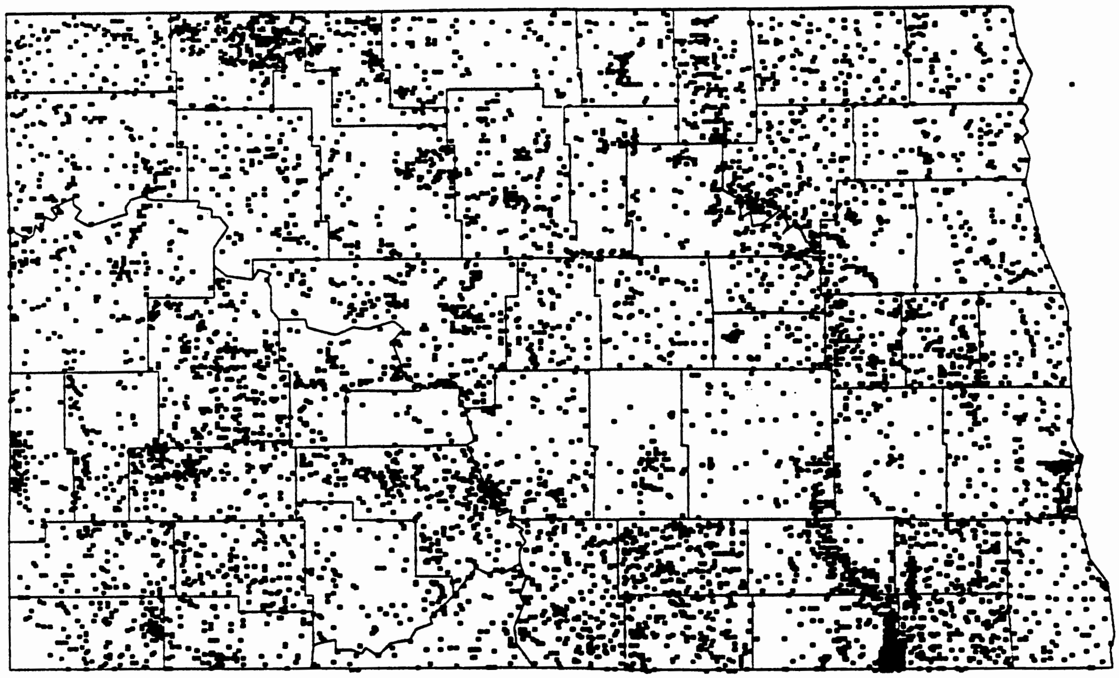


Figure 24. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Chloride

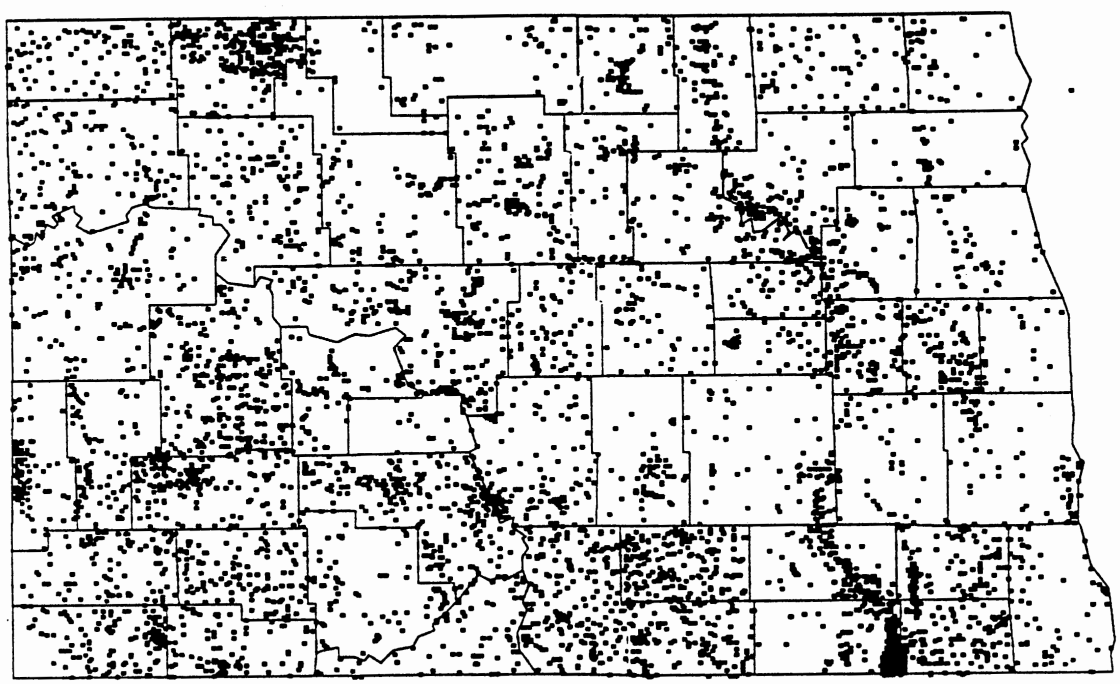


Figure 25. North Dakota: Locations of Wells Where Water Contained Chloride Concentrations Less Than or Equal to 125 mg/l

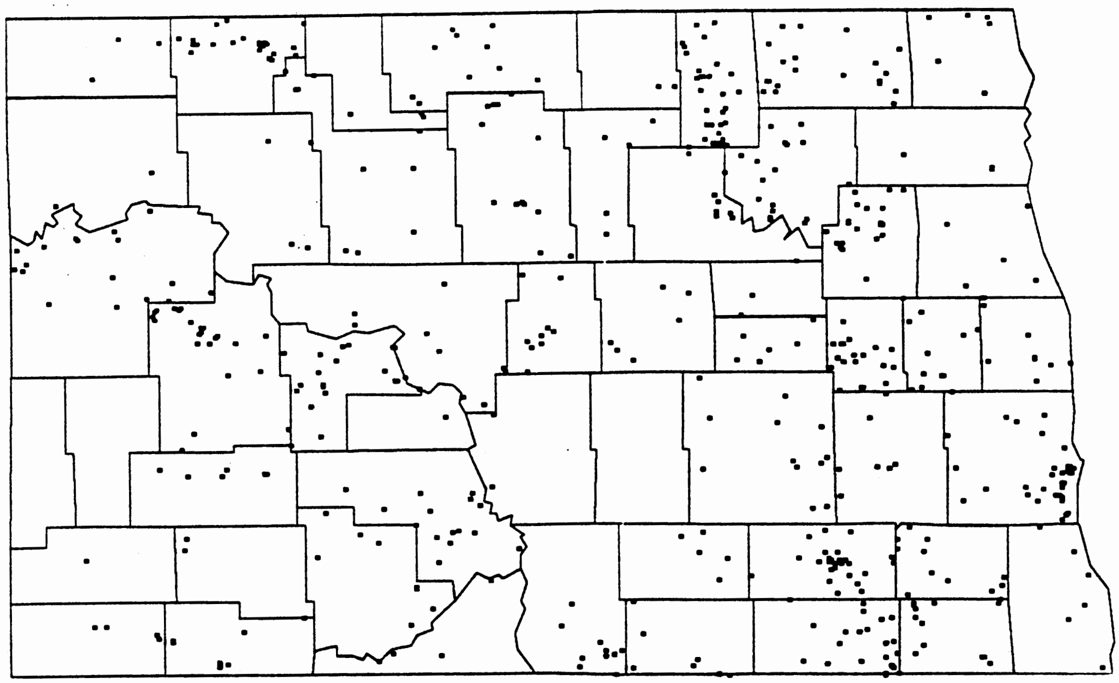


Figure 26. North Dakota: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

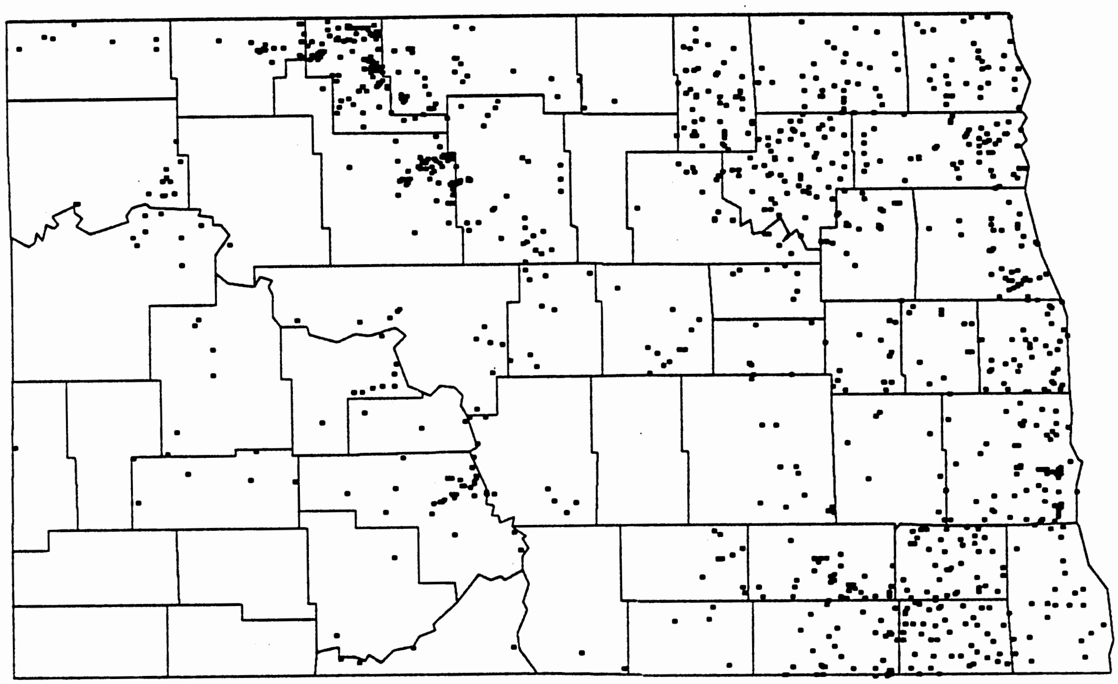


Figure 27. North Dakota: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 250 mg/l

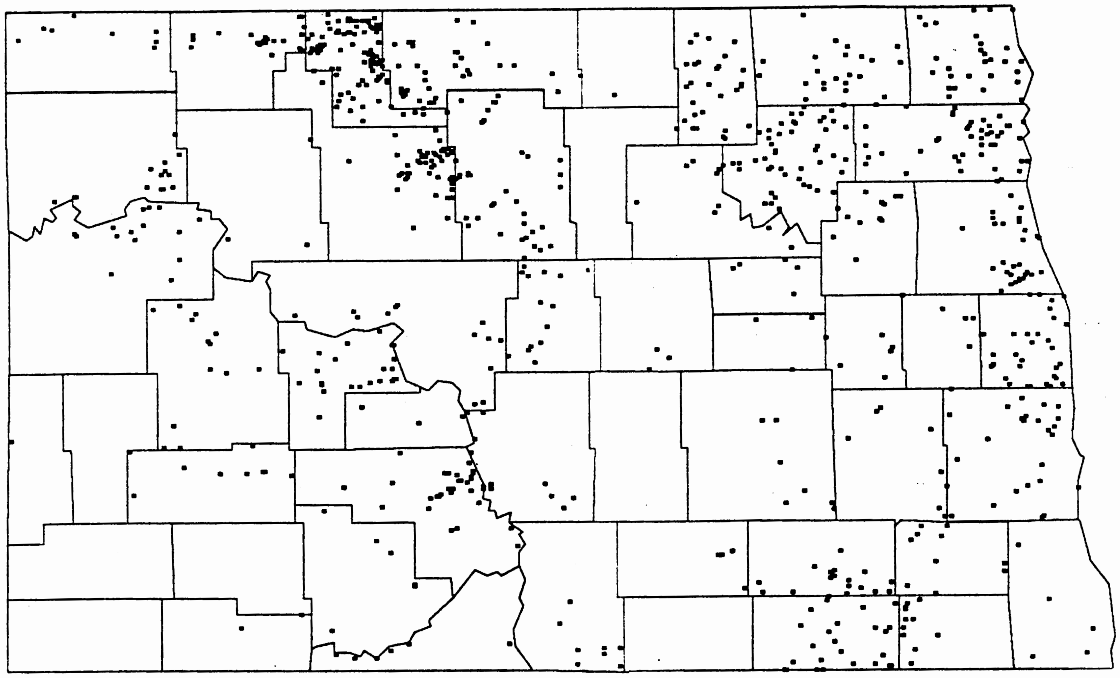


Figure 28. North Dakota: Locations of Wells Where Water Contained Chloride Concentrations Equal to or Greater Than the 90th Percentile

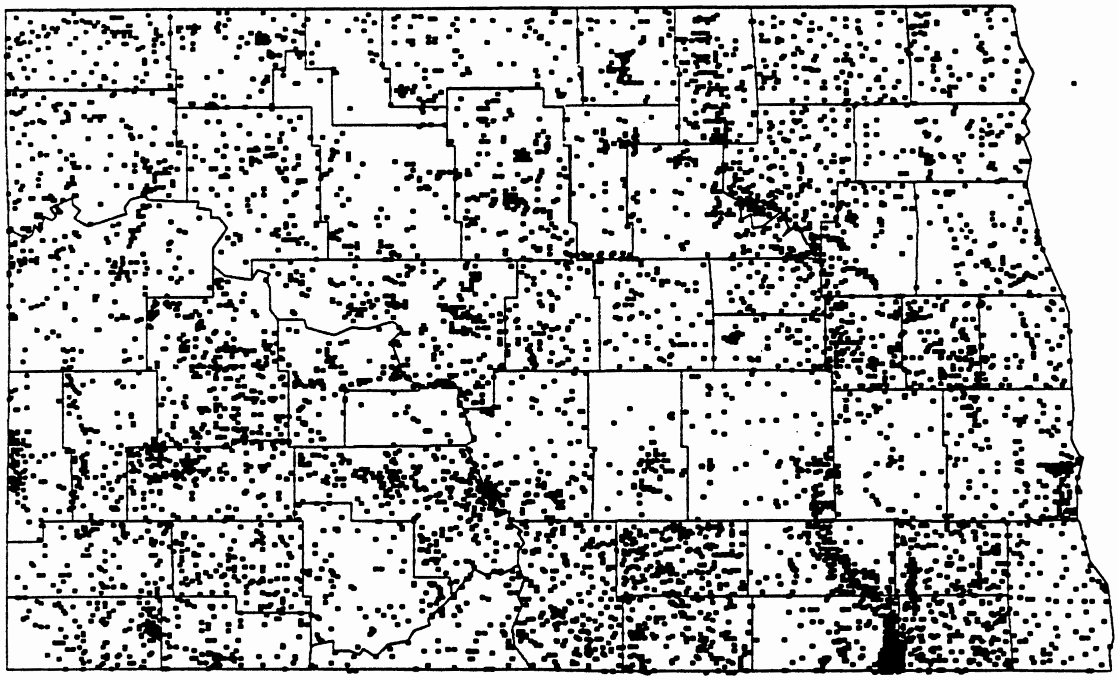


Figure 29. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Sulfate

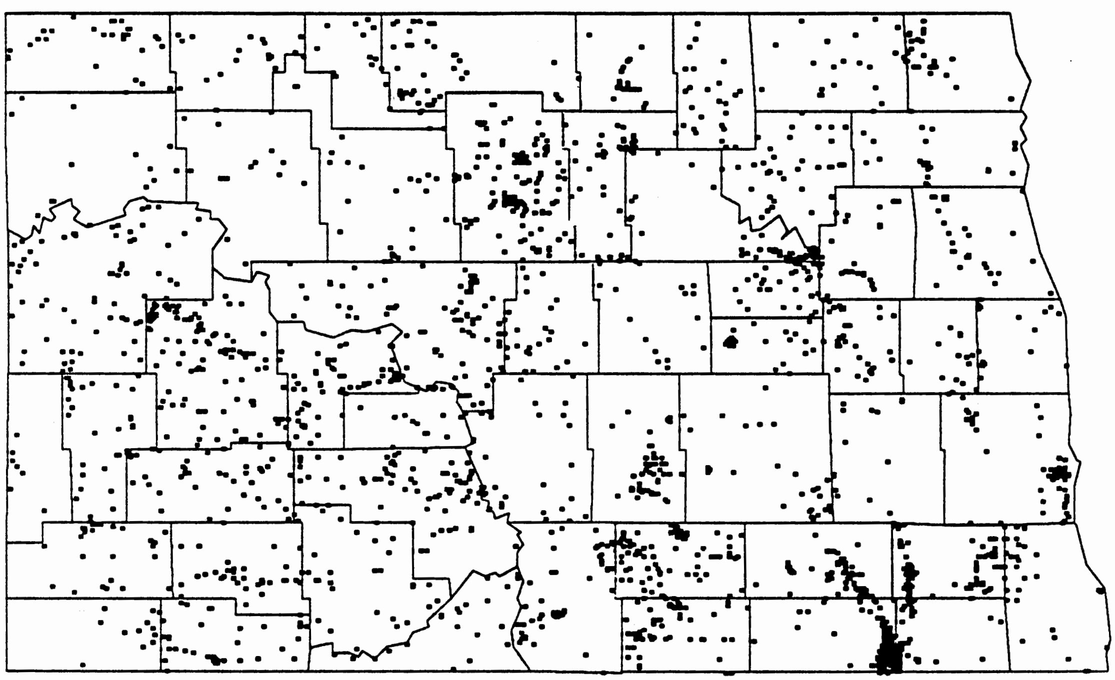


Figure 30. North Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Less Than or Equal to 125 mg/l

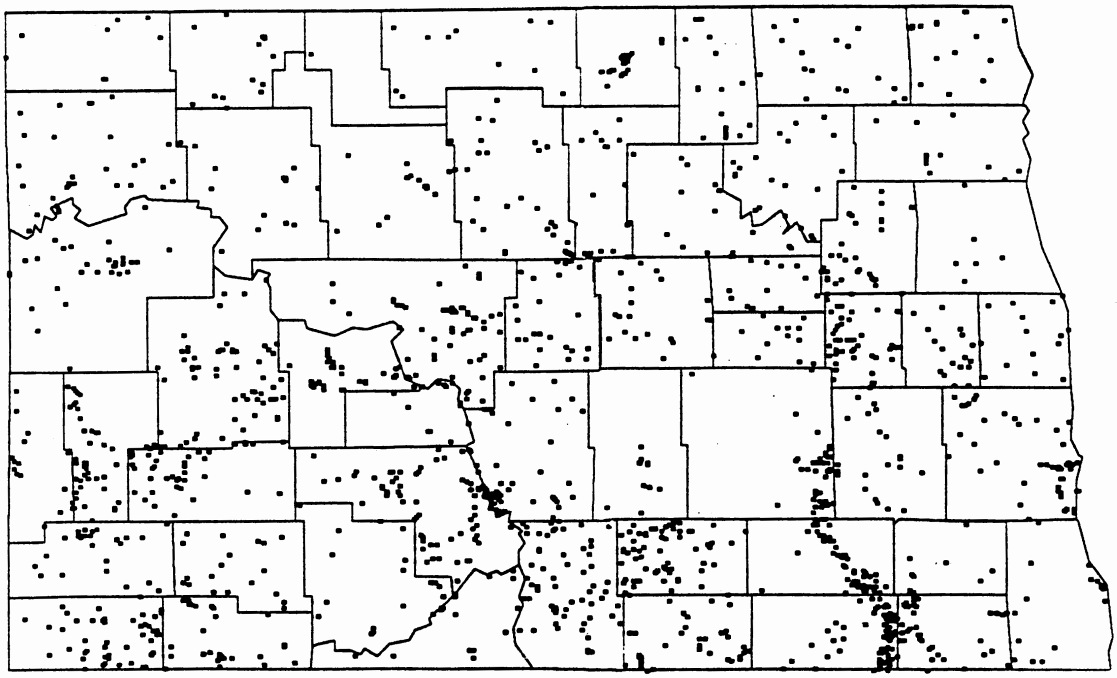


Figure 31. North Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

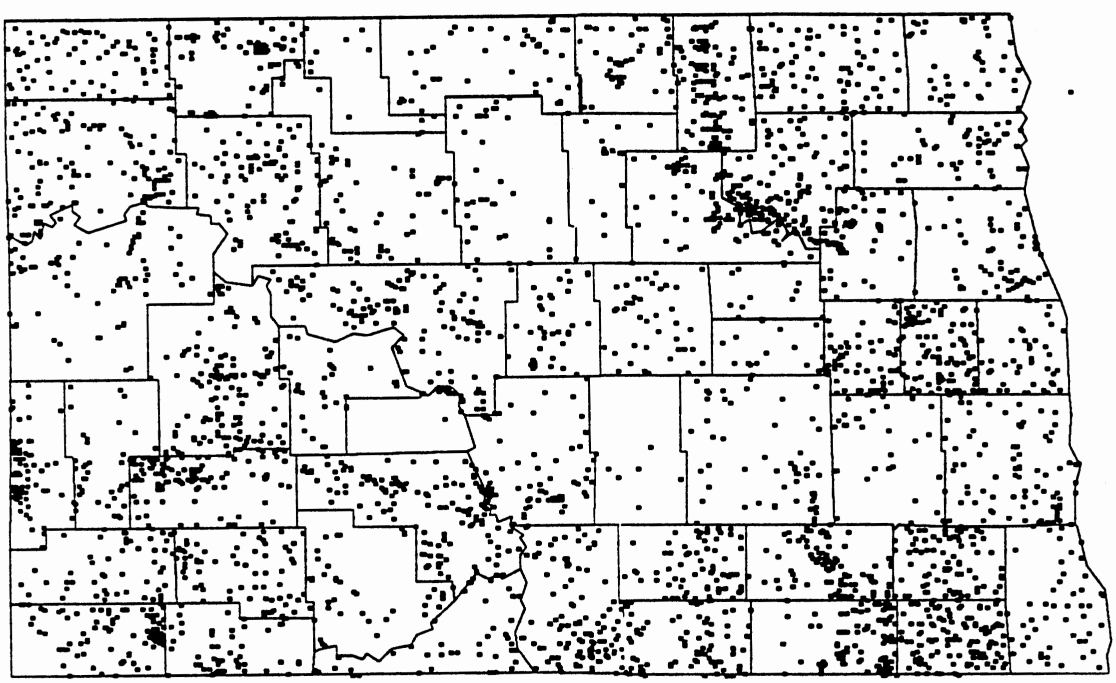


Figure 32. North Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 250 mg/l

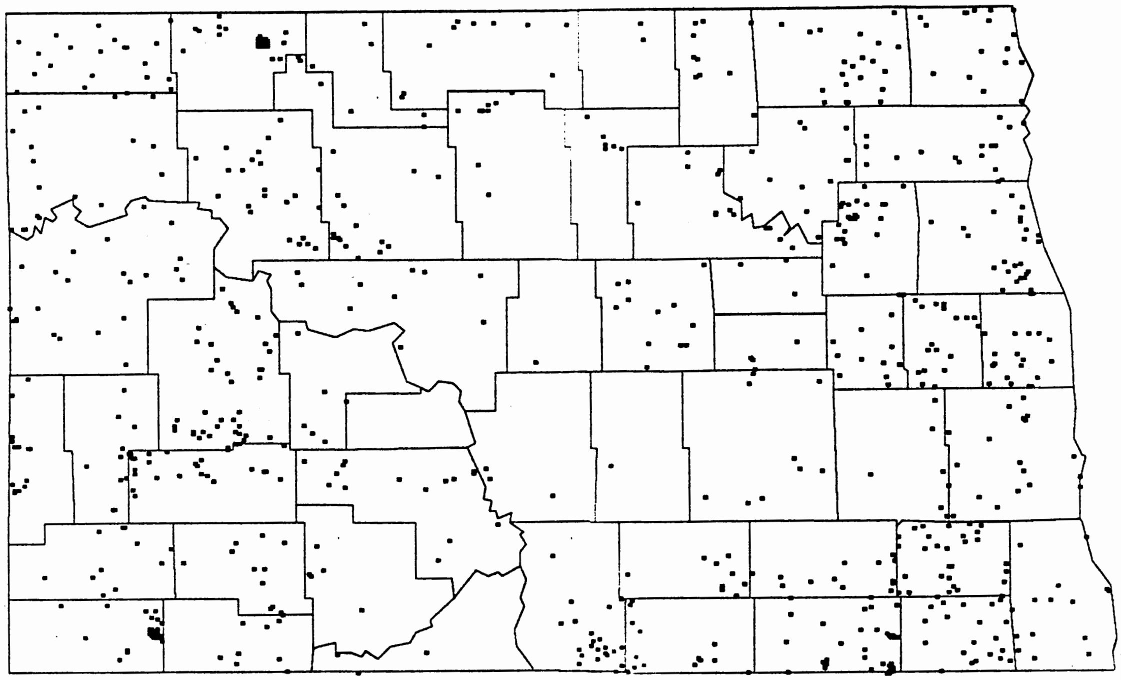


Figure 33. North Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Equal to or Greater Than the 90th Percentile

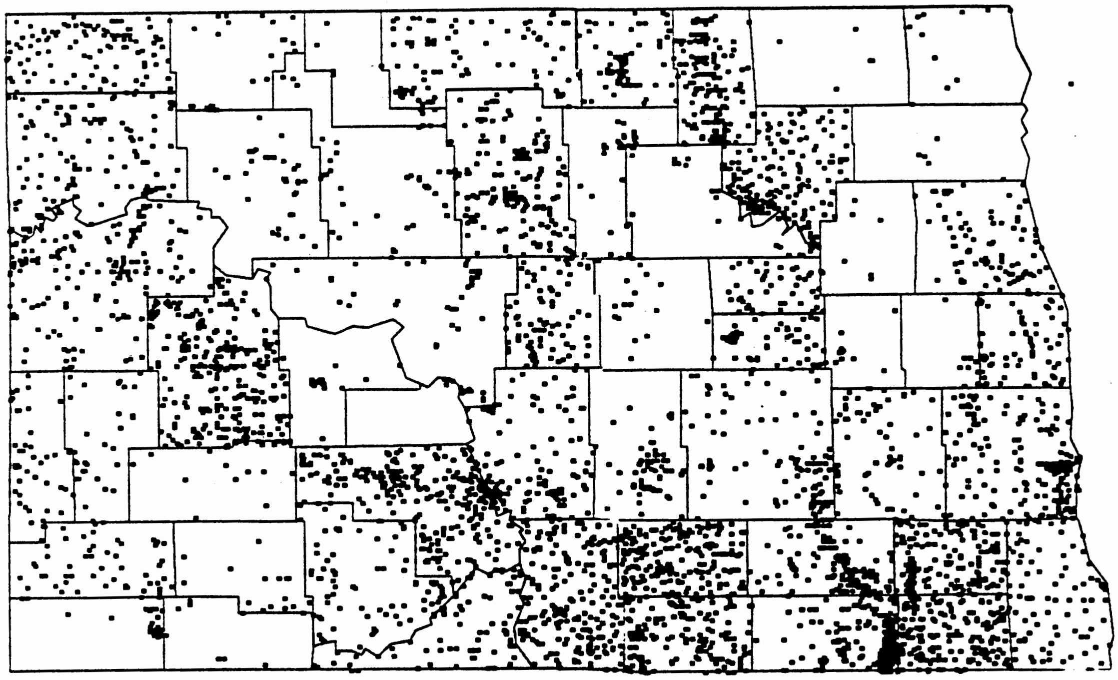


Figure 34. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate Measured as N

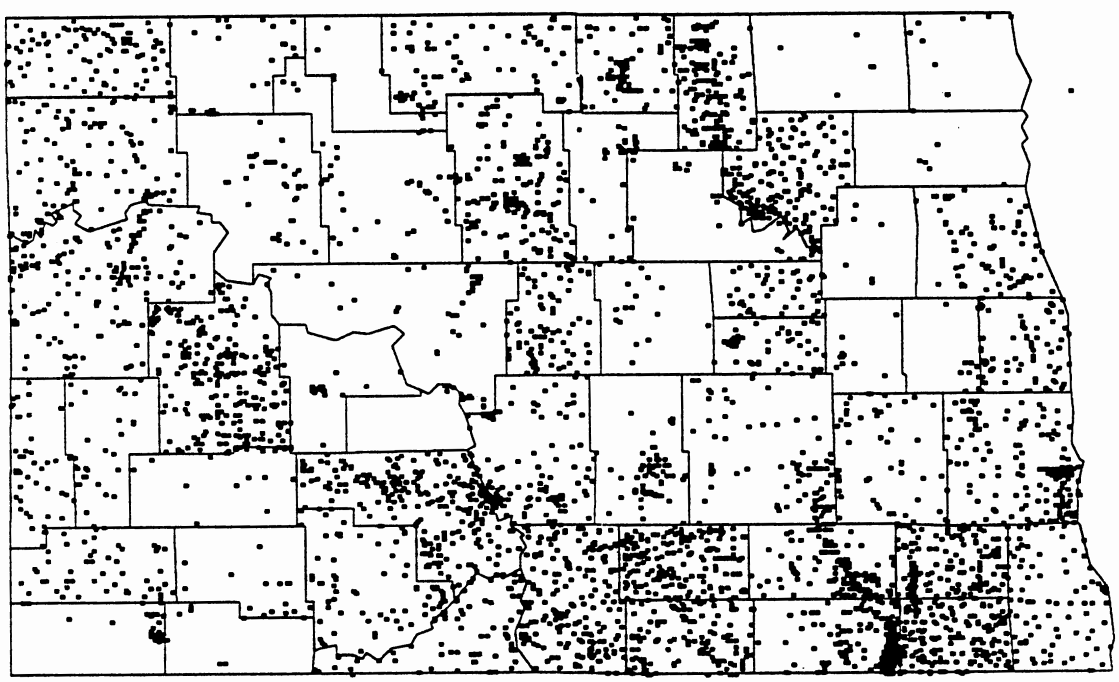


Figure 35. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 5 mg/l as N

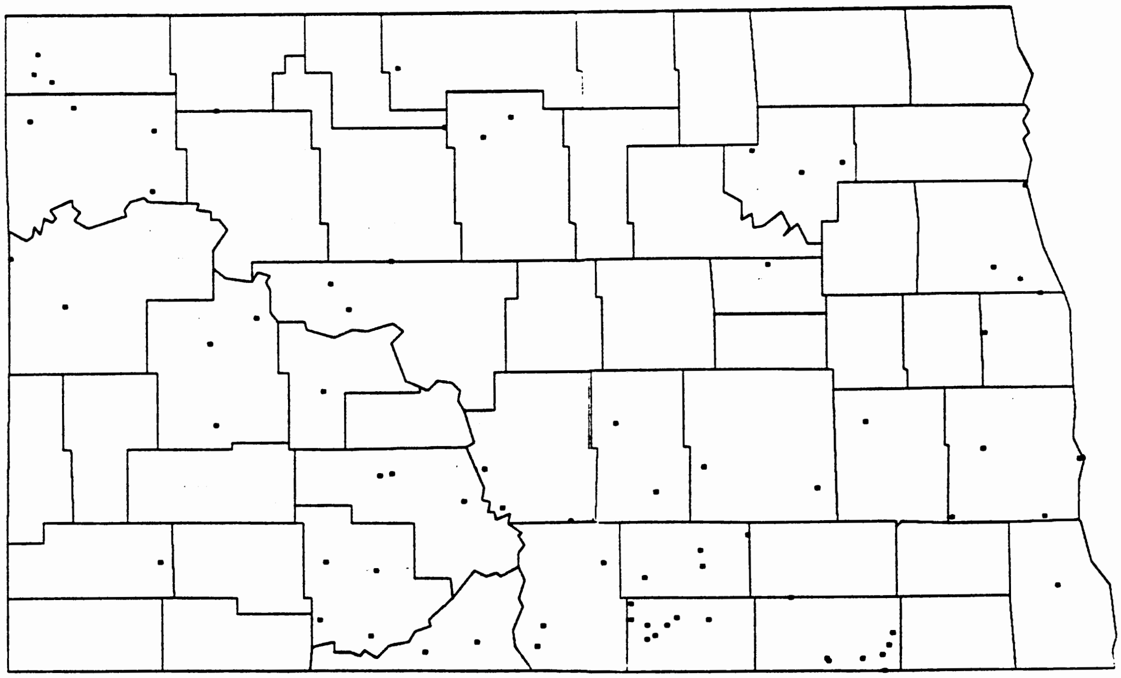


Figure 36. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 5 mg/l as N but Less Than or Equal to 10 mg/l as N

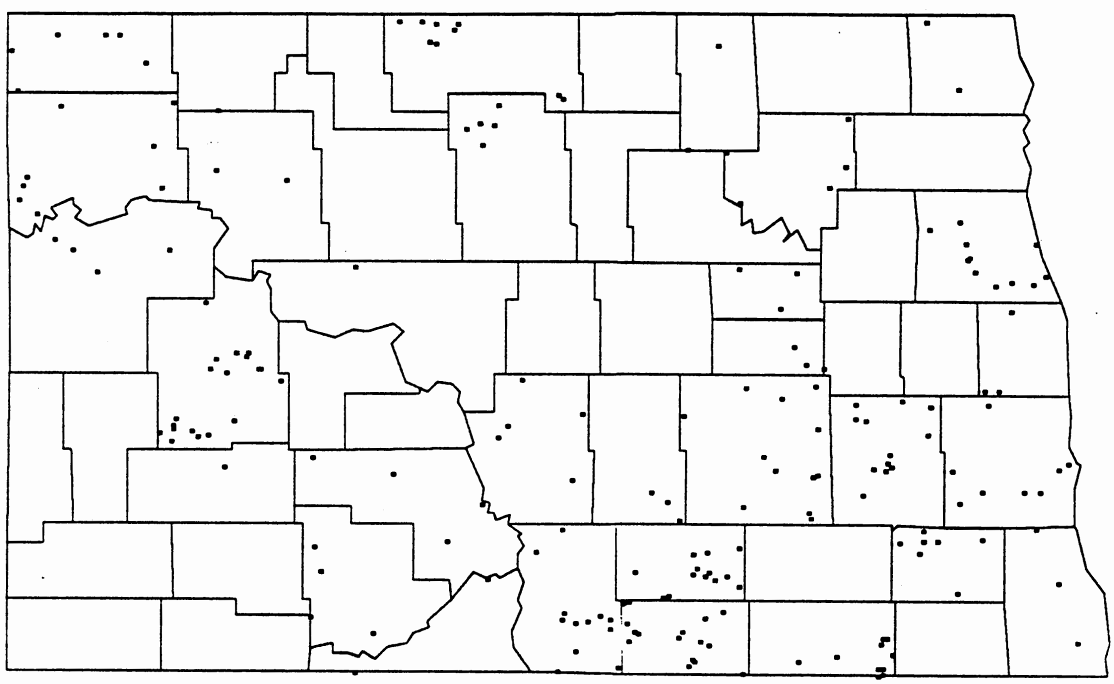


Figure 37. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 10 mg/l as N

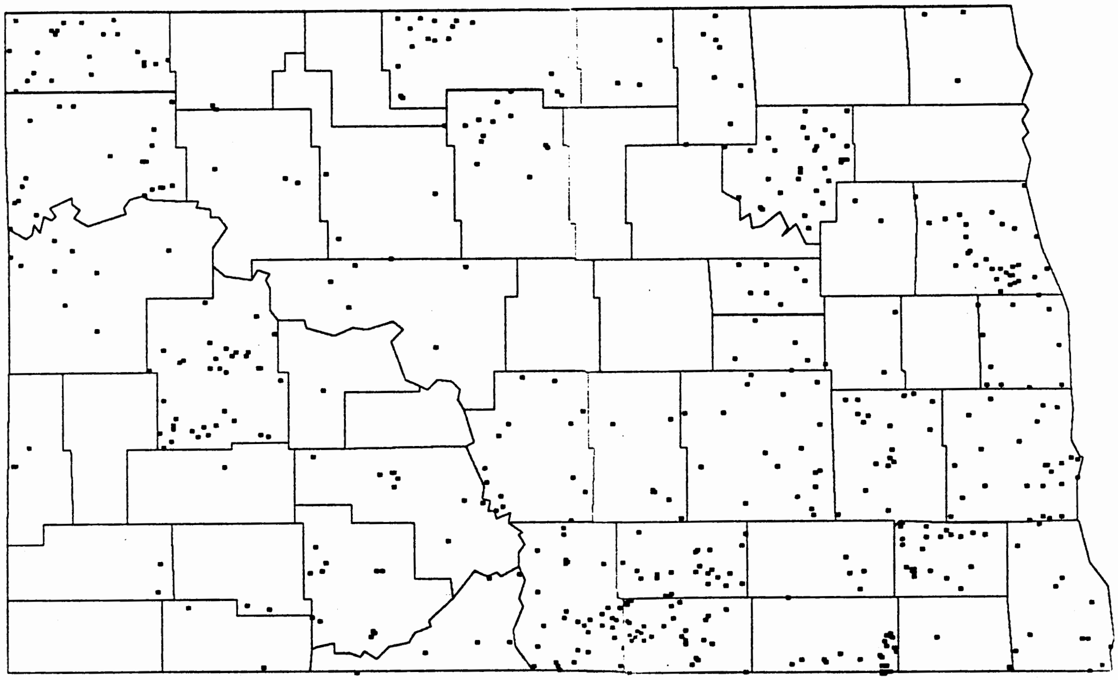


Figure 38. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as N, Equal to or Greater Than the 90th Percentile

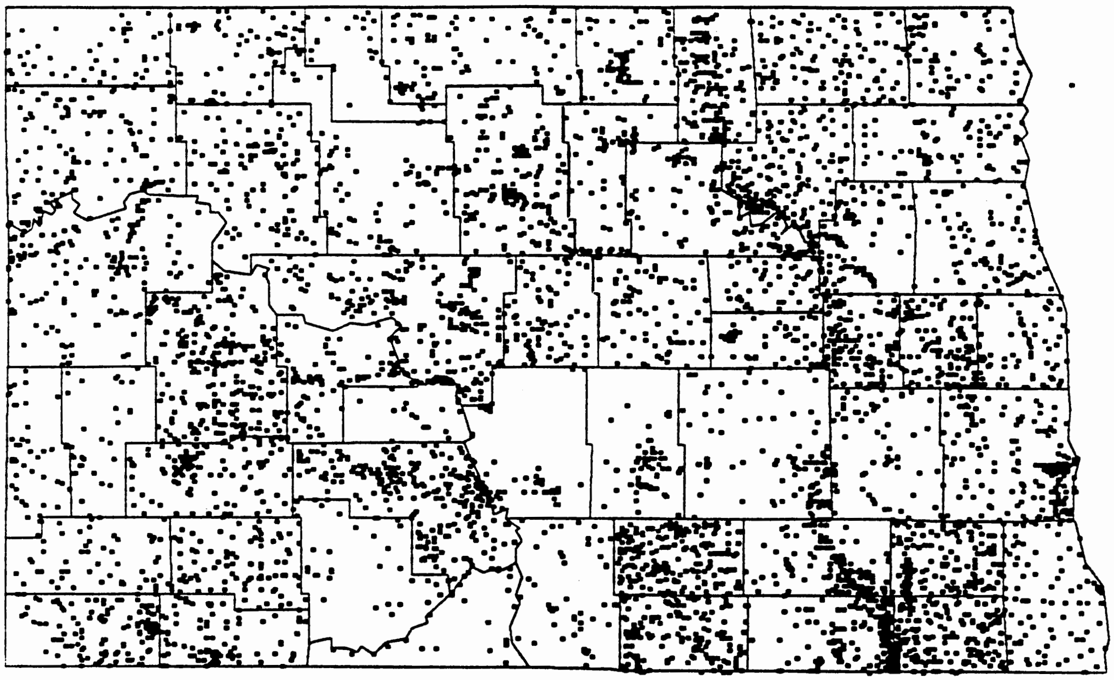


Figure 39. North Dakota: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate as NO3

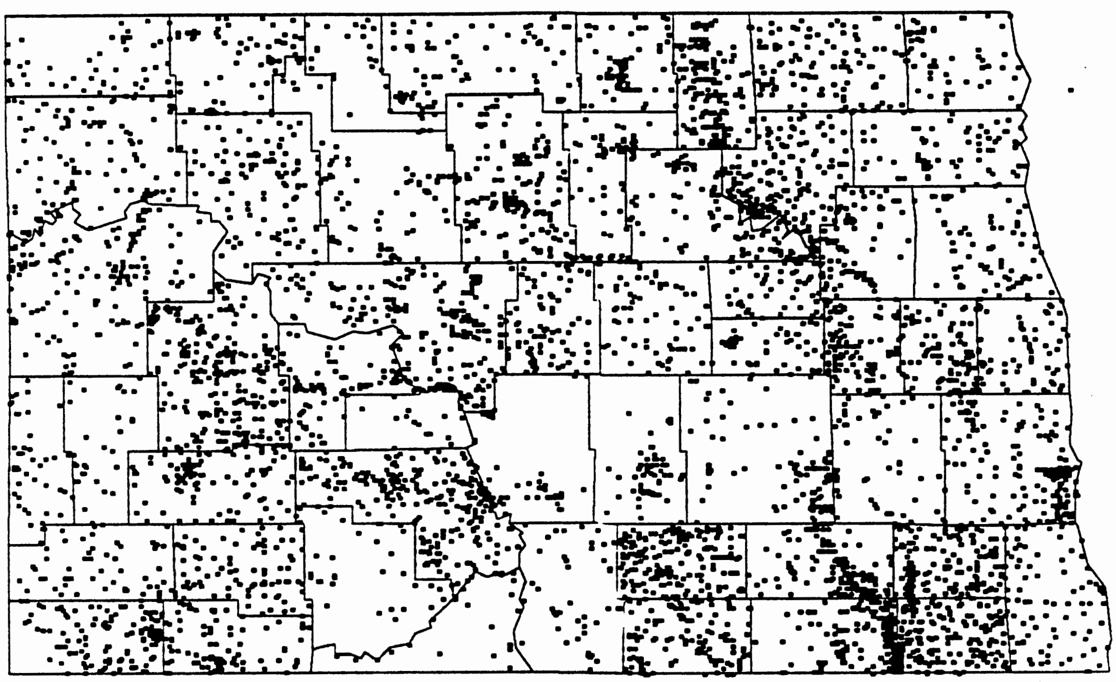


Figure 40. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 25 mg/l as NO3

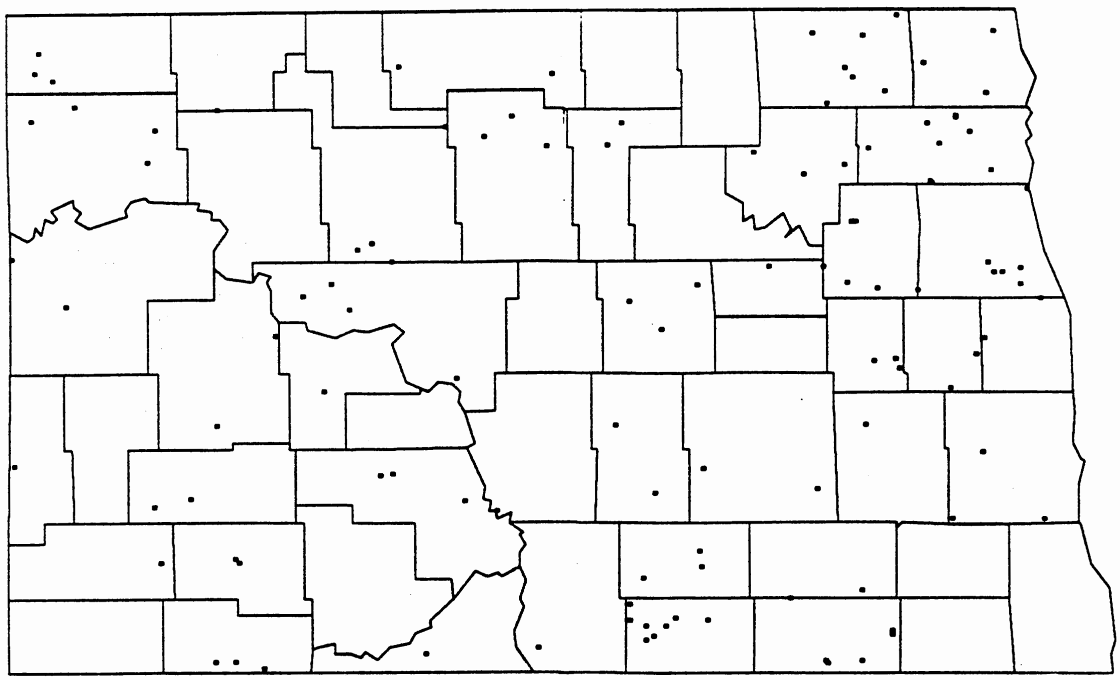


Figure 41. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 25 mg/l as NO3 but Less Than or Equal to 45 mg/l as NO3

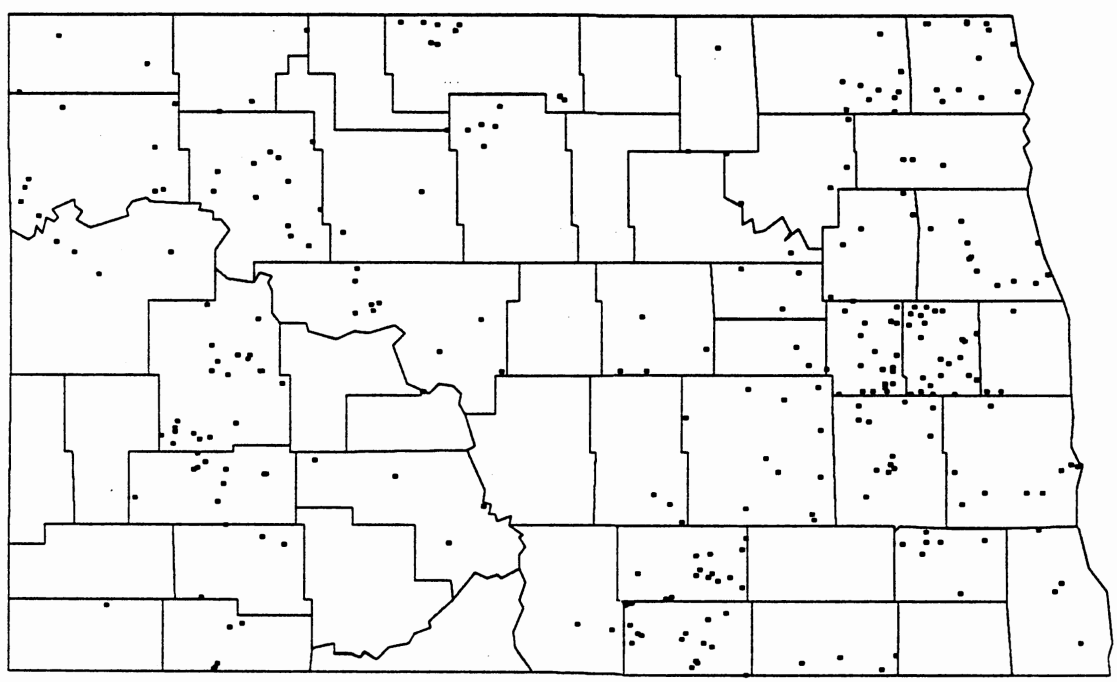


Figure 42. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 45 mg/l as NO3

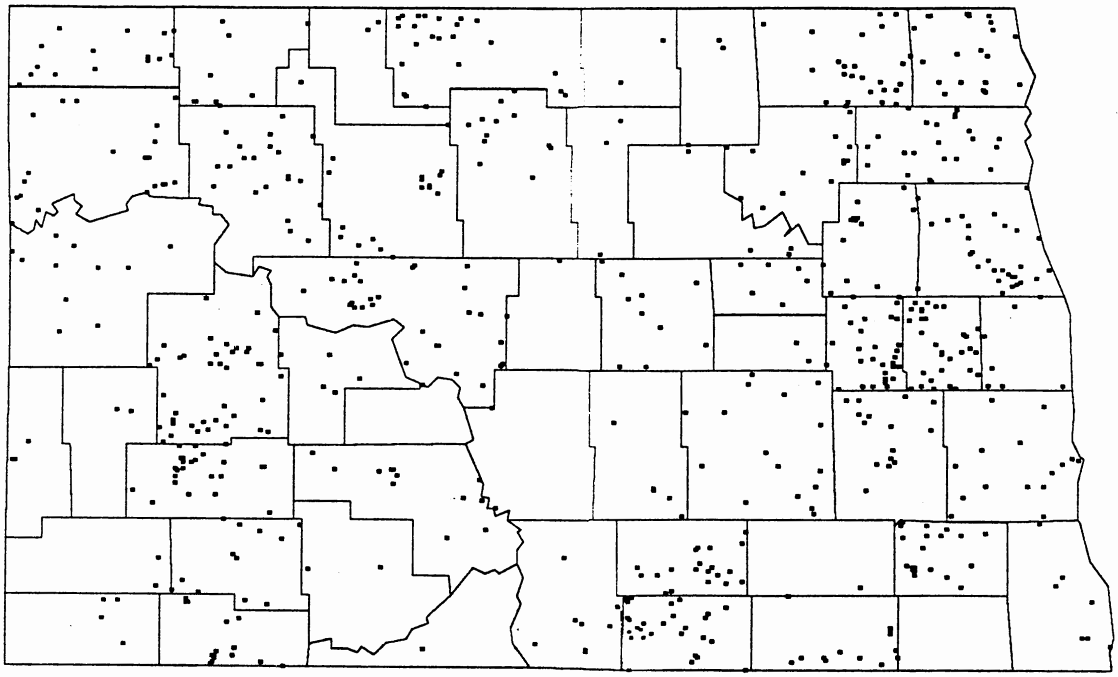


Figure 43. North Dakota: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as NO3, Equal to or Greater Than the 90th Percentile

South Dakota

General Setting

South Dakota contains approximately 77,000 square miles. Annual average precipitation varies from about 16 inches in the west-central part of the state to over 24 inches in the southeast. Rainfall in the Black Hills in southwestern South Dakota ranges from 16 inches to about 24 inches in the higher elevations. The western half of the state is drained by eastern flowing rivers that terminate in the southerly flowing Missouri River. Eastern South Dakota is principally drained by the James and Big Souix River systems.

South Dakota is underlain largely by Mesozoic to Paleozoic age clastic bedrock that dips westward into the Kennedy Basin. The western flank of the basin has been upturned sharply by the intrusion that created the Black Hills. Precambrian age metamorphic and igneous rocks crop out in the Black Hills. Cretaceous age poorly consolidated fine grained sandstone units occur in northwestern South Dakota. Tertiary age rock that is primarily composed of interbedded sandstone and shale occurs in south-central South Dakota. The eastern half of the state is covered by glacial till and outwash deposits that consists of gravel, sand, and silt.

Discussion

Table 6 exhibits the number of analyses measured, the percentage of samples that exceed E.P.A. drinking water standards, and the percentage in each range of concentration. A map of the major aquifers in South Dakota and their descriptions is depicted in Figures 44 and 45. Maps illustrating the location of wells and selected ground water quality in South Dakota are shown in Figures 46-76.

The data base contained very few ground-water analyses in South Dakota. Less than 102 analyses are available for each of the chemical constituents addressed in this investigation. Due to this lack of information, it would be difficult to make a meaningful assessment of the quality of ground water in South Dakota.

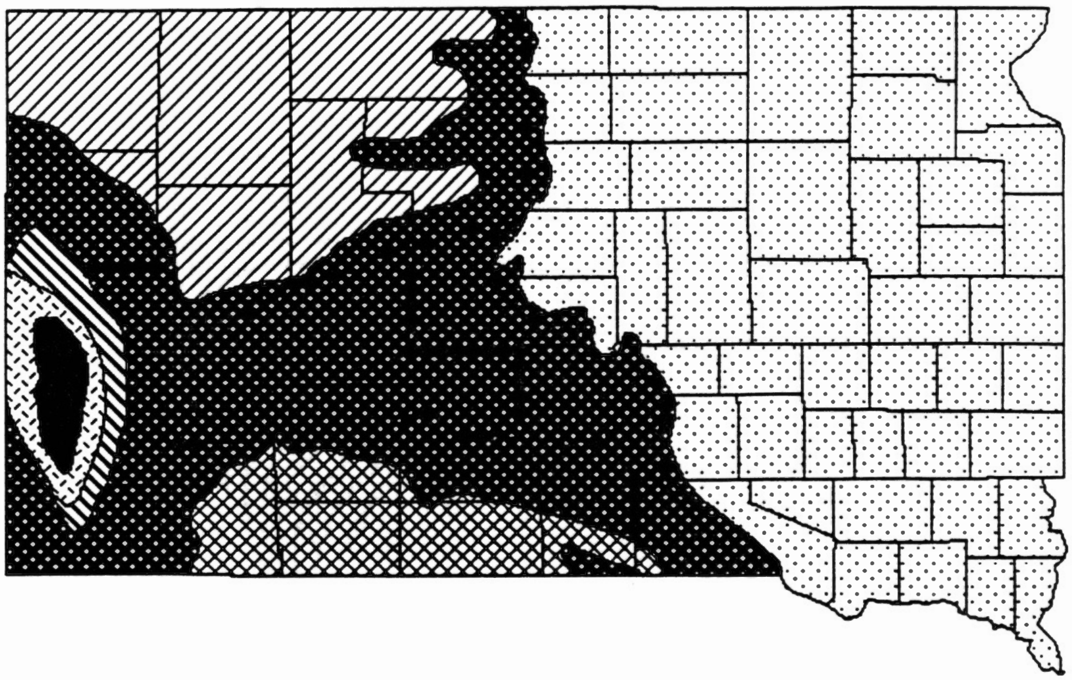
TABLE 6

SOUTH DAKOTA: NUMERICAL SUMMARIES
OF WATER ANALYSES

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
TDS		500*	85	•
All Samples	89		•	•
0 - 500	33		•	37
501 - 1000	21		•	24
Greater than 1000	35		•	57
Equal to or Greater than			•	•
the 90th Percentile	8		•	9
Hardness		None	•	•
All Samples	85		•	•
0 - 60	12		•	14
61 - 120	6		•	7
121 - 180	5		•	6
Greater than 180	62		•	73
Equal to or Greater than			•	•
the 90th Percentile	4		•	5
Chloride		250	12	•
All Samples	101		•	•
0 - 125	82		•	81
126 - 250	8		•	8
Greater than 250	12		•	12
Equal to or Greater than			•	•
the 90th Percentile	11		•	11
Sulfate		250	12	•
All Samples	17		•	•
0 - 125	14		•	82
126 - 250	1		•	6
Greater than 250	2		•	12
Equal to or Greater than			•	•
the 90th Percentile	13		•	76

TABLE 6 (continued)

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
Nitrate as N		10	12	•
All Samples	17		•	•
0 - 5	14		•	82
6 - 10	1		•	6
Greater than 10	2		•	12
Equal to or Greater than			•	•
the 90th Percentile	1		•	6
Nitrate as NO3		45	9	•
All Samples	33		•	•
0 - 25	30		•	91
26 - 45	0		•	0
Greater than 45	3		•	9
Equal to or Greater than			•	•
the 90th Percentile	6		•	18



EXPLANATION

Glacial Drift and Alluvial Aquifers

SEDIMENTARY BEDROCK AQUIFERS

High Plains Aquifer

Fort Union-Hell Creek-Fox Hills Aquifers

Niobrara-Codell and Dakota-Newcastle Aquifers

Inuan Kara, Sundance, Minnelusa, Madison,
Red River, and Deadwood Aquifers

CONFINING UNITS AND BASEMENT ROCKS

Shale Confining Unit

Not a Principle Aquifer

Figure 44. South Dakota: Map of Major Aquifers (Modified from U.S.G.S., 1985)

[Ft = feet; gal/min = gallons per minute; mg/L = milligrams per liter. Sources: Reports of the U.S. Geological Survey and the South Dakota Geological Survey]

Aquifer name and description	Well characteristics			Remarks
	Depth (ft)	Yield (gal/min)		
	Common range	Common range	May exceed	
Glacial-drift and alluvial aquifers: Outwash and alluvium; unconsolidated sand, gravel, and silt. May be confined or unconfined.	20 – 400	3 – 50	2,000	Glacial drift underlies most of State east of Missouri River. Alluvium found along major streams. Water fresh to moderately saline; commonly suitable for irrigation. Big Sioux aquifer in southeastern South Dakota yields adequate supplies for Sioux Falls, State's largest city.
Sedimentary bedrock aquifers:				
High Plains aquifer: Sand, fine to medium; unconsolidated to poorly consolidated sandstone, silt, gravel, and clay. Unconfined.	10 – 570	5 – 100	1,500	Most common source of water on Pine Ridge and Rosebud Indian Reservations. Supplies towns of Martin and Pine Ridge. Some irrigation development. Water quality generally suitable for most uses. Consists of lower Ogallala Formation and Arikaree Formation Miocene age.
Fort Union–Hell Creek–Fox Hills aquifers: Sandstone, very fine to fine-grained, poorly consolidated; soft clay; lignite beds. Unconfined.	100 – 1,000	2 – 40	500	Most common source of water in northwestern South Dakota. Fox Hills aquifer supplies towns of Bison, Lemmon, and Timber Lake. Water commonly fresh.
Niobrara–Codell aquifer: Shale, chalky, and fine-grained quartz sandstone. Confined or unconfined.	150 – 300	2 – 30	300	Used extensively for livestock and domestic purposes in central South Dakota and southern James River basin. Water generally soft and moderately saline.
Dakota-Newcastle aquifer: Sandstone, interbedded with shale and siltstone. Confined.	300 – 4,000	2 – 50	1,500	Major source of water for domestic and stock use. Supplies water to many small public-supply systems. Water commonly moderately saline to very saline.
Inyan Kara aquifer: Sandstone, interbedded with shale and siltstone. Confined.	200 – 4,900	5 – 40	1,000	Considered to be an underdeveloped source of water for domestic and stock use. Water quality ranges from fresh in west to moderately saline in east to very saline in north.
Sundance aquifer: Shale interbedded with fine-grained sandstone, limestone, and sandy shale. Confined.	100 – 5,400	5 – 100	1,000	Important source of water for livestock in central part of State. Water commonly saline except near surface exposures in the west.
Minnelusa aquifer: Five major sandstone units separated by limestone, dolomite, shale, and anhydrite beds. Confined.	100 – 6,800	5 – 100	4,000	Major ground-water reservoir. Source for stock and domestic wells in central and western South Dakota. Water of suitable quality for irrigation (slightly saline or fresh) obtained from several wells near outcrops in the Black Hills. Most wells completed in Minnelusa flow.
Madison aquifer: Limestone, and dolomite containing beds of shale, anhydrite, and halite. Confined.	100 – 9,000	10 – 100	2,000	May be most important bedrock aquifer system in South Dakota. Comprises one or more aquifers that can yield large quantities of fresh to saline water under significant artesian pressure. Several producing wells are more than 4,000 ft deep. Supplies such western South Dakota towns as Philip, Midland, Eagle Butte, and Dupree.
Red River aquifer: Dolomite and dolomitic limestone. Confined.	1,100 – 9,700	5 – 100	1,000	Although not being used as a principal source of water in South Dakota, considered a major artesian aquifer. Dissolved-solids concentrations may exceed 60,000 mg/L. Maximum water temperatures of about 250 degrees Farenheit reported.
Deadwood aquifer: Sandstone, soft, thin-bedded, slabby dolomite and limestone; limestone-pebble conglomerate; and beds of glauconitic shale. Confined.	40 – 10,200	3 – 50	500	Except in the Black Hills area, aquifer not used, and potential for development, although probably significant, is not known. Salinity may range from moderately saline to very saline.

Figure 45. South Dakota: Major Aquifer Descriptions and Well Characteristics (Modified from U.S.G.S., 1985)

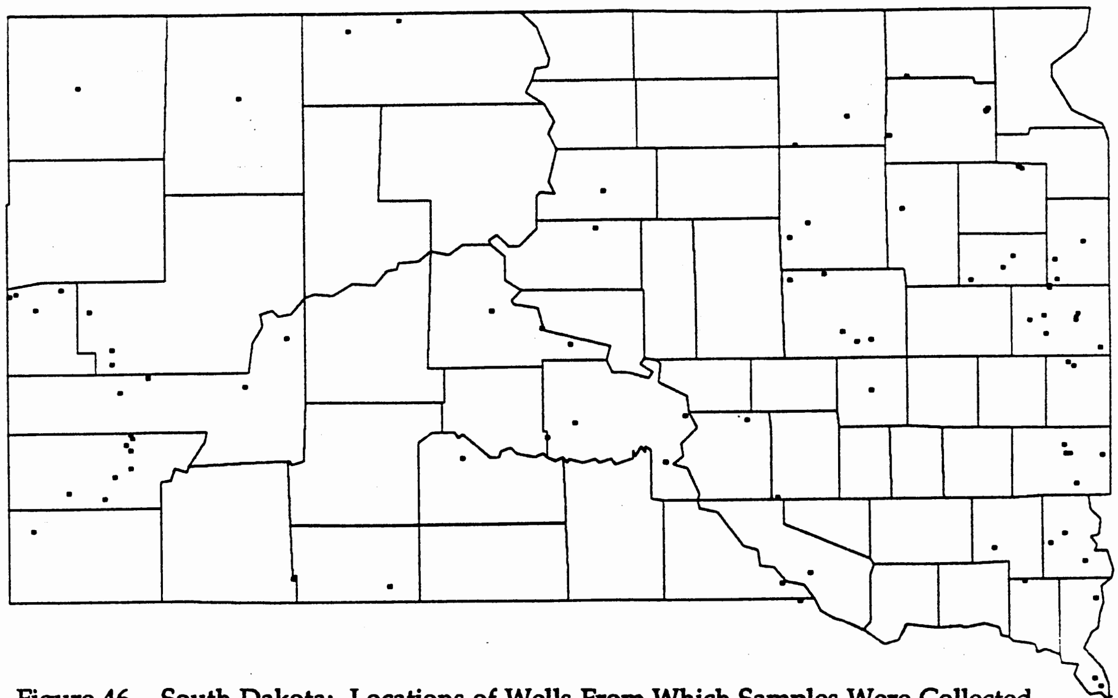


Figure 46. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Total Dissolved Solids.

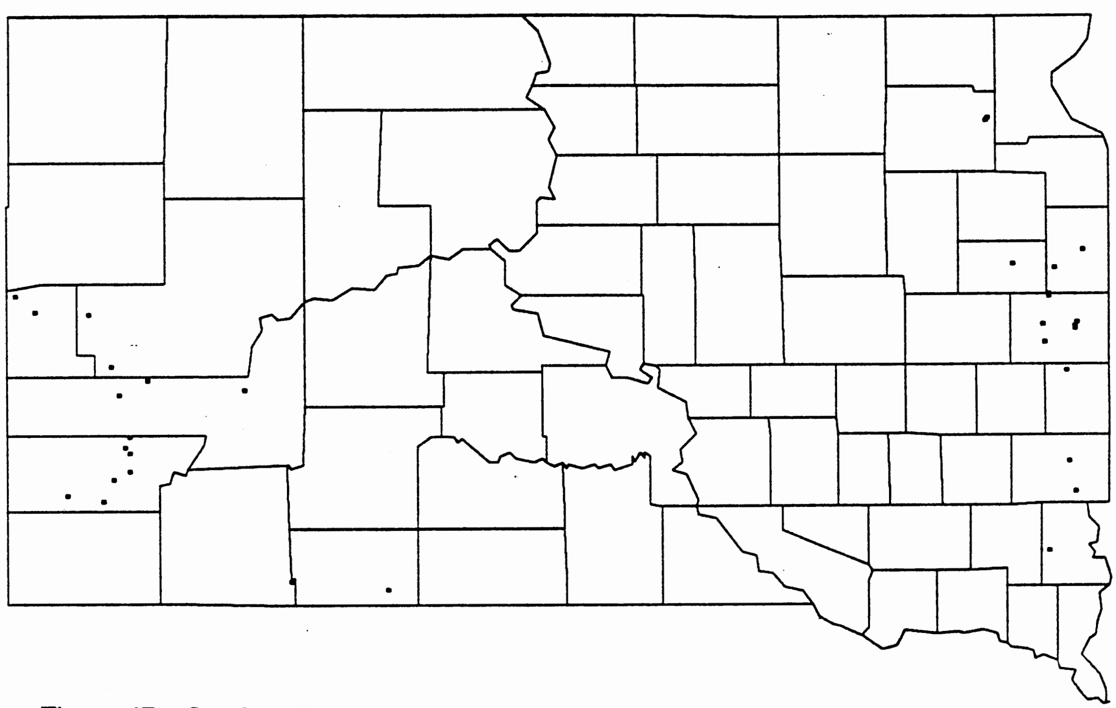


Figure 47. South Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Less Than or Equal to 500 mg/l

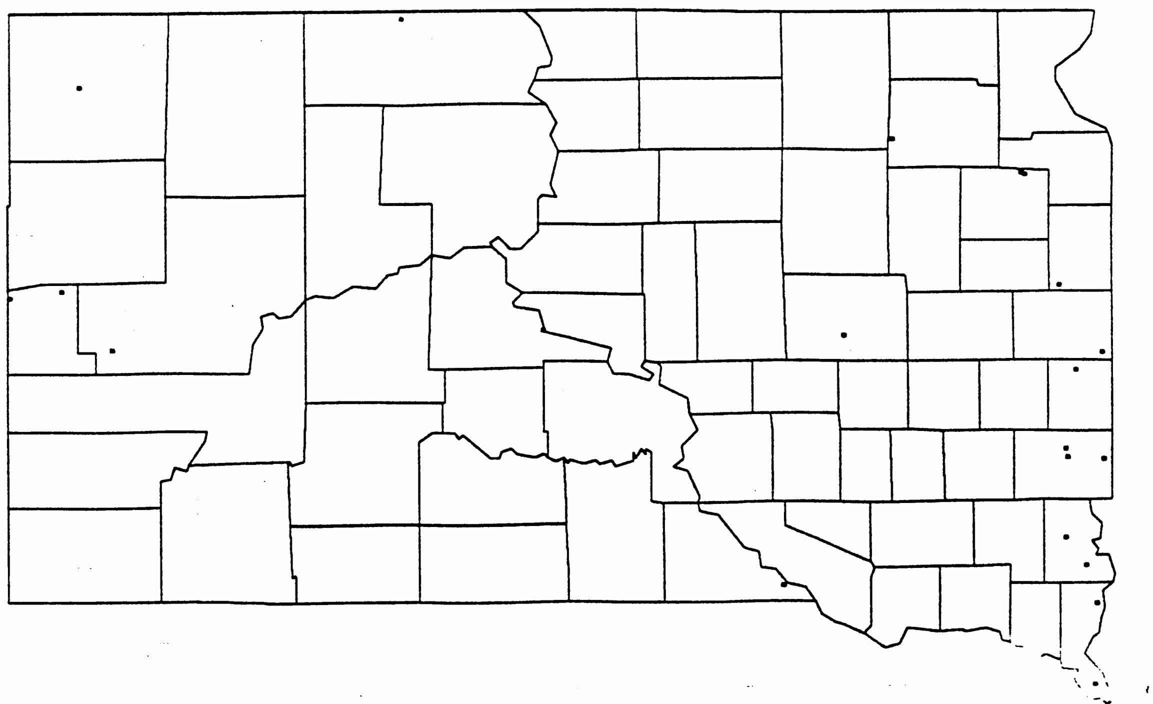


Figure 48. South Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 500 mg/l but Less Than or Equal to 1000 mg/l

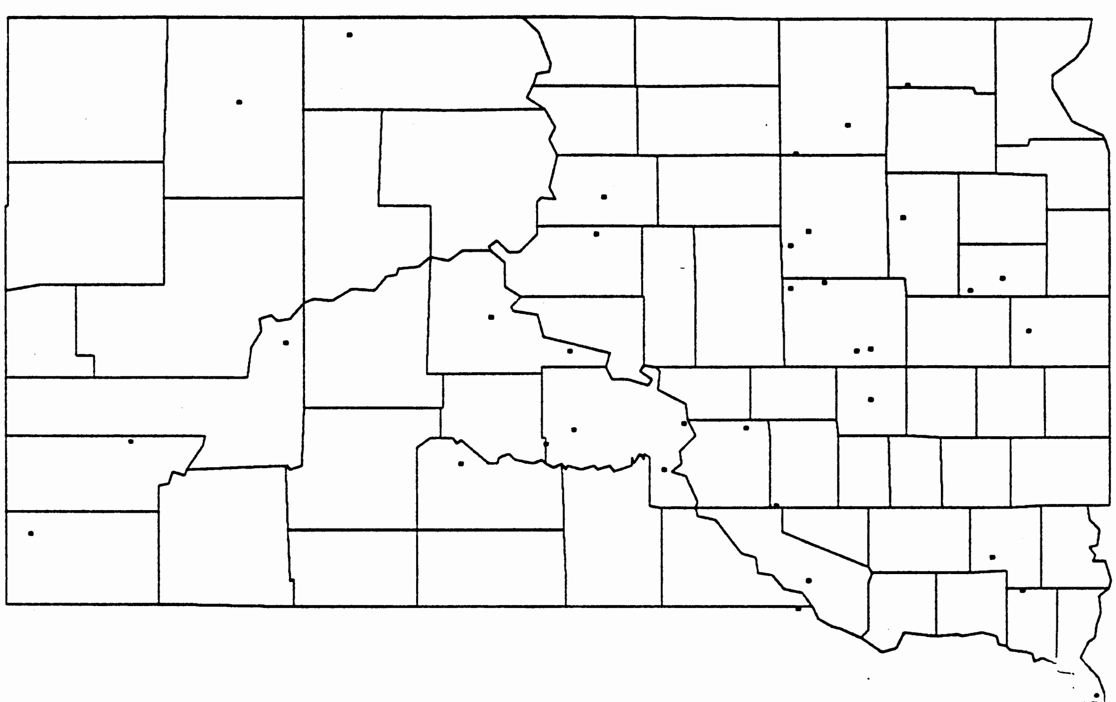


Figure 49. South Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 1000 mg/l

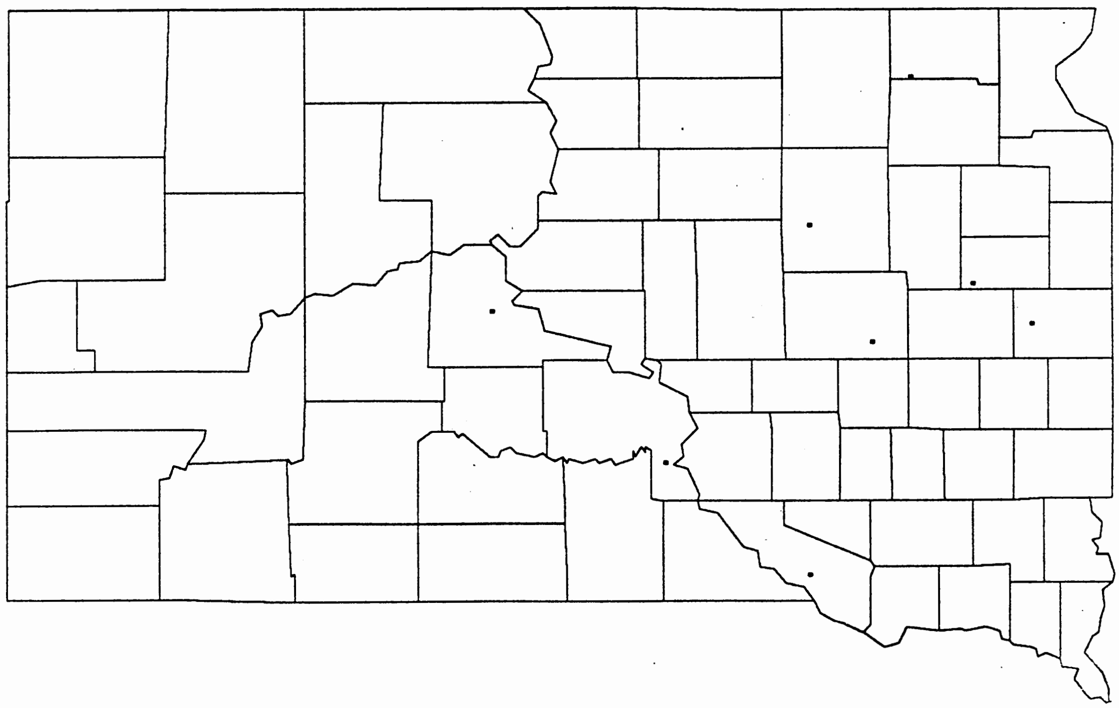


Figure 50. South Dakota: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Equal to or Greater Than the 90th Percentile

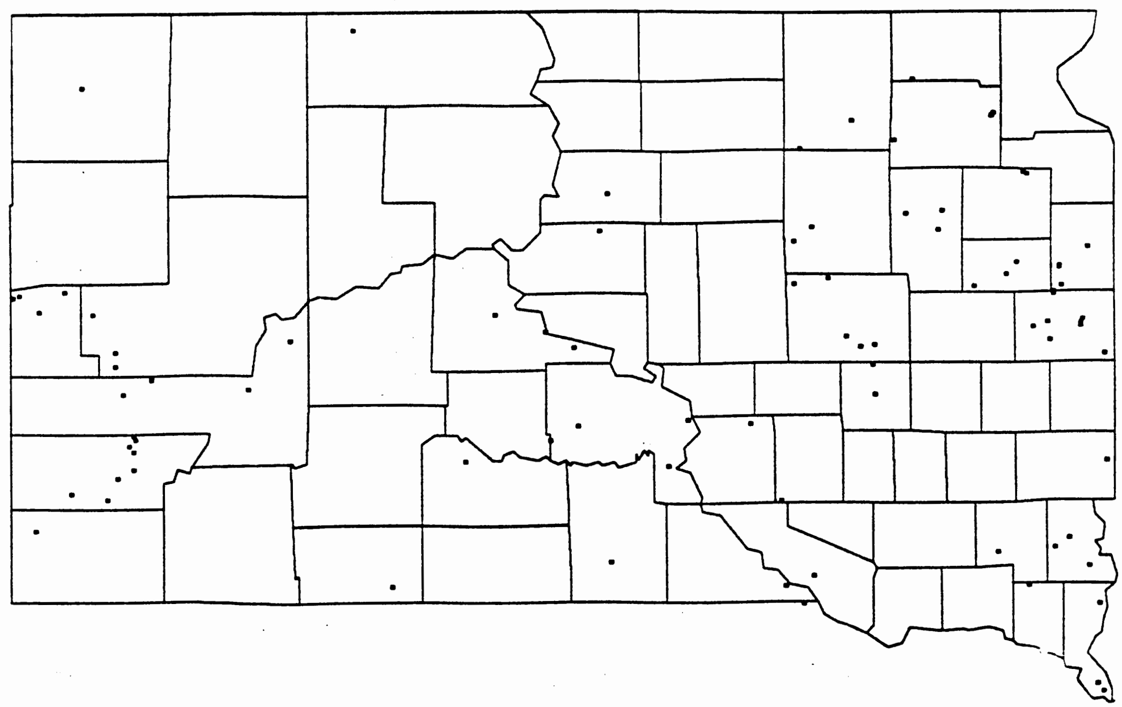


Figure 51. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Hardness

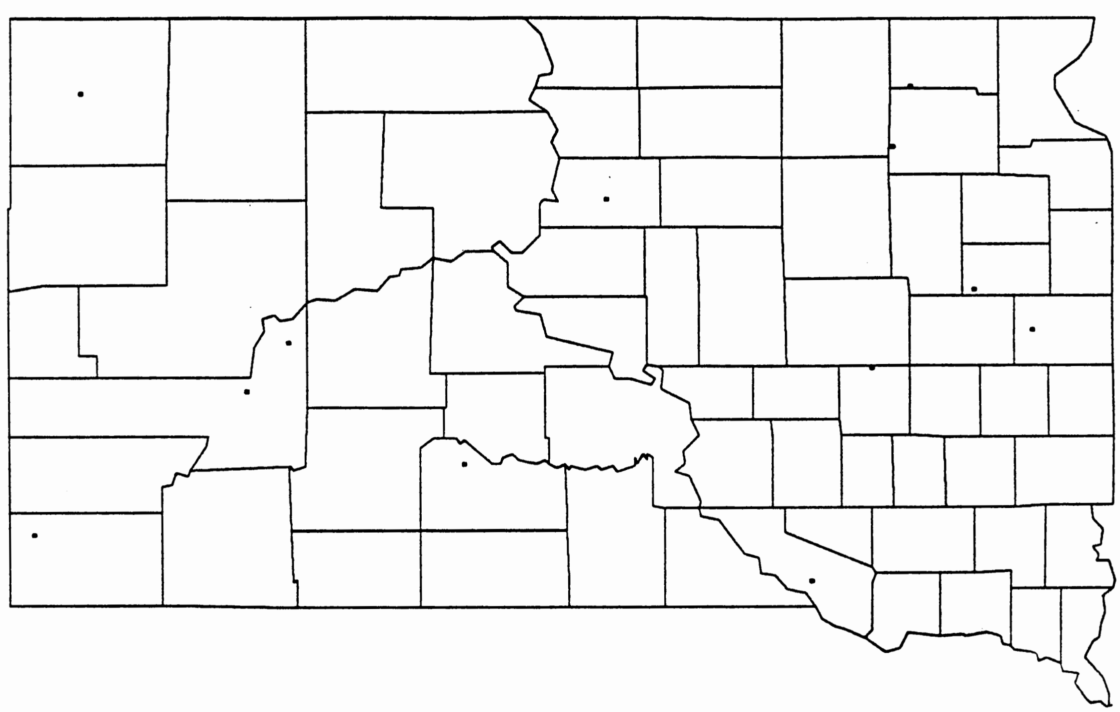


Figure 52. South Dakota: Locations of Wells Where Water Contained Hardness Concentrations Less Than or Equal to 60 mg/l

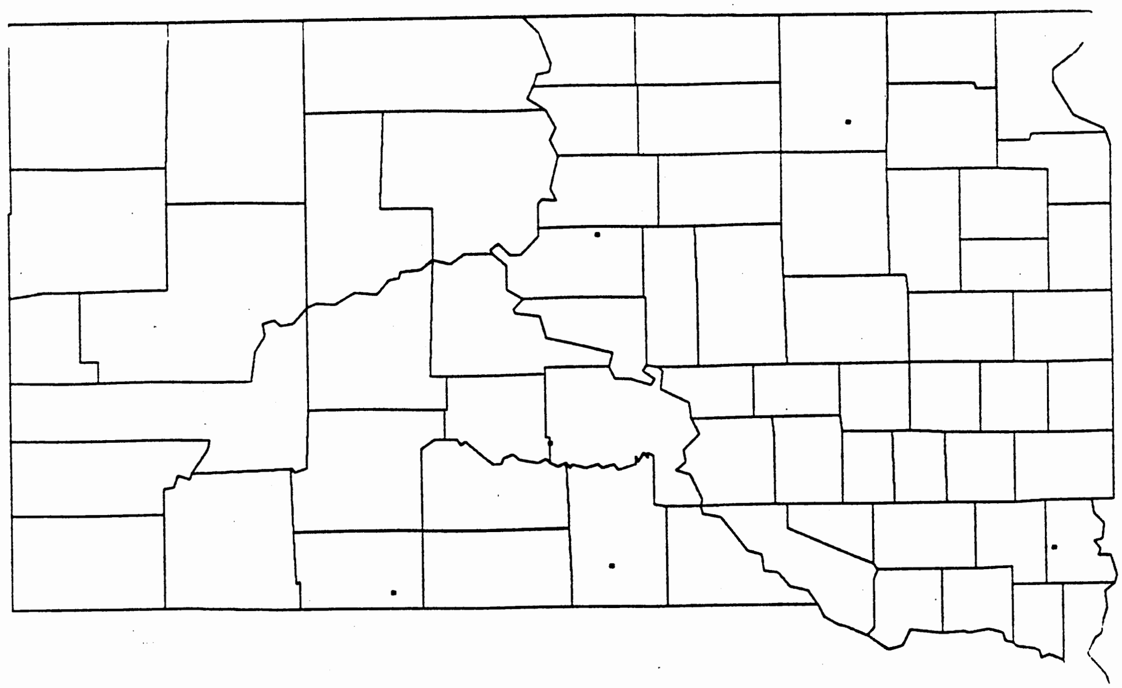


Figure 53. South Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 60 mg/l but Less Than or Equal to 120 mg/l

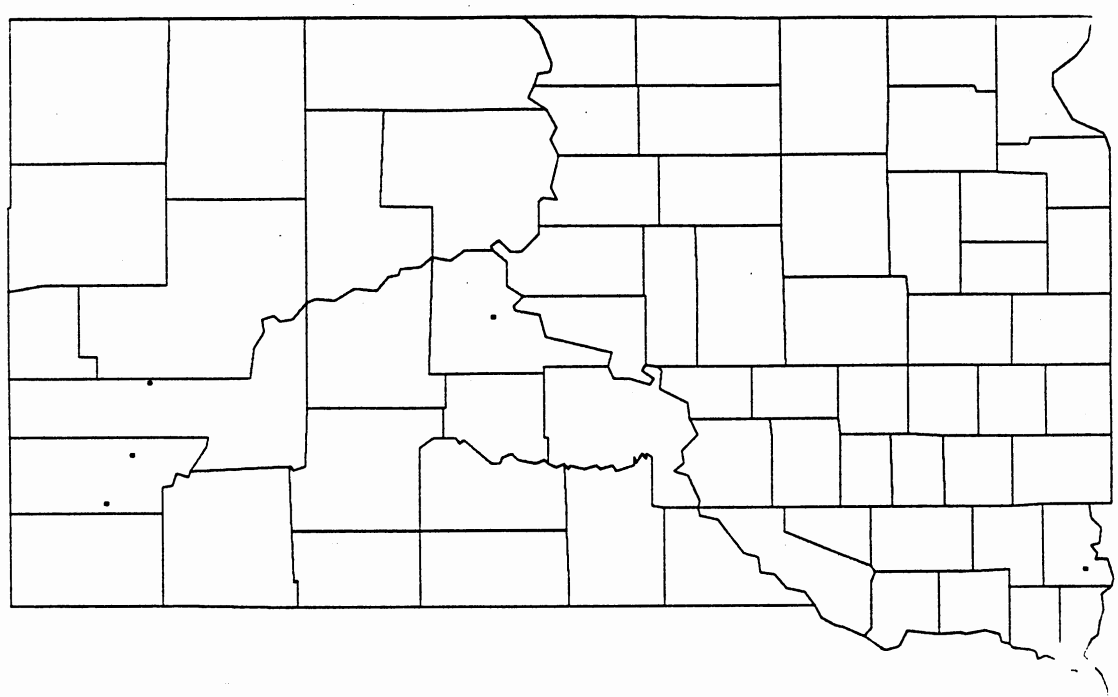


Figure 54. South Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 120 mg/l but Less Than or Equal to 180 mg/l

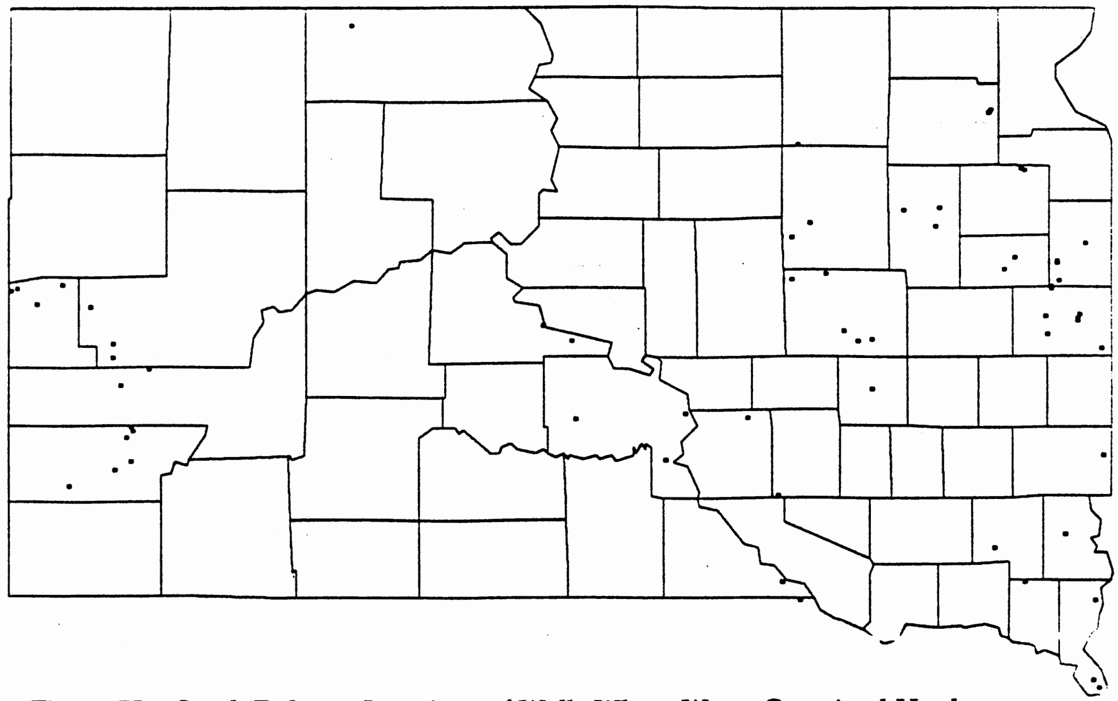


Figure 55. South Dakota: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 180 mg/l

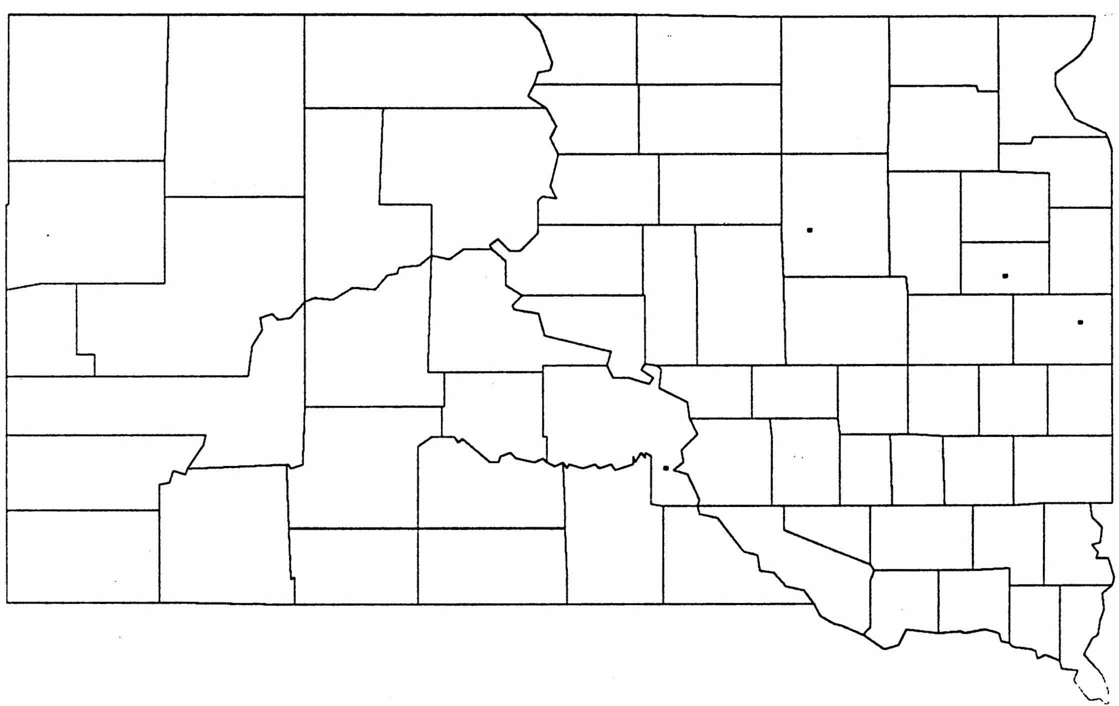


Figure 56. South Dakota: Locations of Wells Where Water Contained Hardness Concentrations Equal to or Greater Than the 90th Percentile

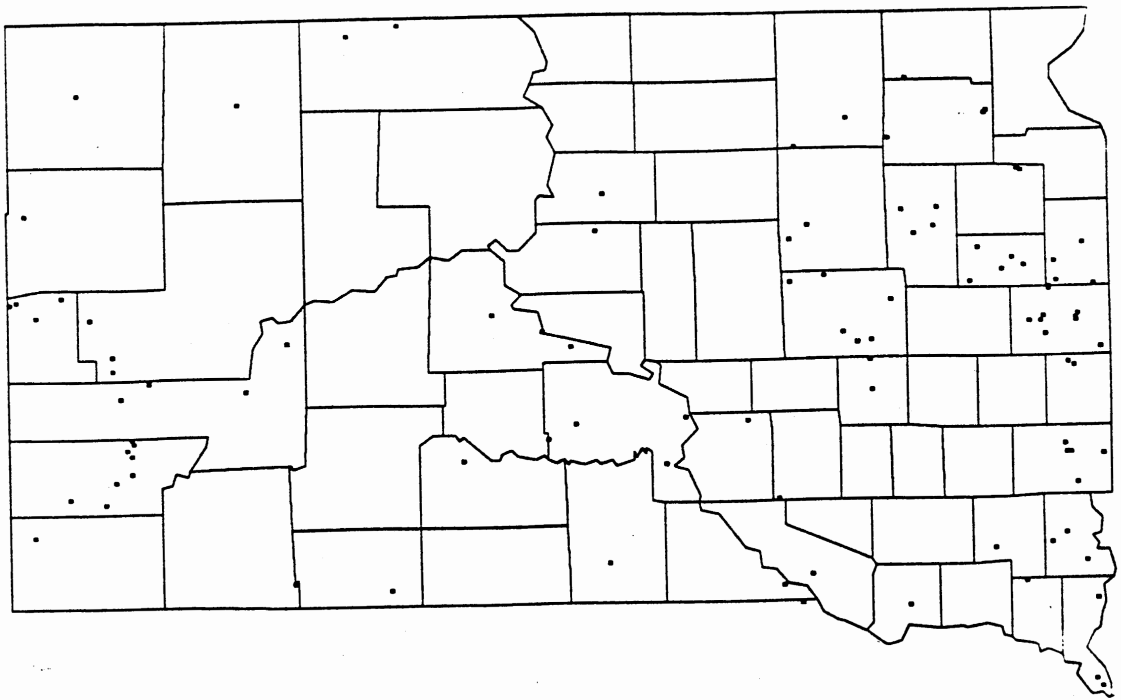


Figure 57. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Chloride

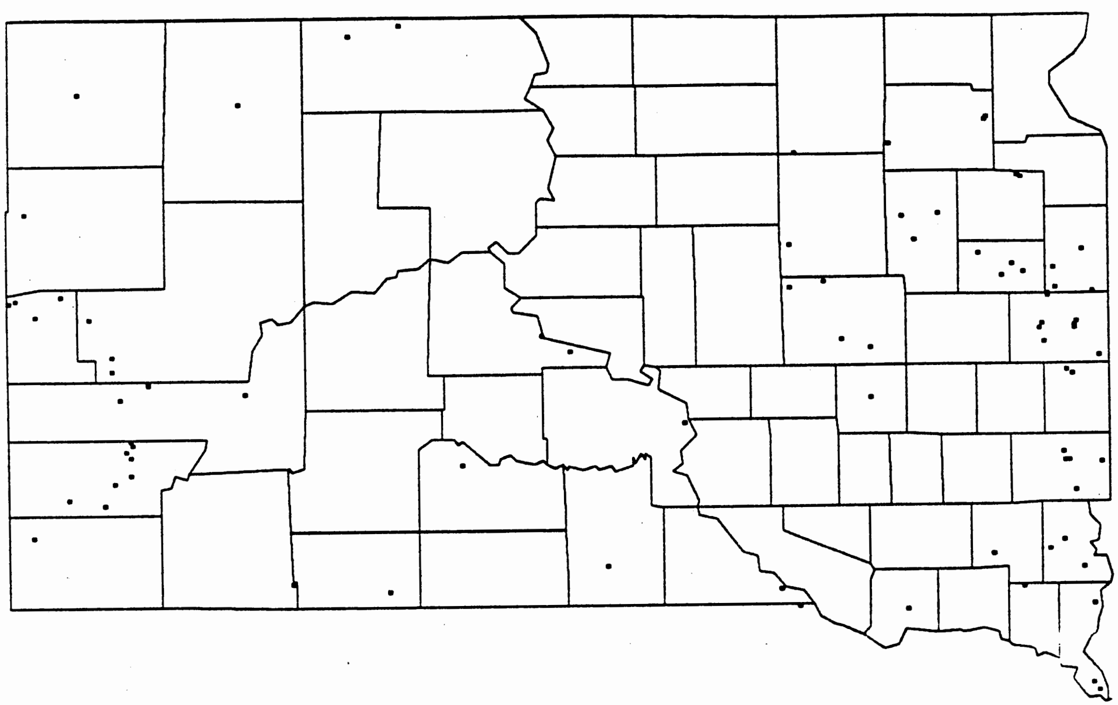


Figure 58. South Dakota: Locations of Wells Where Water Contained Chloride Concentrations Less Than or Equal to 125 mg/l

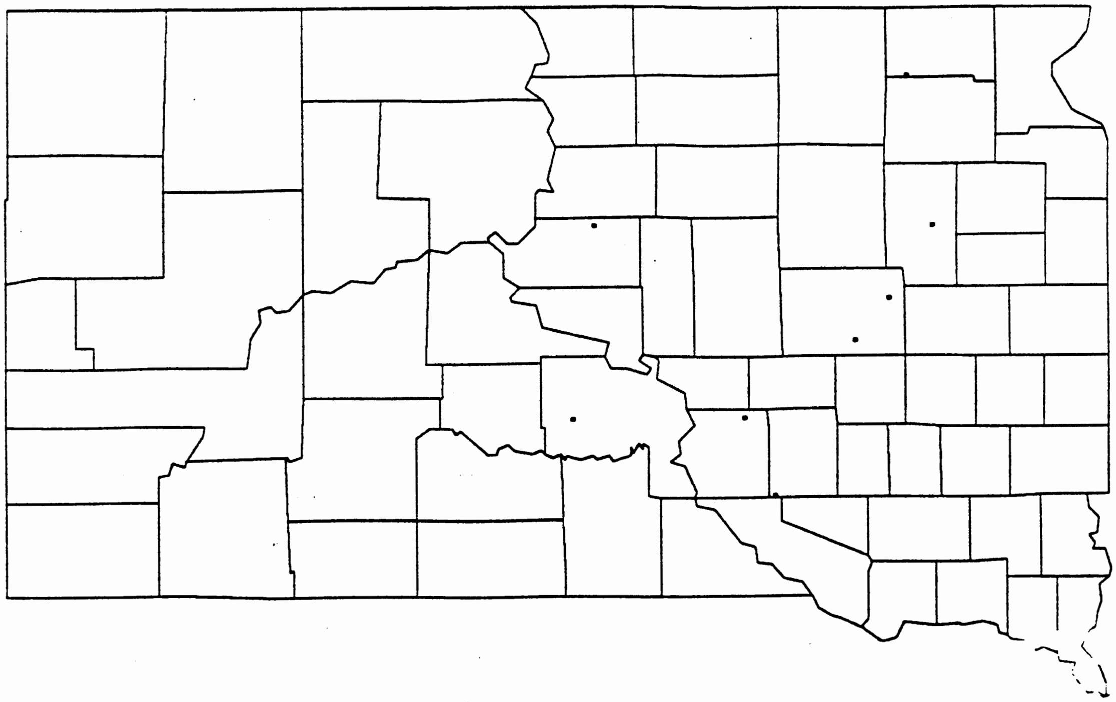


Figure 59. South Dakota: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

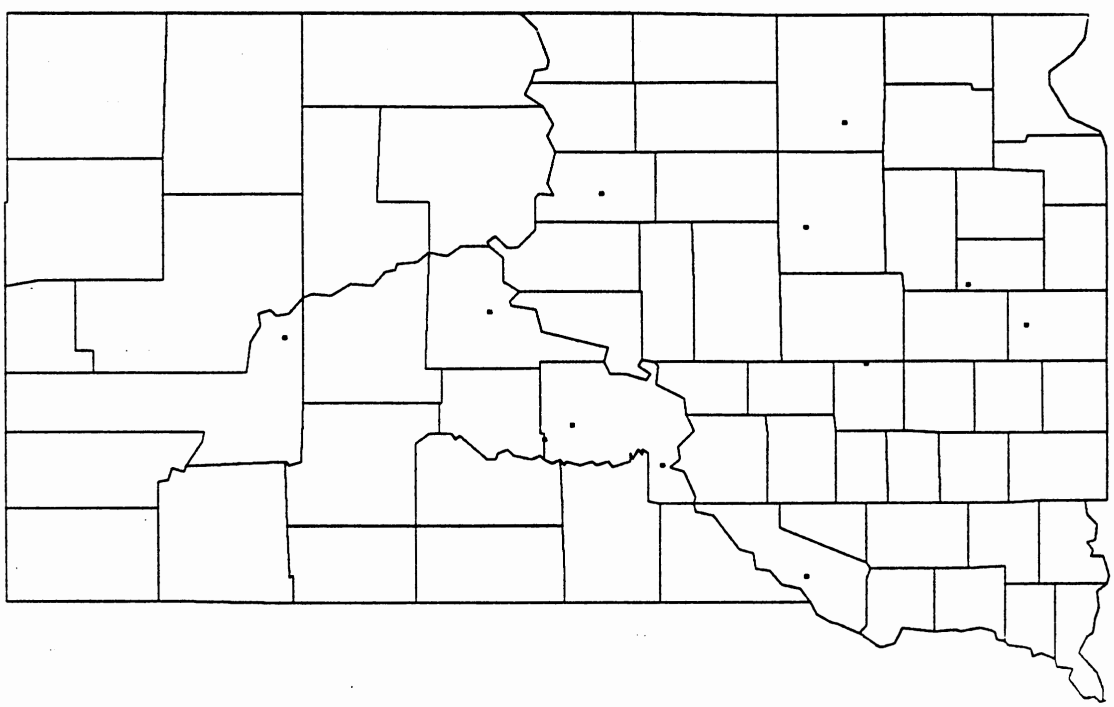


Figure 60. South Dakota: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 250 mg/l

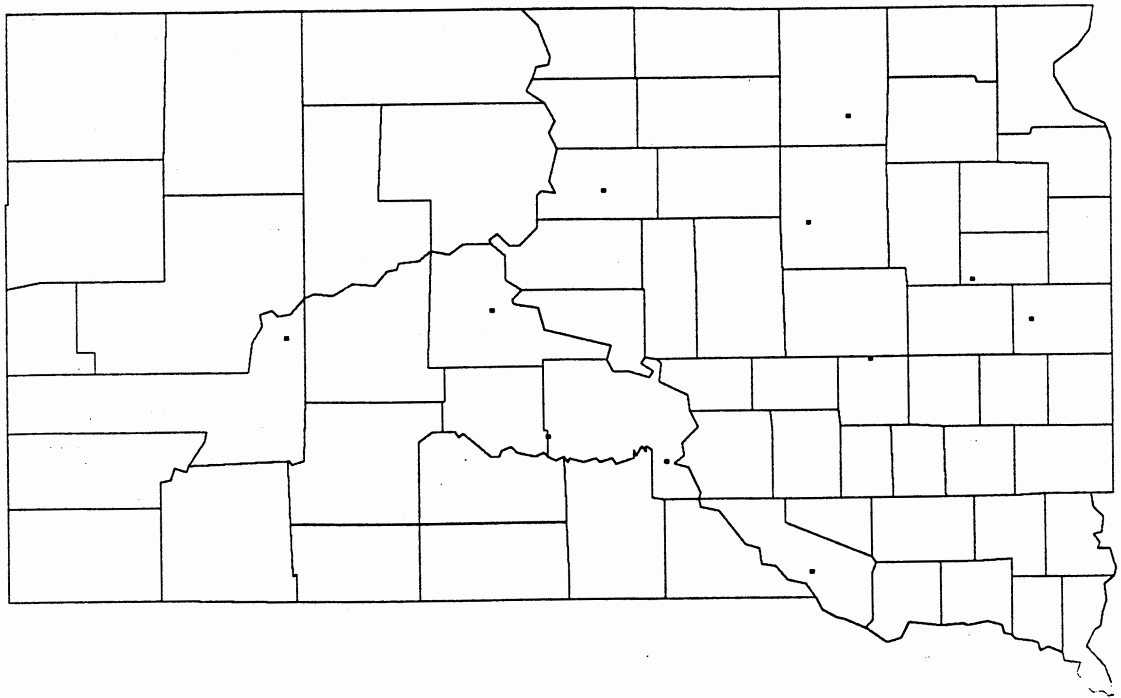


Figure 61. South Dakota: Locations of Wells Where Water Contained Chloride Concentrations Equal to or Greater Than the 90th Percentile

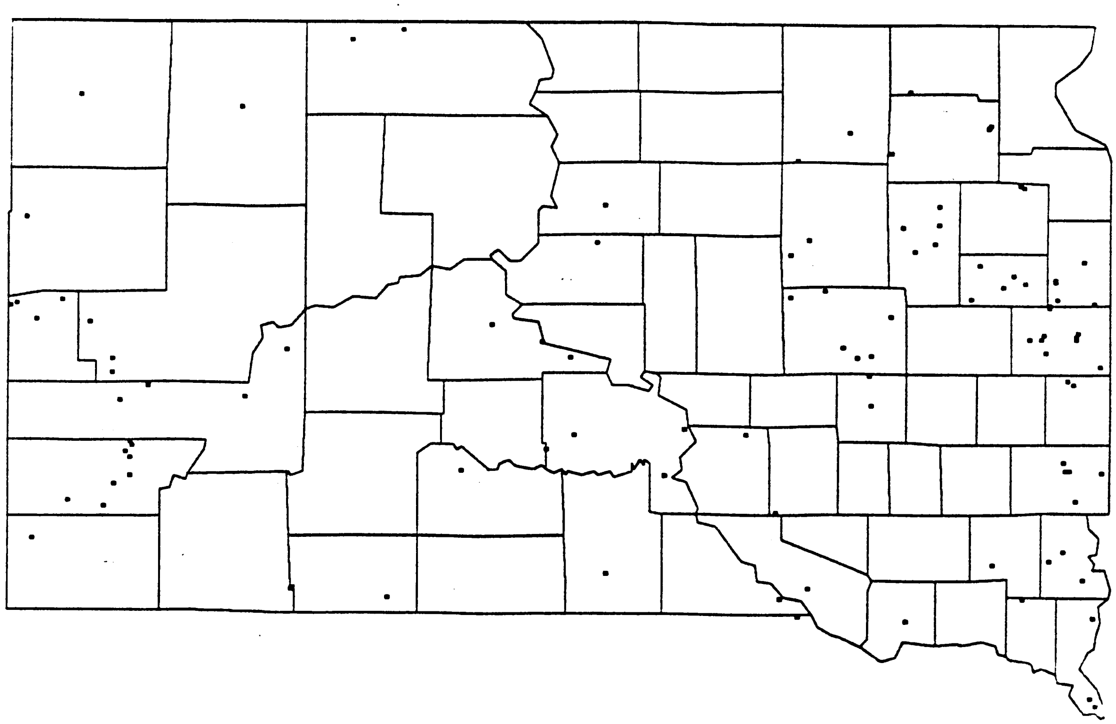


Figure 62. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed For Sulfate

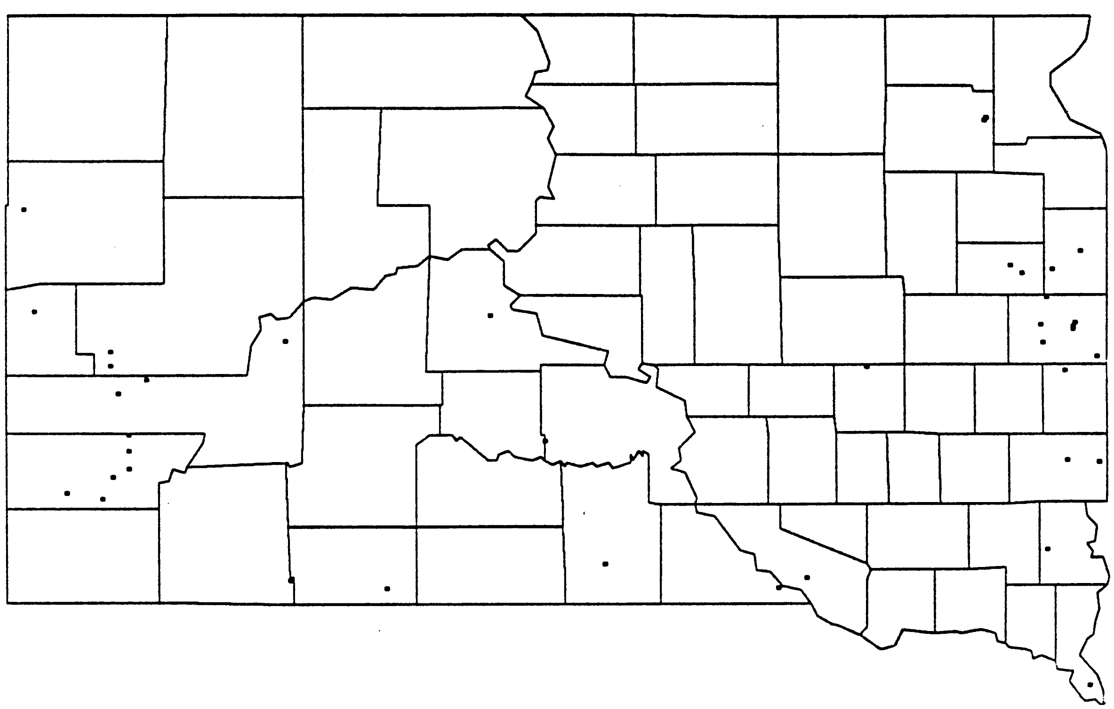


Figure 63. South Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Less Than or Equal to 125 mg/l

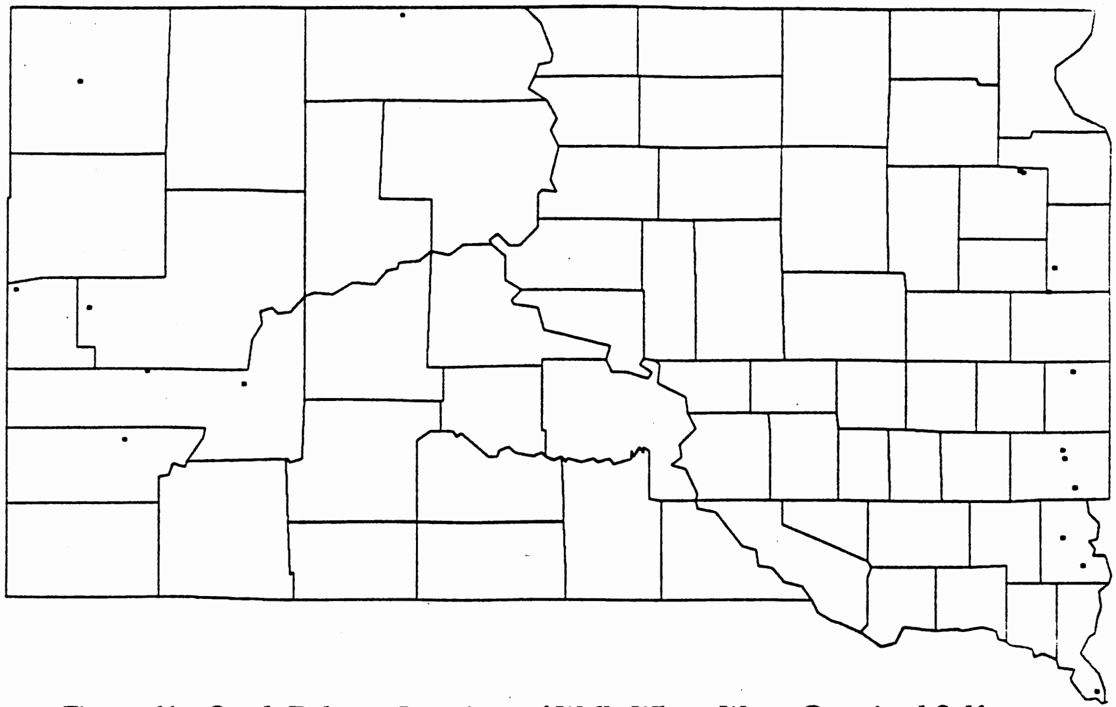


Figure 64. South Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

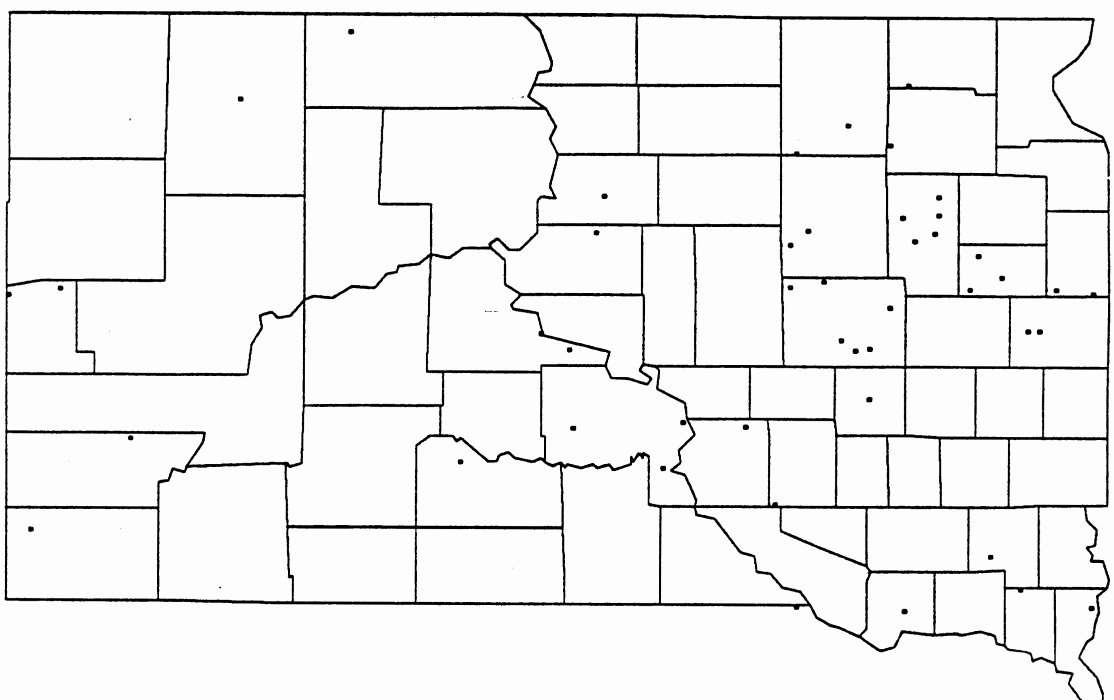


Figure 65. South Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 250 mg/l

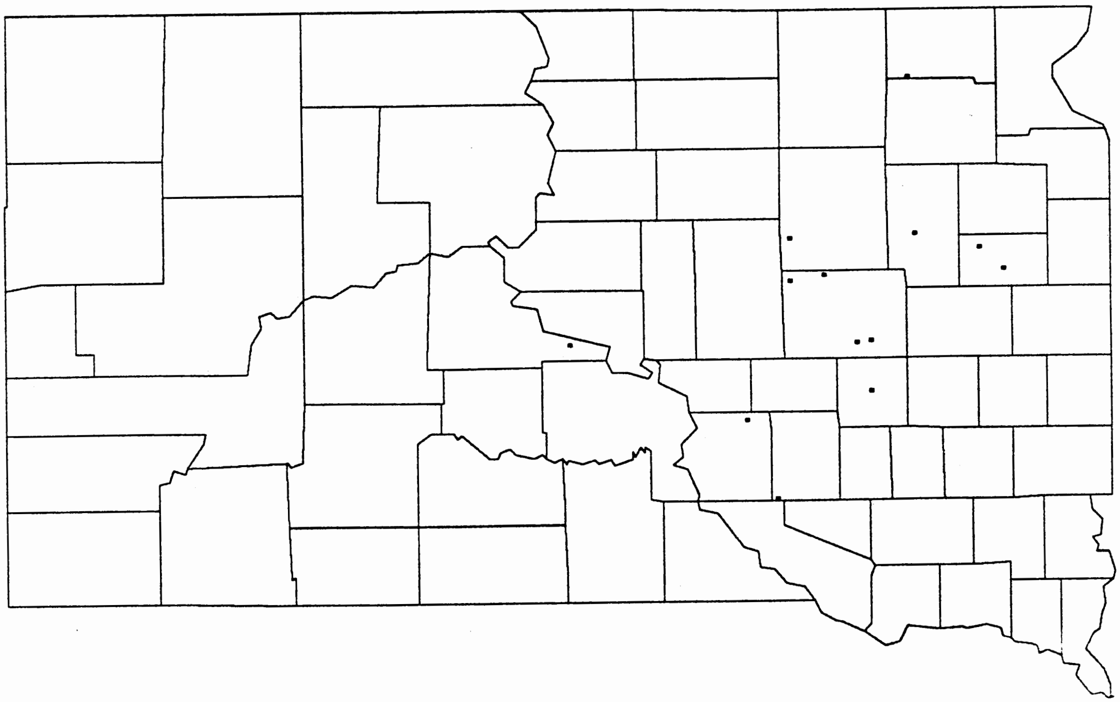


Figure 66. South Dakota: Locations of Wells Where Water Contained Sulfate Concentrations Equal to or Greater Than the 90th Percentile

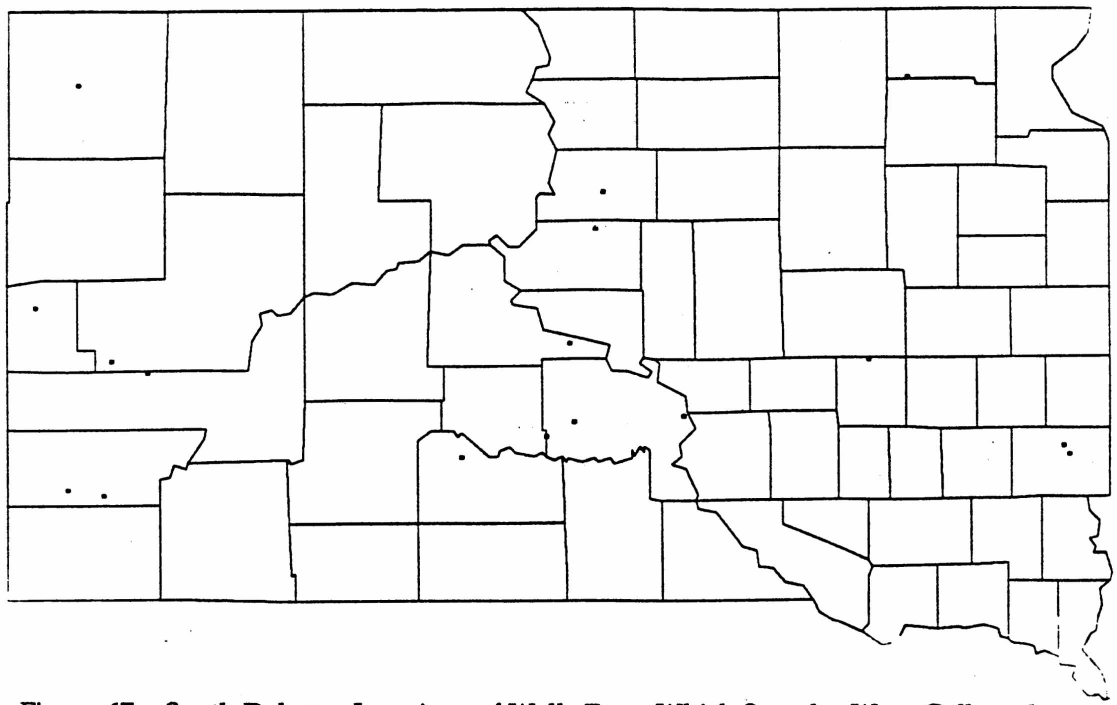


Figure 67. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate Measured as N

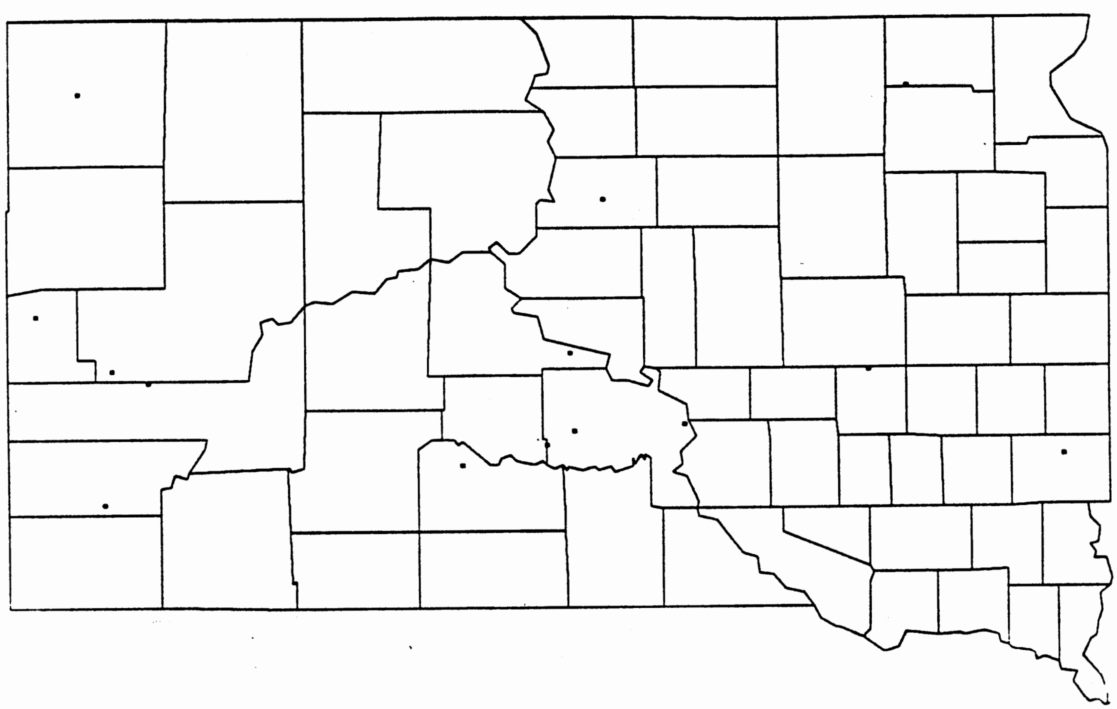


Figure 68. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 5 mg/l as N

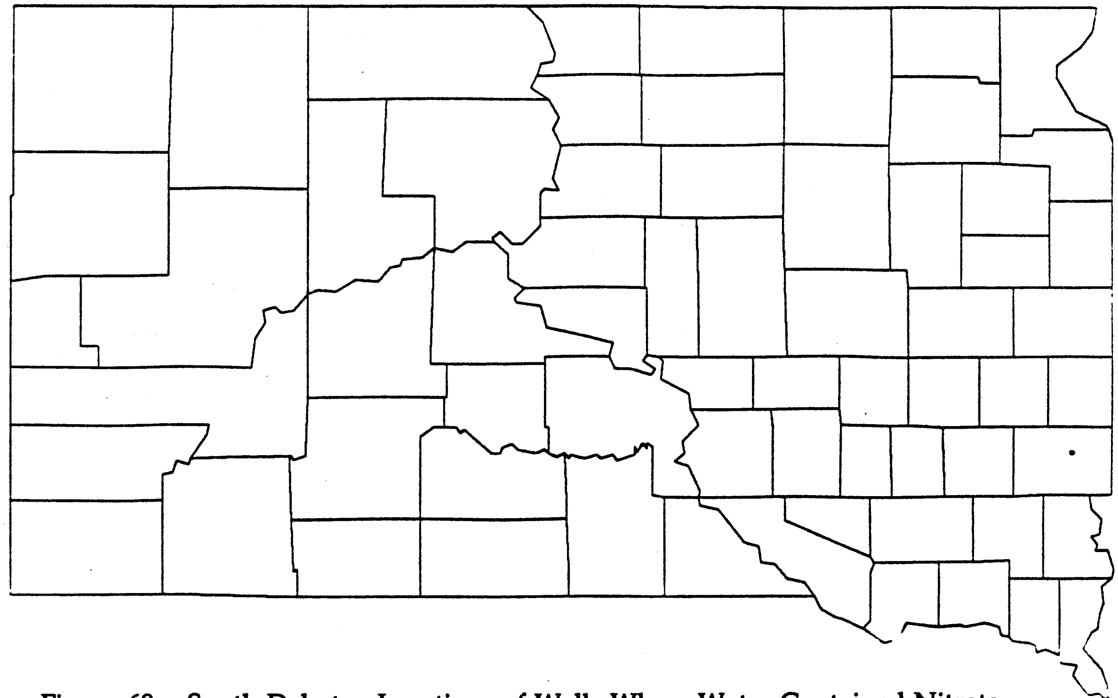


Figure 69. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 5 mg/l as N but Less Than or Equal to 10 mg/l as N

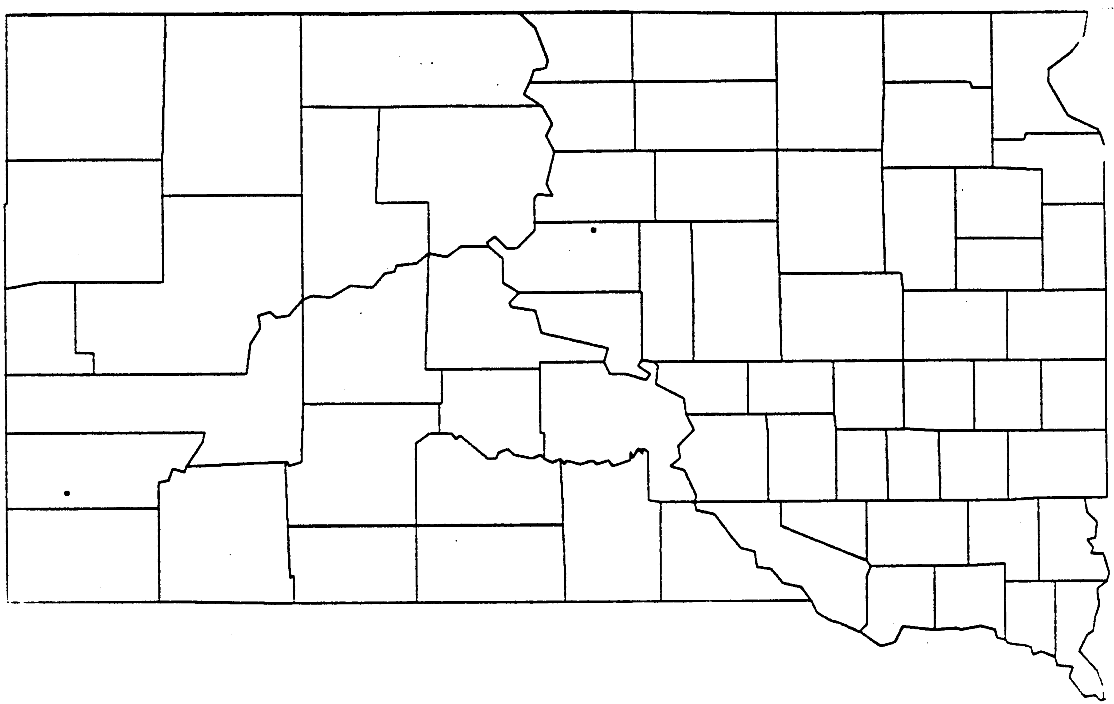


Figure 70. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 10 mg/l as N

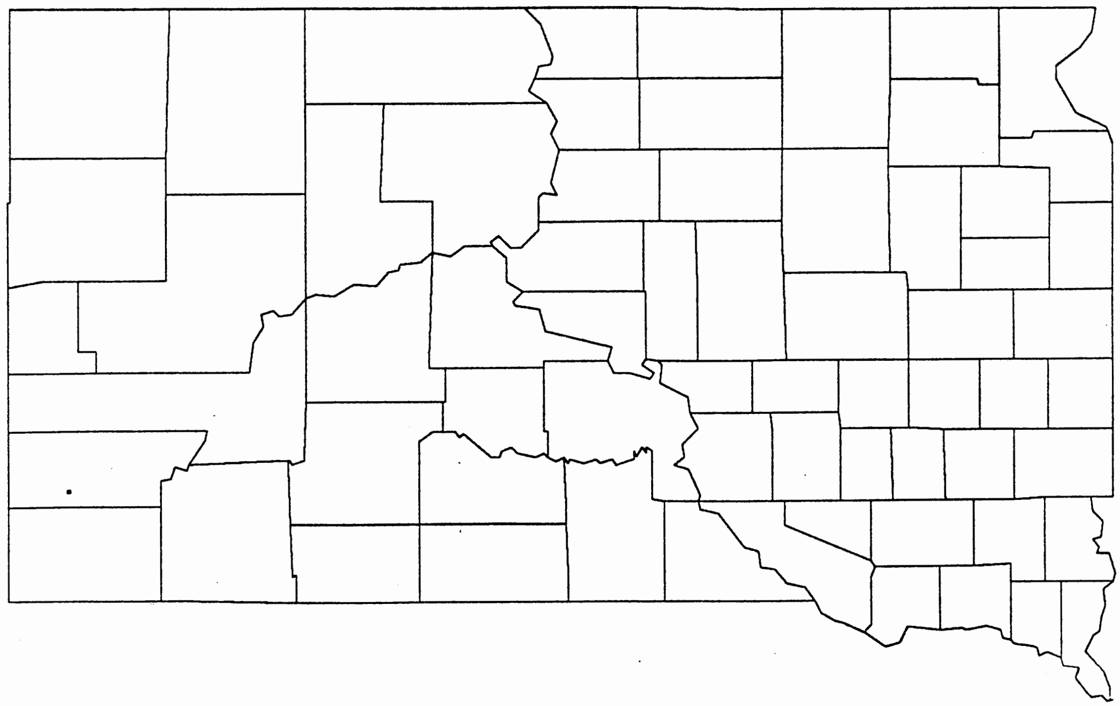


Figure 71. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as N, Equal to or Greater Than the 90th Percentile

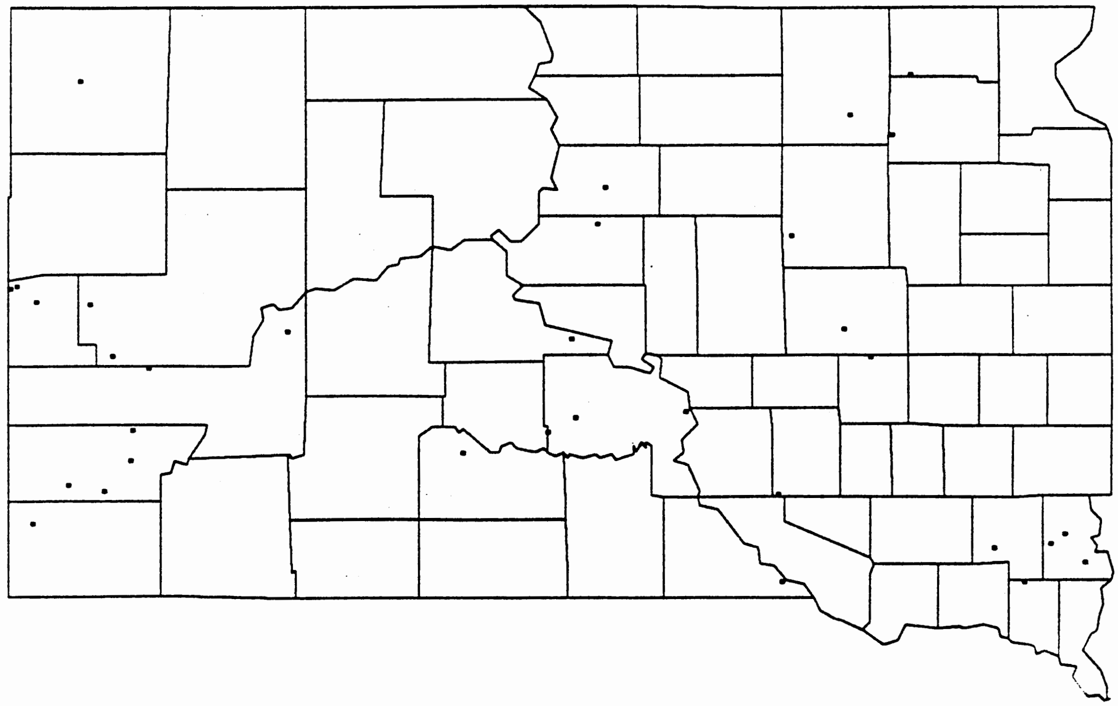


Figure 72. South Dakota: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate as NO3

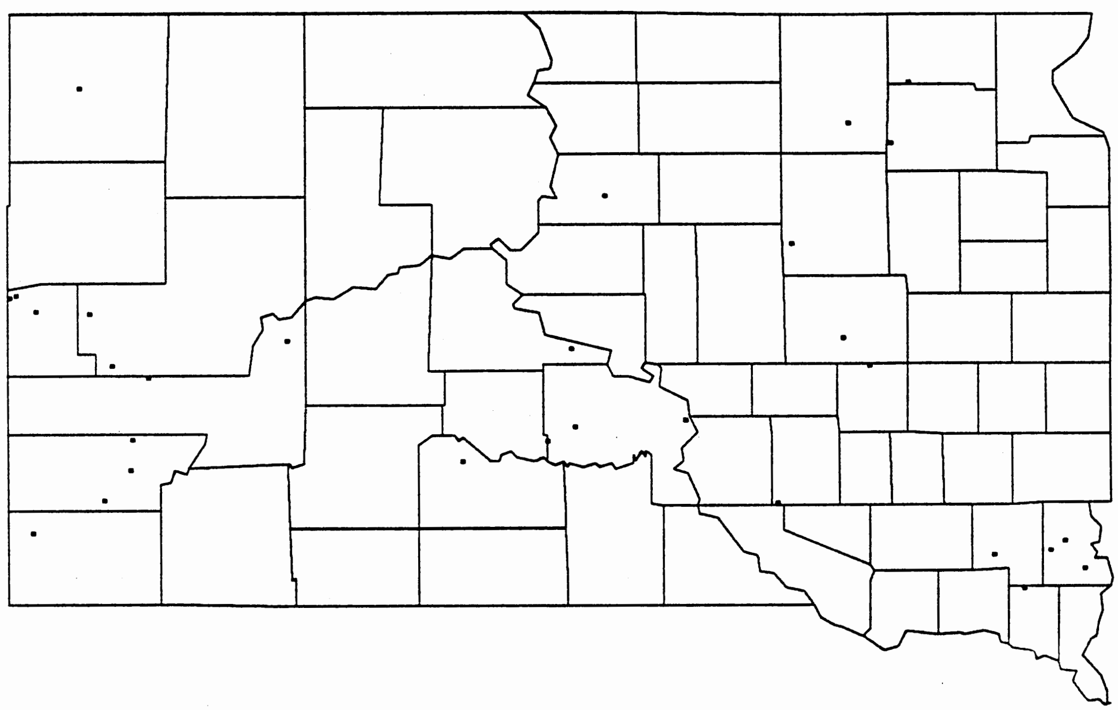


Figure 73. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 25 mg/l as NO3

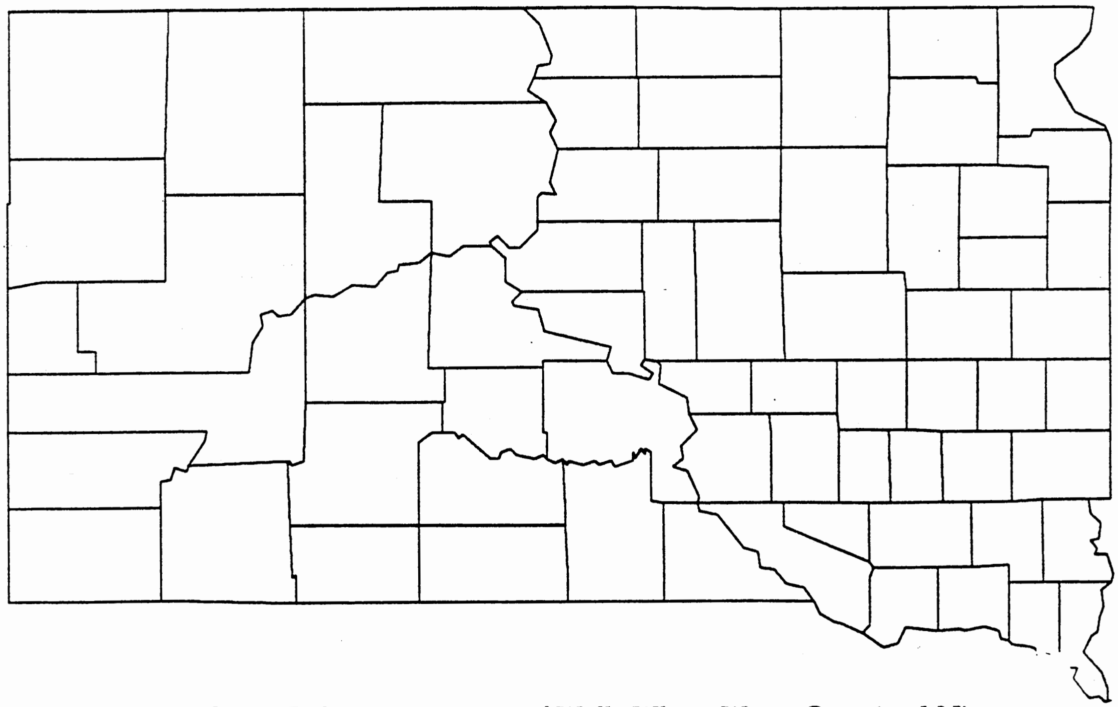


Figure 74. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 25 mg/l as NO3 but Less Than or Equal to 45 mg/l as NO3

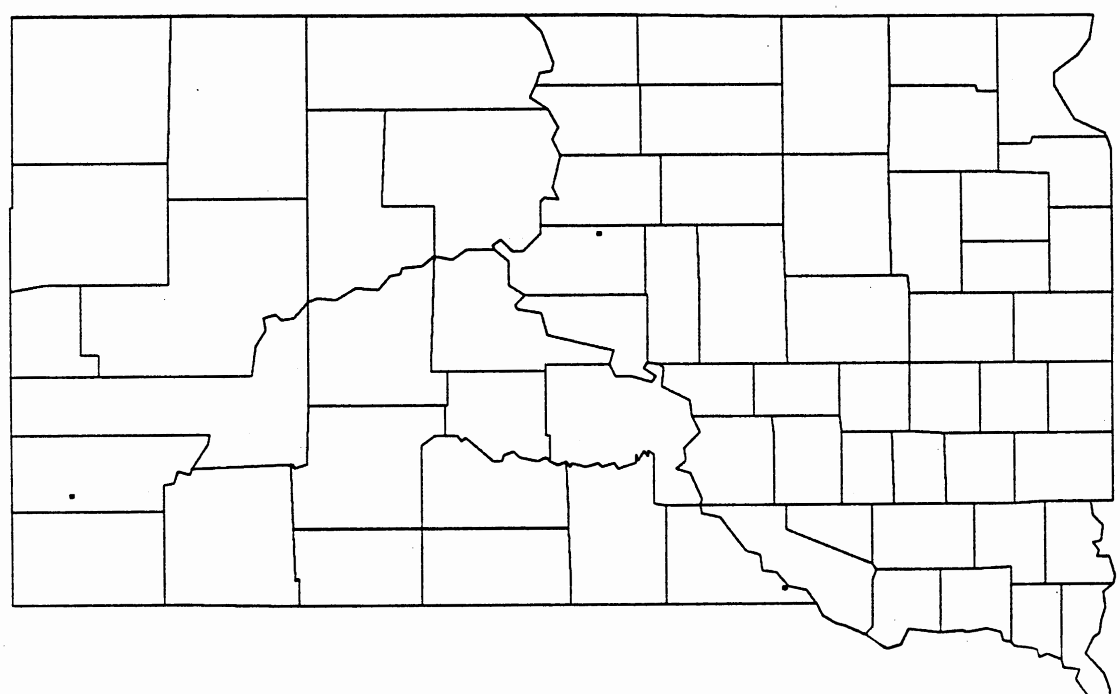


Figure 75. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 45 mg/l as NO3

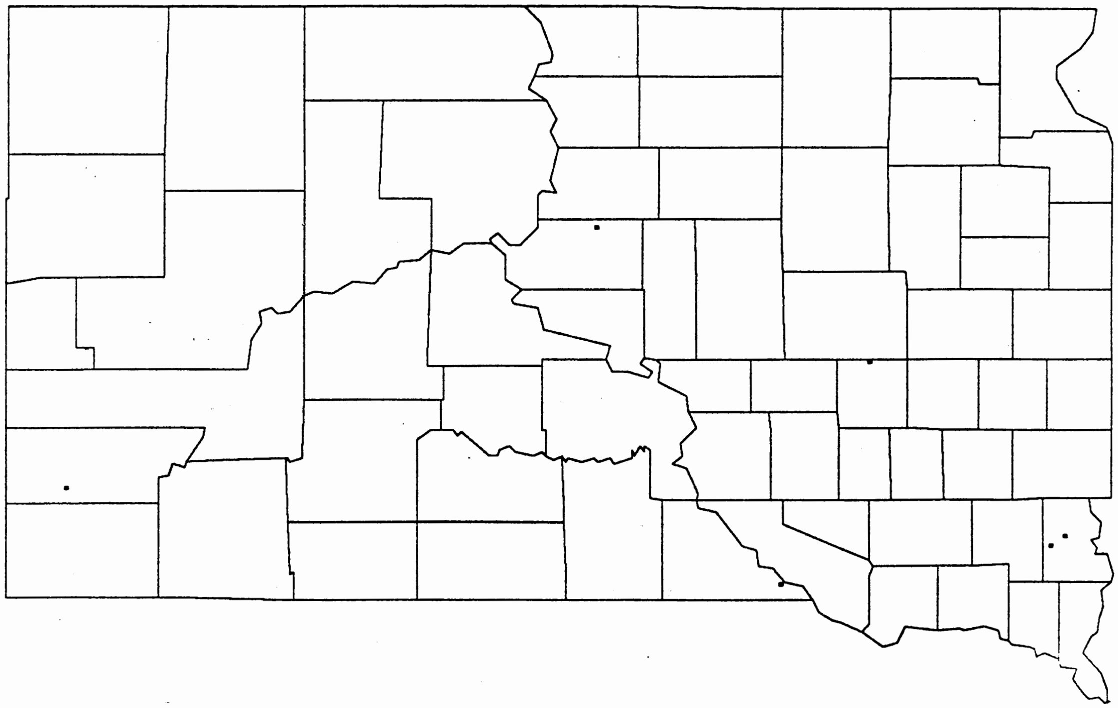


Figure 76. South Dakota: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as NO3, Equal to or Greater Than the 90th Percentile

Nebraska

General Setting

Nebraska contains approximately 77,000 square miles. Annual average precipitation ranges from less than 16 inches in the western part of Nebraska to about 32 inches in the southeast. The state is drained by the eastern flowing Niobrara, Platte and Republican River systems. These rivers terminate in the Missouri River that bounds Nebraska on the east.

Nebraska is underlain by Paleozoic to Mesozoic age bedrock that dips gently into shallow structural basins. These strata are primarily composed of shale with some sandstone units. Glacial drift covers much of the bedrock in Nebraska's eastern margin. Quaternary age loess, fluvial, and dune sand deposits mantle the central region. Much of western Nebraska is covered by the Tertiary age Ogallala Formation. This formation consists of unconsolidated to semiconsolidated deposits of gravel, sand, silt and clay.

Discussion

Table 7 exhibits the number of analyses measured, the percentage of samples that exceed E.P.A. drinking water standards, and the percentage in each range of concentration. A map of the major aquifers in Nebraska and their descriptions is depicted in Figures 77 and 78. Maps illustrating the location of wells and selected ground water quality in Nebraska are shown in Figures 79-109.

Over 1600 samples were analyzed for total dissolved solids in Nebraska. About 76 percent contain less than the recommended level of 500 mg/l. Approximately 24 percent of those sampled exceed 1000 mg/l. Figures 80 and 82 indicate that the samples were drawn from the glaciated eastern margin, and to a lesser extent, the southern part of Nebraska. Many of those wells located in the southern part of the state lie along the Platte River.

Hardness concentrations exceed 180 mg/l in 62 percent of those wells sampled. Figure 88 shows that the majority of these wells are located in the southeastern half of Nebraska. The wells containing very hard water are somewhat evenly distributed without regard to major aquifer present (Figure 77). Figure 85 indicates wells containing soft water are located in central and western Nebraska. These areas are occupied by dune sand and fluvial deposits of Quaternary age.

Chloride was measured in over 2500 wells in the state. About 95 percent of those samples contained less than or equal to 125 mg/l of chloride. Of the 2551 samples measured for sulfate, approximately 10 percent exceed the recommended limit of 250 mg/l. Figure 98 shows that these wells are located in the glaciated eastern margin and along the Platte River in southern Nebraska.

Data from Table 7 shows that 13 percent of the samples tested for nitrate exceed the recommended limits. These wells are predominantly located in the eastern half of the state. One common source for nitrate is heavy use of some fertilizers. This is most likely to be the cause of higher concentrations of nitrate in Nebraska.

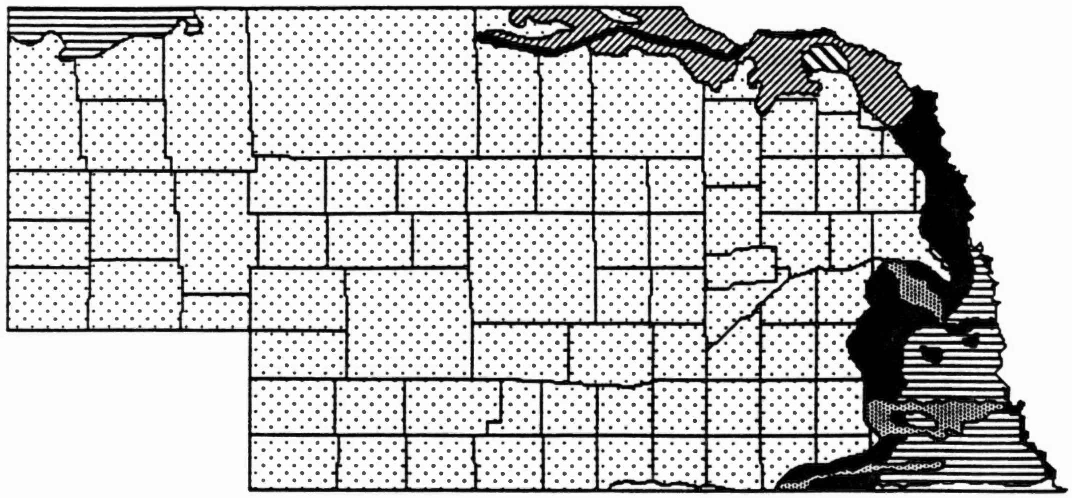
TABLE 7

NEBRASKA: NUMERICAL SUMMARIES
OF WATER ANALYSES

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
TDS		500*	24	•
All Samples	1603		•	•
0 - 500	1211		•	76
501 - 1000	251		•	15
Greater than 1000	141		•	9
Equal to or Greater Than			•	•
the 90th Percentile	163		•	10
Hardness		None	•	
All Samples	2519		•	•
0 - 60	217		•	9
61 - 120	267		•	11
121 - 180	476		•	19
Greater than 180	1559		•	62
Equal to or Greater Than			•	•
the 90th Percentile	251		•	10
Chloride		250	3	•
All Samples	2569		•	•
0 - 125	2439		•	95
126 - 250	42		•	2
Greater than 250	88		•	3
Equal to or Greater Than			•	•
the 90th Percentile	260		•	10
Sulfate		250	10	•
All Samples	2551		•	•
0 - 125	2066		•	81
126 - 250	243		•	9
Greater than 250	242		•	10
Equal to or Greater Than			•	•
the 90th Percentile	262		•	10

TABLE 7 (continued)

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
Nitrate as N		10	10	•
All Samples	151		•	•
0 - 5	124		•	82
6 - 10	8		•	5
Greater than 10	19		•	13
Equal to or Greater Than			•	•
the 90th Percentile	16		•	11
Nitrate as NO3		45	13	•
All Samples	1502		•	•
0 - 25	1258		•	82
26 - 45	124		•	5
Greater than 45	120		•	13
Equal to or Greater Than			•	•
the 90th Percentile	152		•	10



EXPLANATION

UNCONSOLIDATED ALLUVIAL AQUIFERS

Valley Alluvial Aquifers

Paleovalley Alluvial Aquifers

CONSOLIDATED SANDSTONE AND CARBONATE ROCK AQUIFERS

High Plains Aquifer System

Niobrara Aquifer

Dakota Aquifer System

Undifferentiated Aquifers in Cretaceous Rocks

Undifferentiated Aquifers in Paleozoic Rocks

Figure 77. Nebraska: Map of Major Aquifers (Modified from U.S.G.S., 1985)

[Ft = feet; gal/min = gallons per minute; mg/L = milligrams per liter. Sources: Reports of the U.S. Geological Survey and Nebraska State agencies]

Aquifer name and description	Well characteristics			Remarks
	Depth (ft)	Yield (gal/min)		
	Common range	Common range	May exceed	
Aquifers in unconsolidated deposits:				
Valley alluvial aquifers: Unconsolidated sand, gravel, silt, and clay. Unconfined.	30 - 100	300 - 750	1,500	Differentiable only in areas where High Plains aquifer system not present. Locally, water contains excessive concentrations of iron.
Paleovalley alluvial aquifers: Unconsolidated sand, gravel, silt, and clay. Generally unconfined.	50 - 150	500 - 1,000	1,500	Differentiable only in areas where High Plains aquifer system not present.
High Plains aquifer system: Unconsolidated and poorly consolidated sand, gravel, silt, and clay. Unconfined to partially confined.	30 - 500	500 - 1,000	2,500	Aquifer system comprised of the Ogallala Formation and hydraulically connected sand, gravel, silt, and clay deposits. Nonpoint-nitrate contamination from agricultural sources in several areas where water table is less than 30 ft below land surface and soils are sandy.
Aquifers in consolidated sandstone and carbonate rocks:				
Niobrara aquifer: Chalk and silty marlstone. Unconfined.	75 - 200	300 - 750	1,000	Significant source of water only in areas where secondary porosity has developed. Locally overlain by saturated Quaternary sand and gravel deposits, which may be an adequate source of water or may be used in conjunction with Niobrara aquifer.
Dakota aquifer system: Fine to medium grained, poorly consolidated sandstone and interbedded clays. Where commonly used, generally unconfined or partially confined; confined throughout rest of State.	75 - 600	300 - 750	1,000	Locally overlain by saturated Quaternary sand and gravel deposits that may be an adequate source of water or may be used in conjunction with the Dakota aquifer. Water in areas where aquifer system is used is generally potable (less than 1,000 mg/L dissolved solids) except in west-central and northern Lancaster County where sodium chloride type water with over 40,000 mg/L dissolved solids occurs.
Undifferentiated aquifers in Cretaceous rocks: Chalk and sandstone. Unconfined to confined.	75 - 1,300	10 - 100	750	Locally overlain by saturated Quaternary sand and gravel deposits that may be an adequate source of water or may be used in conjunction with undifferentiated aquifers in Cretaceous rocks. Dissolved solids generally range between 1,000 and 1,500 mg/L.
Undifferentiated aquifers in Paleozoic rocks: Limestone, dolomite, and sandstone. Unconfined or partially confined in upper 200 ft; confined at depth.	30 - 2,200	10 - 200	500	Locally overlain by saturated Quaternary sand and gravel deposits that may be an adequate source of water or may be used in conjunction with undifferentiated aquifers in Paleozoic rocks. Water quality variable, dissolved solids generally less than 1,500 mg/L but may be as much as 6,000 mg/L.

Figure 78. Nebraska: Major Aquifer Descriptions and Well Characteristics (Modified from U.S.G.S., 1985)

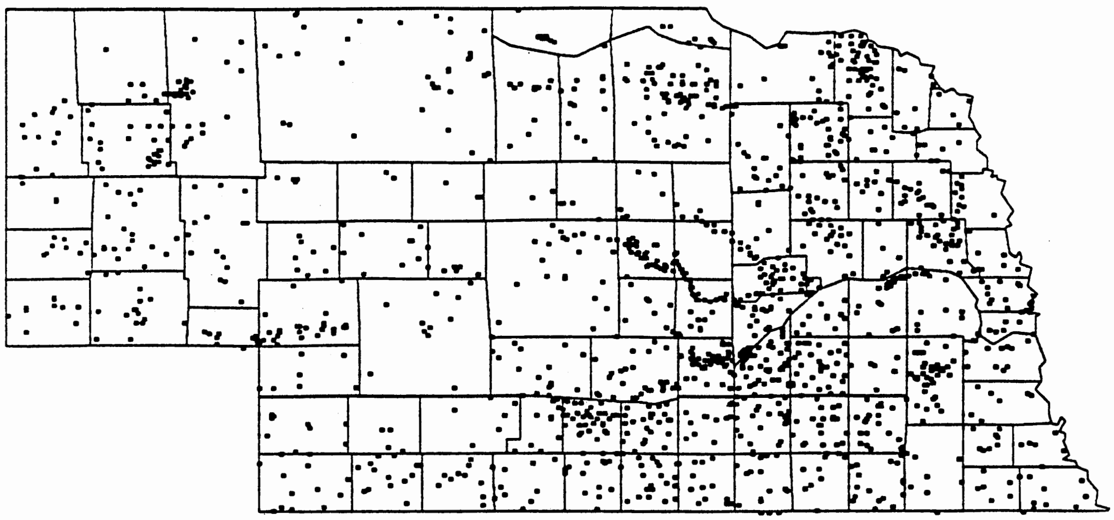


Figure 79. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed For Total Dissolved Solids.

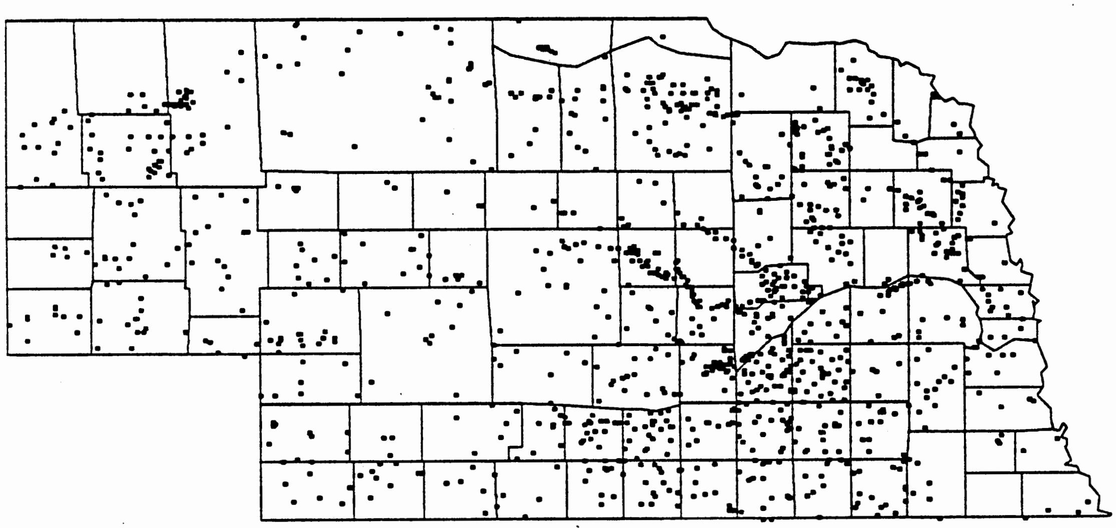


Figure 80. Nebraska: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Less Than or Equal to 500 mg/l

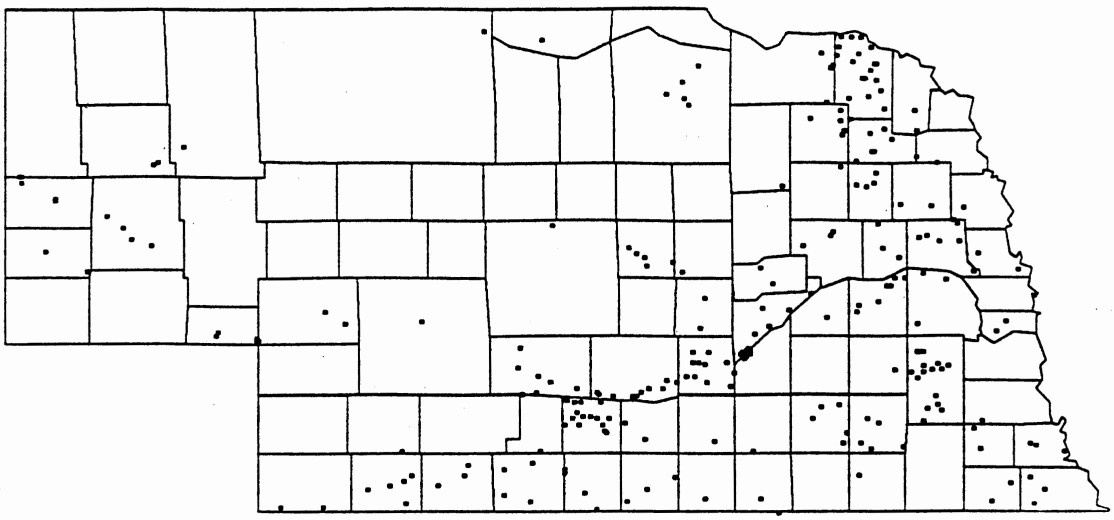


Figure 81. Nebraska: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 500 mg/l but Less Than or Equal to 1000 mg/l

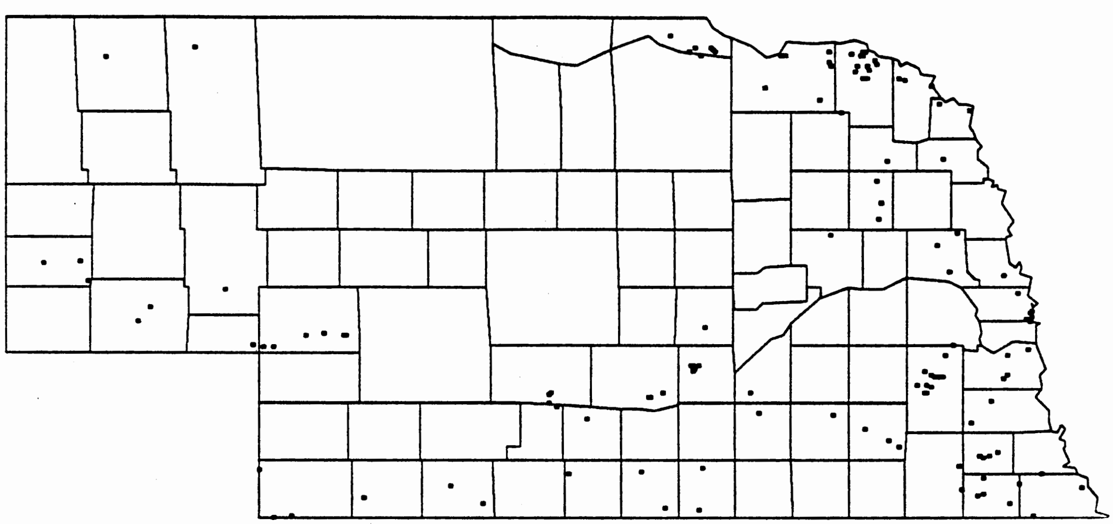


Figure 82. Nebraska: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 1000 mg/l

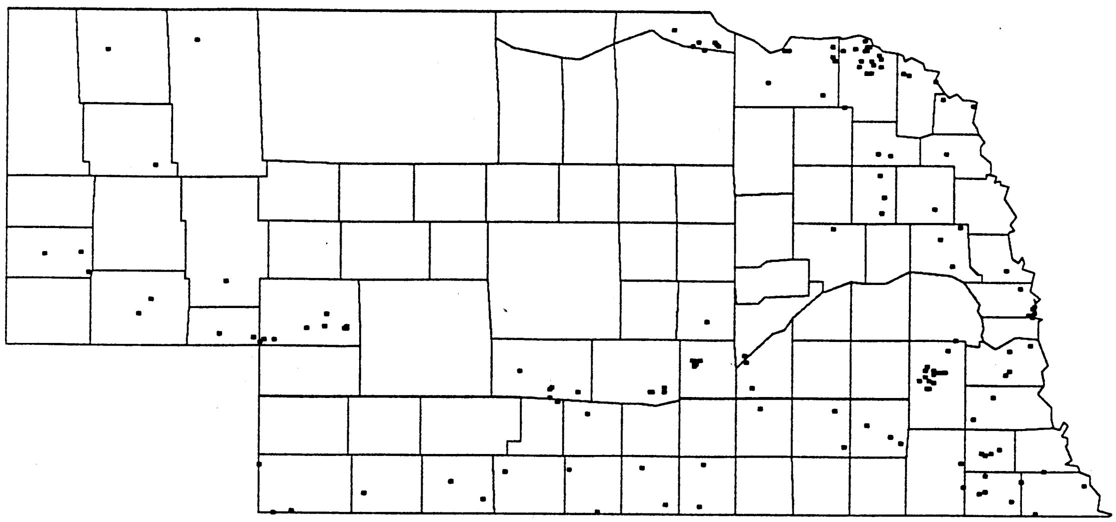


Figure 83. Nebraska: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Equal to or Greater Than the 90th Percentile

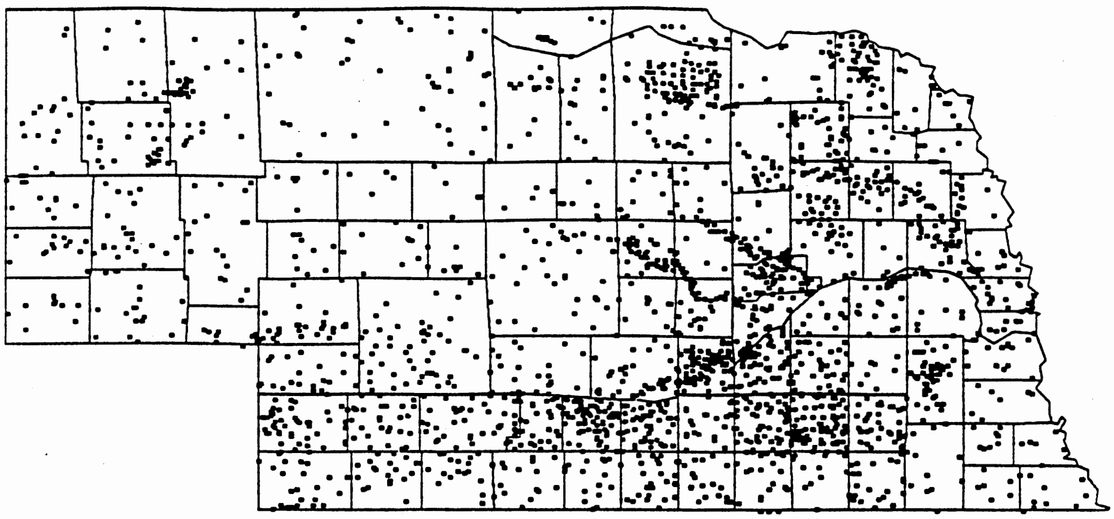


Figure 84. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed For Hardness

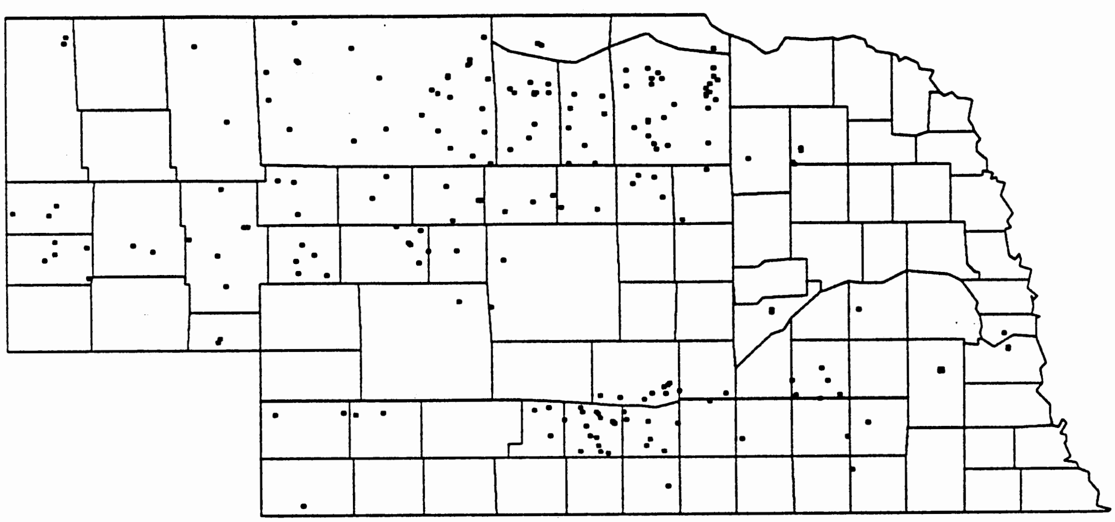


Figure 85. Nebraska: Locations of Wells Where Water Contained Hardness Concentrations Less Than or Equal to 60 mg/l

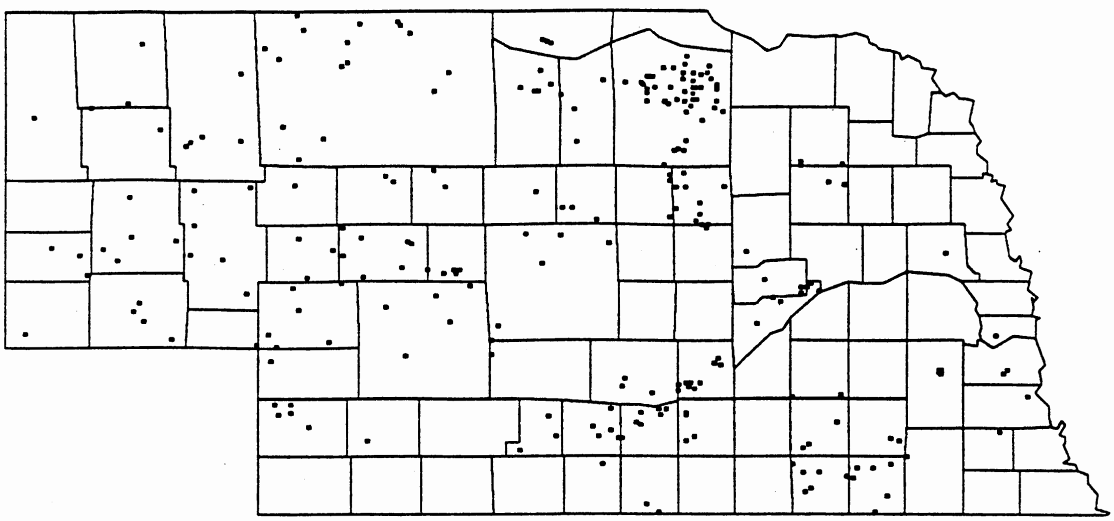


Figure 86. Nebraska: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 60 mg/l but Less Than or Equal to 120 mg/l

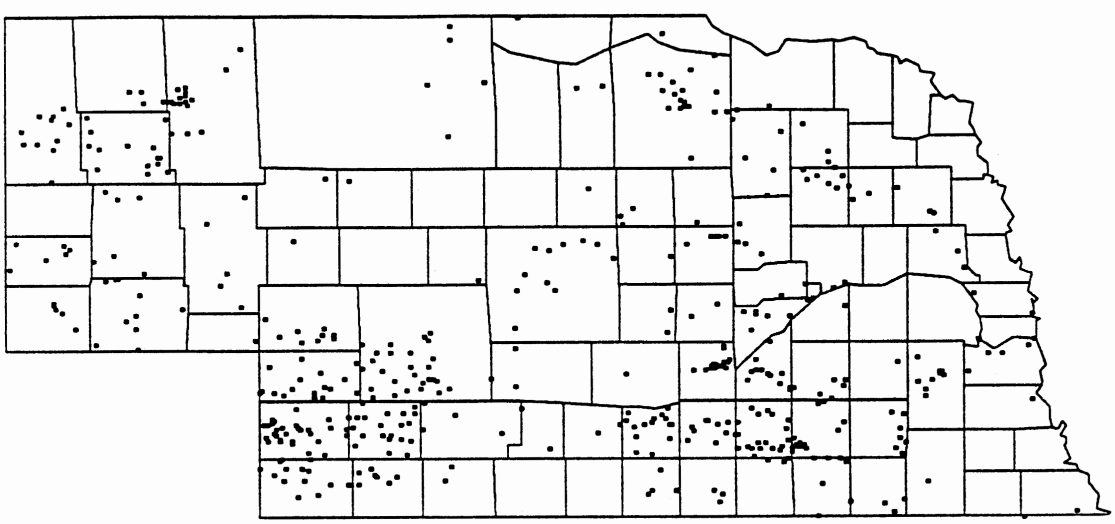


Figure 87. Nebraska: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 120 mg/l but Less Than or Equal to 180 mg/l

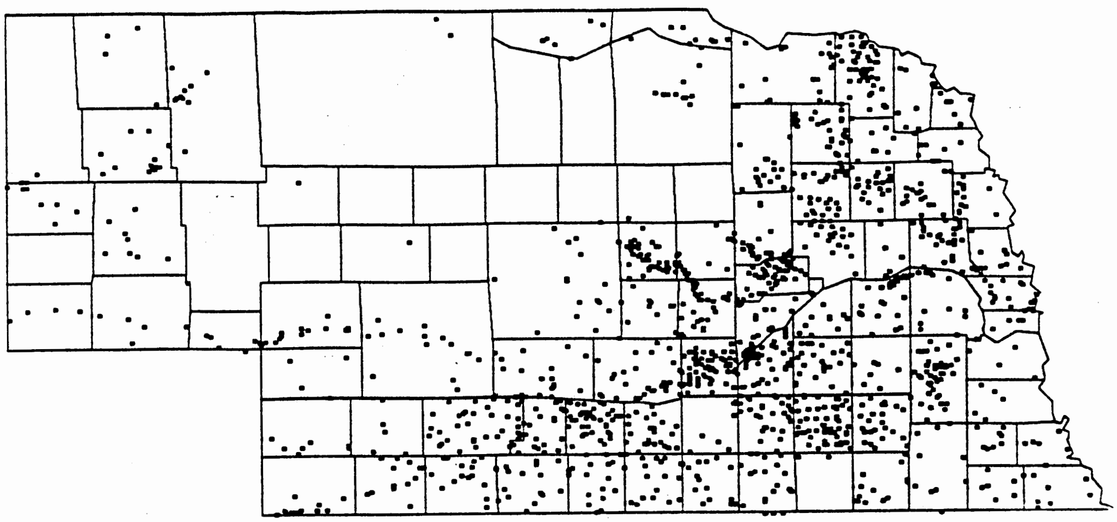


Figure 88. Nebraska: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 180 mg/l

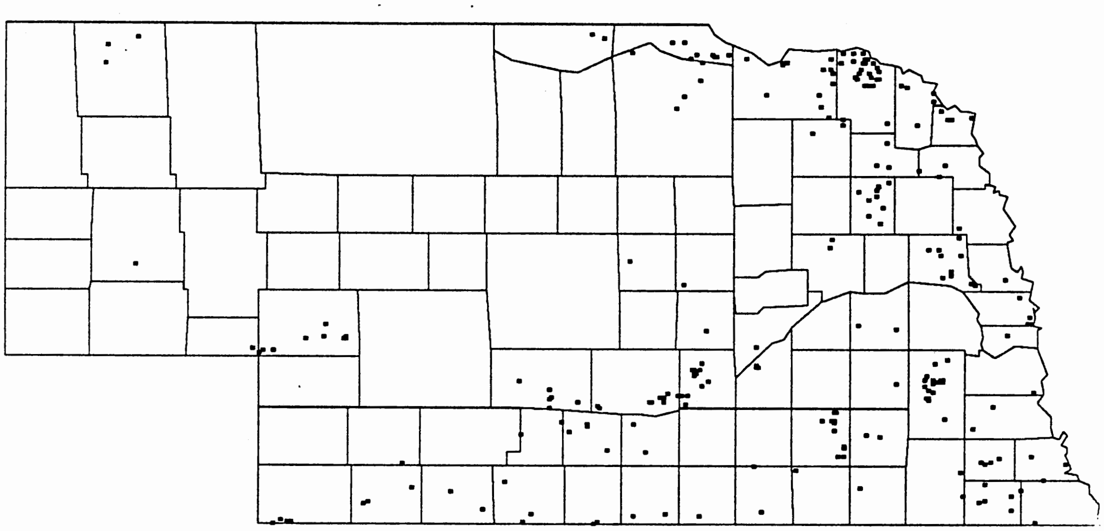


Figure 89. Nebraska: Locations of Wells Where Water Contained Hardness Concentrations Equal to or Greater Than the 90th Percentile

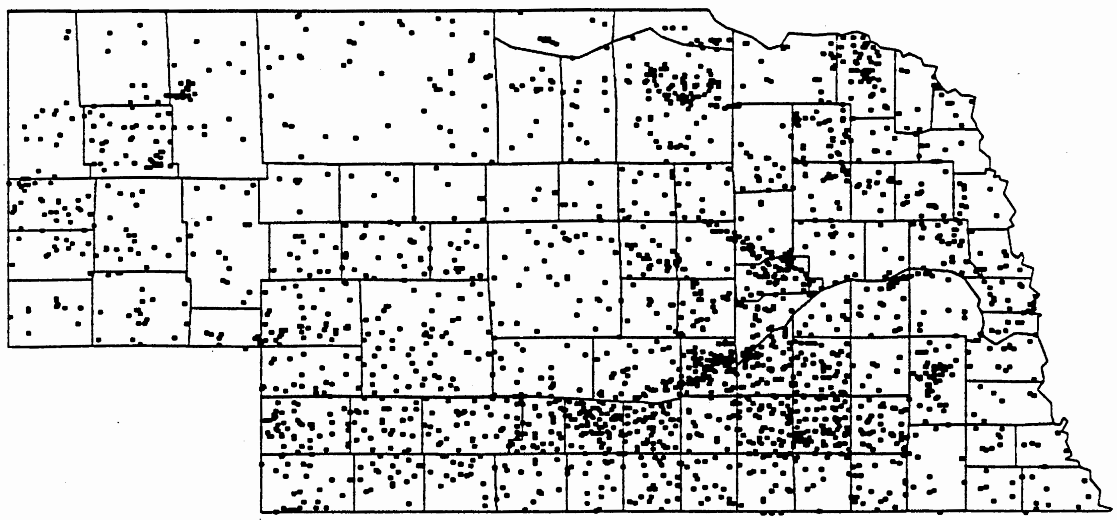


Figure 90. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed For Chloride

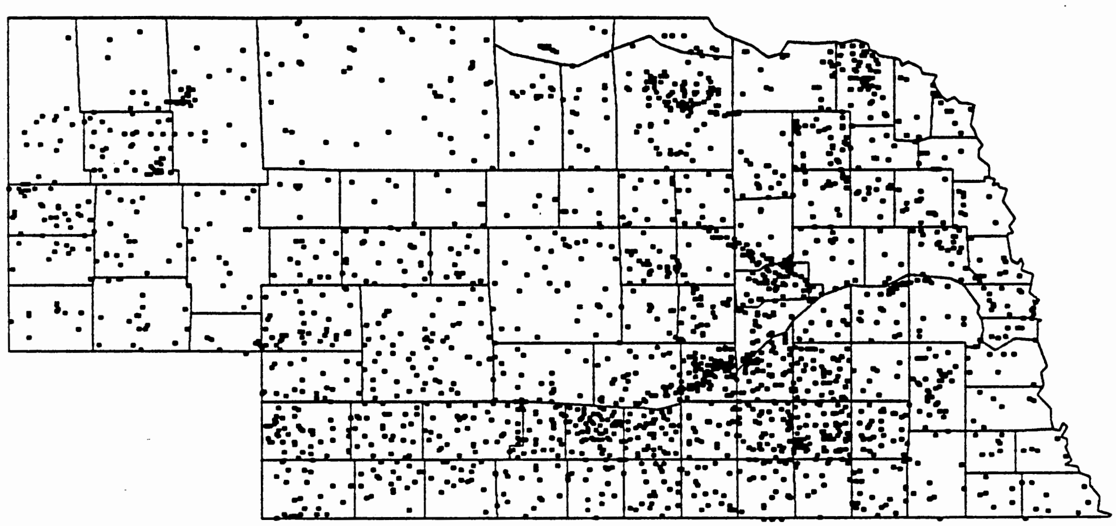


Figure 91. Nebraska: Locations of Wells Where Water Contained Chloride Concentrations Less Than or Equal to 125 mg/l

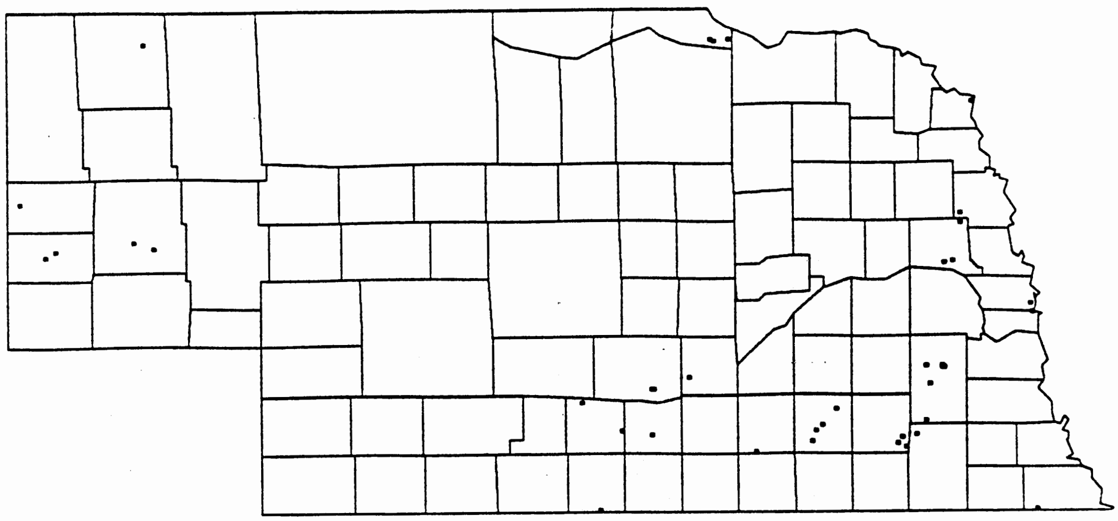


Figure 92. Nebraska: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

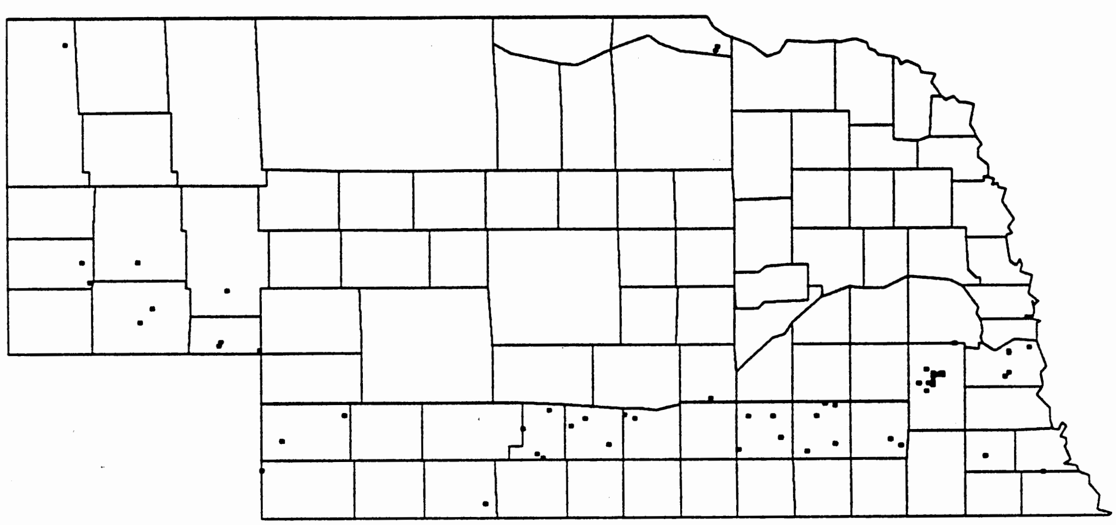


Figure 93. Nebraska: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 250 mg/l

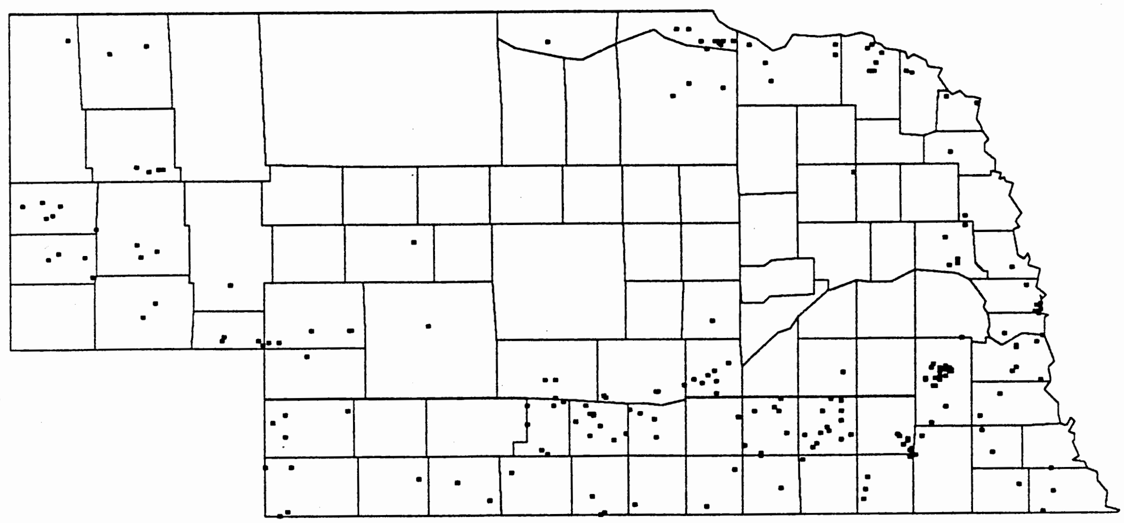


Figure 94. Nebraska: Locations of Wells Where Water Contained Chloride Concentrations Equal to or Greater Than the 90th Percentile

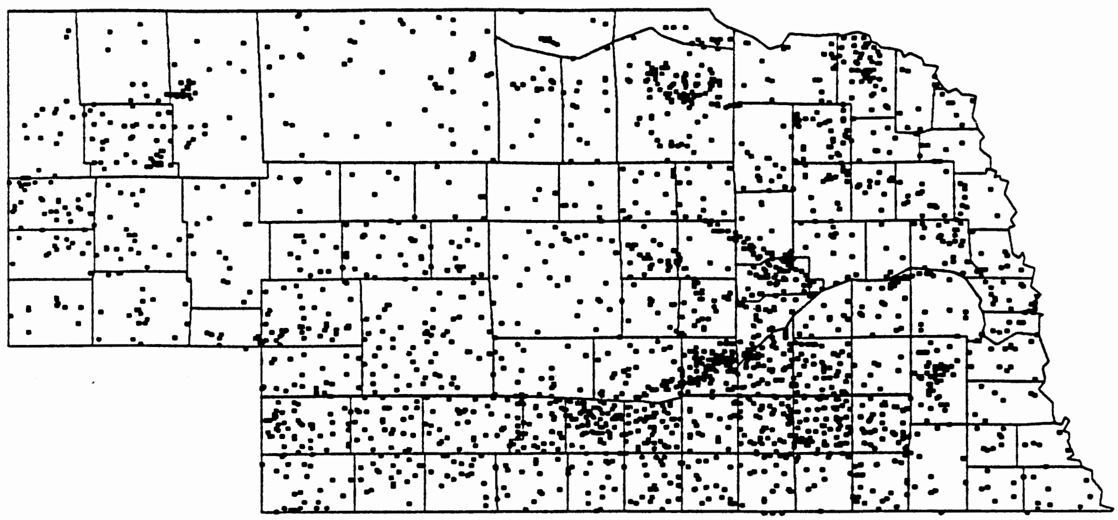


Figure 95. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed For Sulfate

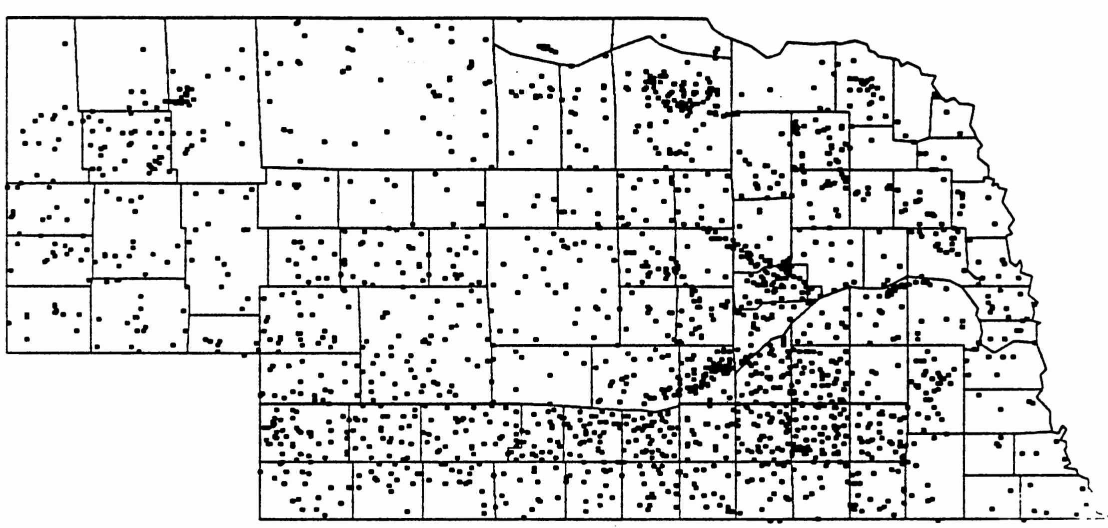


Figure 96. Nebraska: Locations of Wells Where Water Contained Sulfate Concentrations Less Than or Equal to 125 mg/l

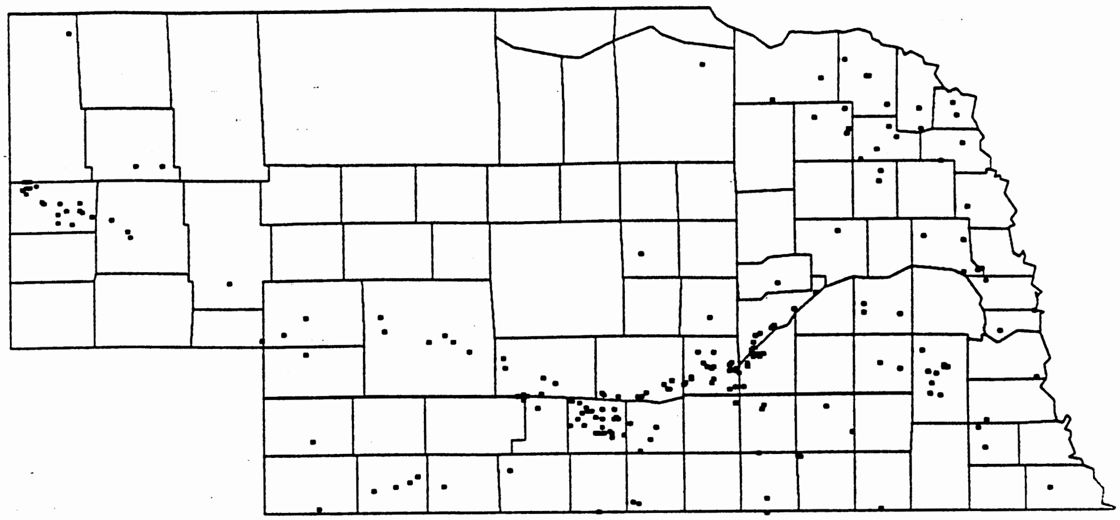


Figure 97. Nebraska: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

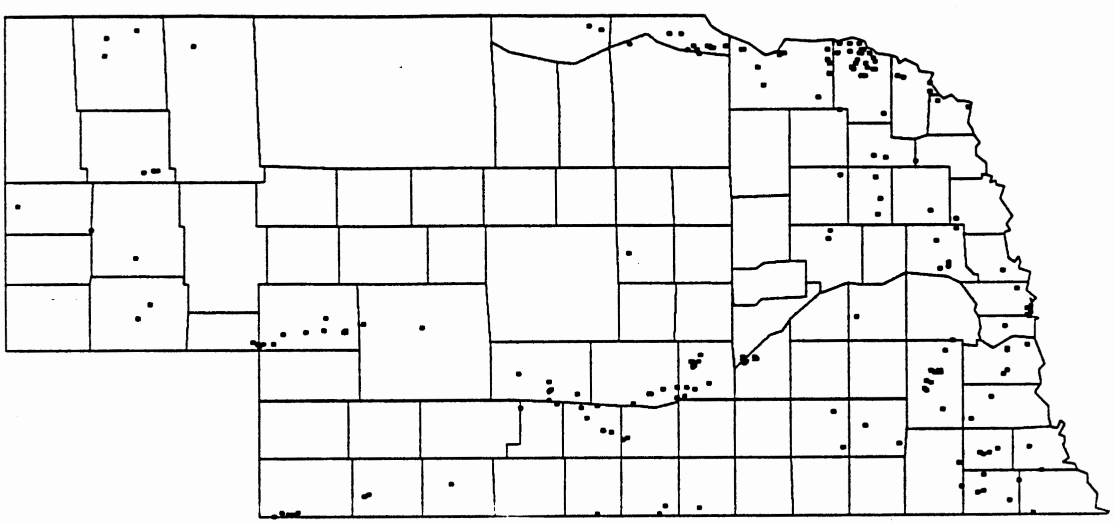


Figure 98. Nebraska: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 250 mg/l

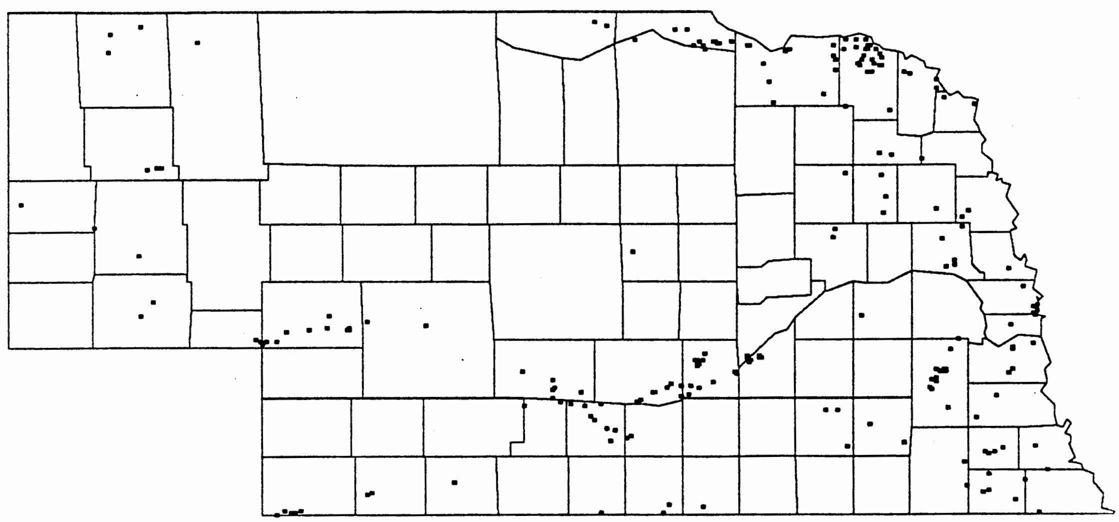


Figure 99. Nebraska: Locations of Wells Where Water Contained Sulfate Concentrations Equal to or Greater Than the 90th Percentile

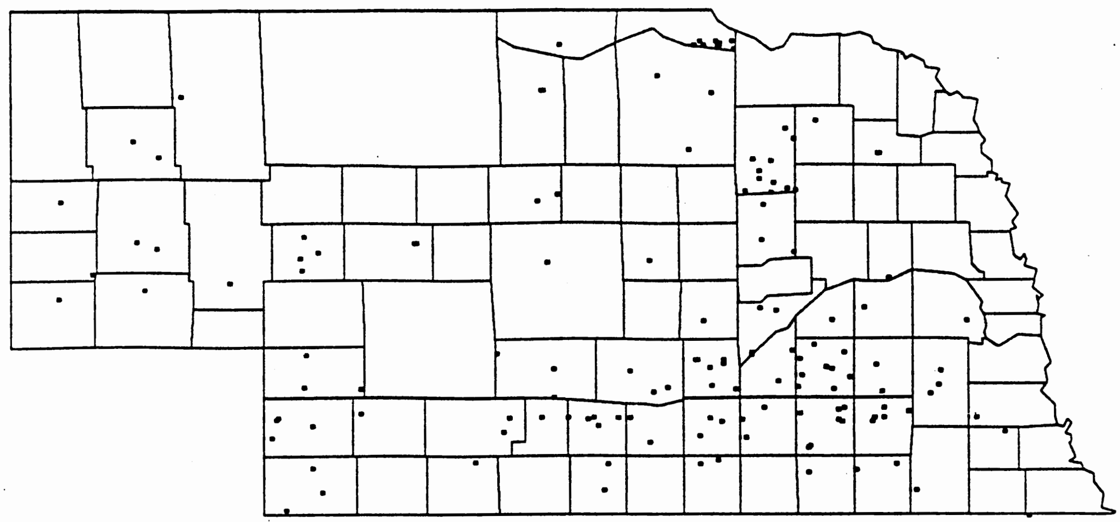


Figure 100. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate Measured as N

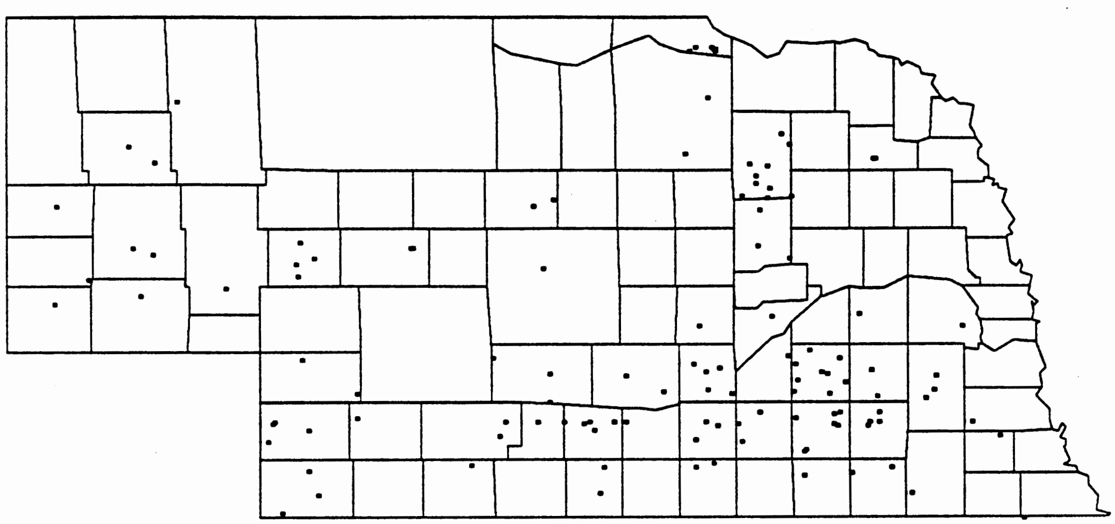


Figure 101. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 5 mg/l as N

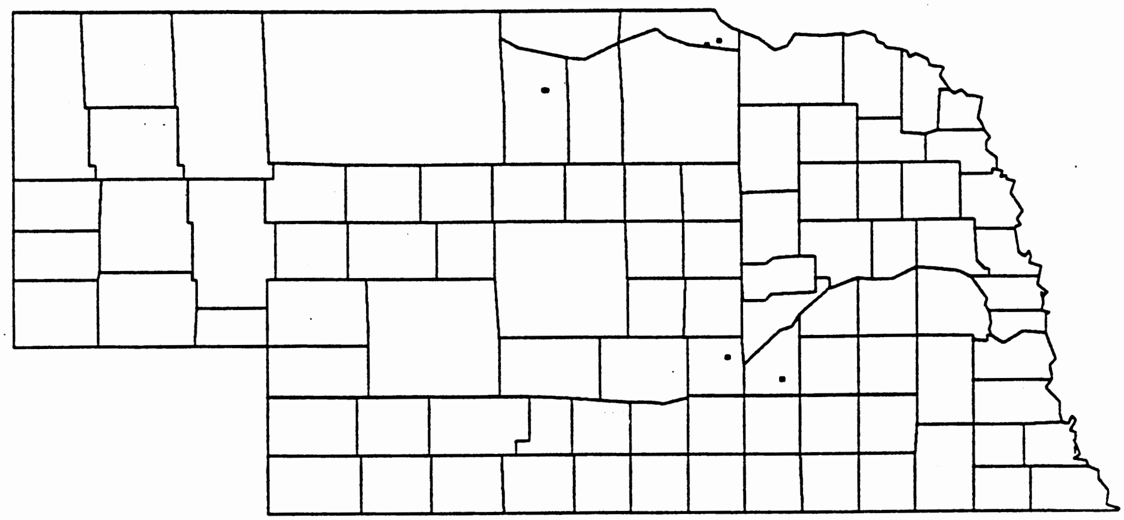


Figure 102. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 5 mg/l as N but Less Than or Equal to 10 mg/l as N

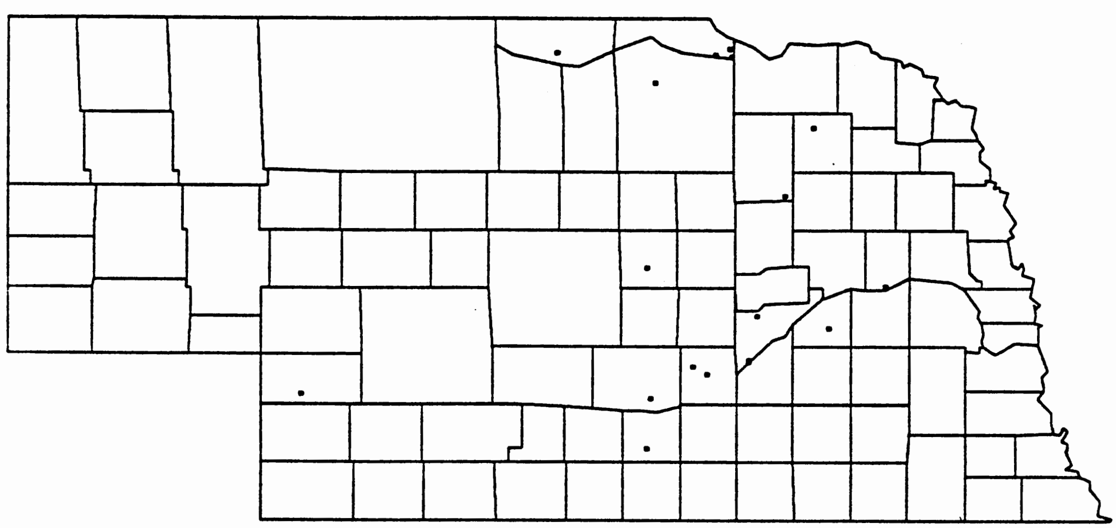


Figure 103. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 10 mg/l as N

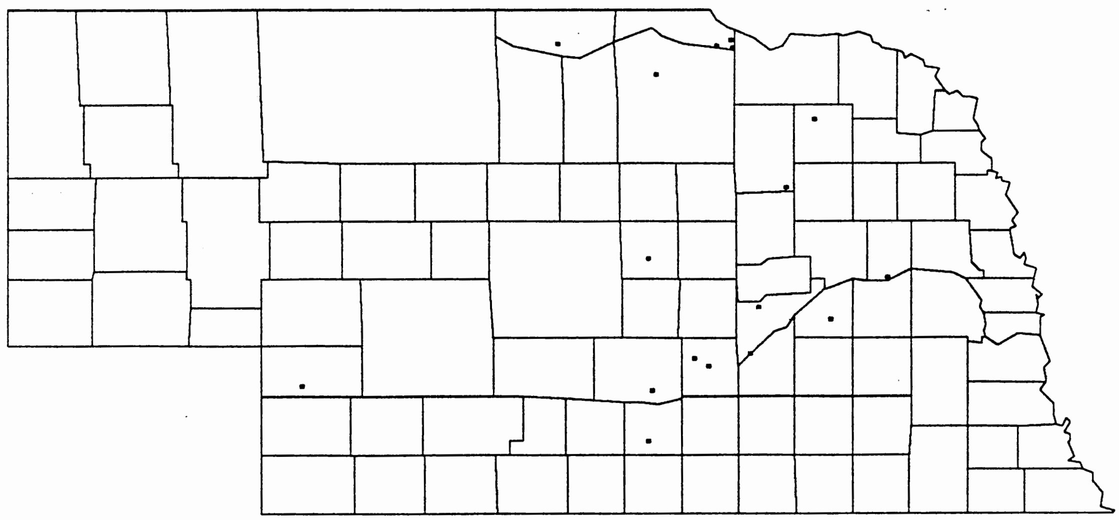


Figure 104. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as N, Equal to or Greater Than the 90th Percentile

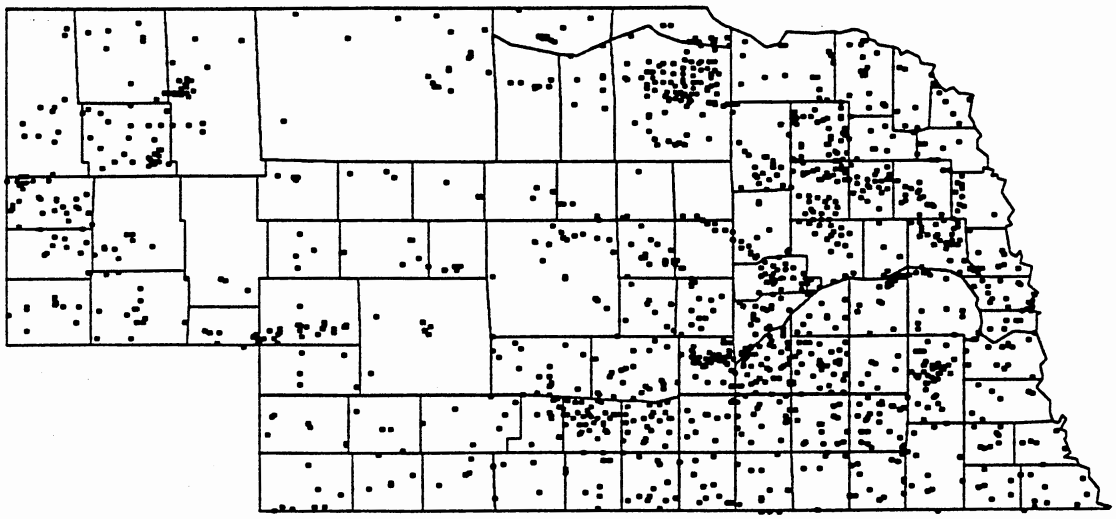


Figure 105. Nebraska: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate as NO3

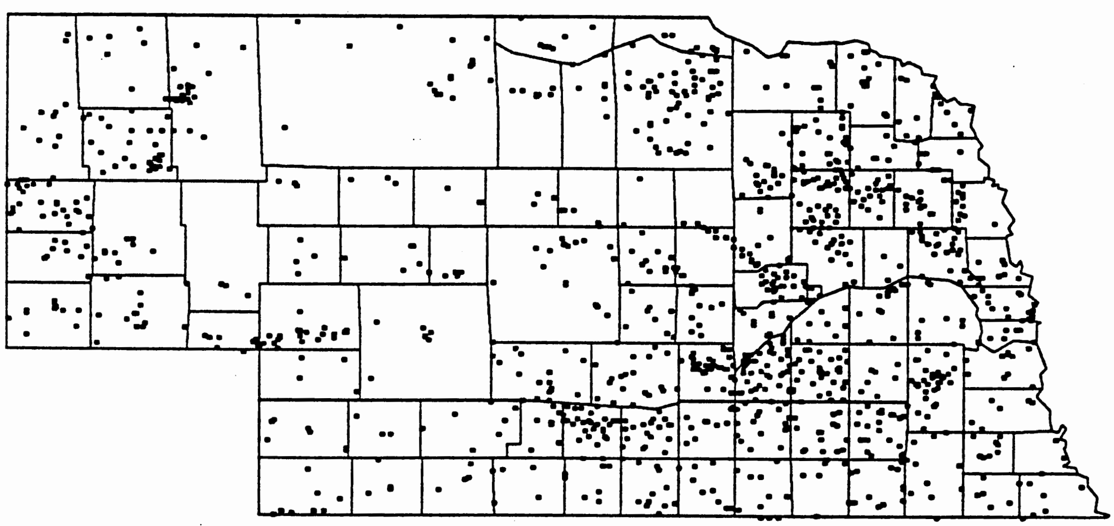


Figure 106. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 25 mg/l as NO3

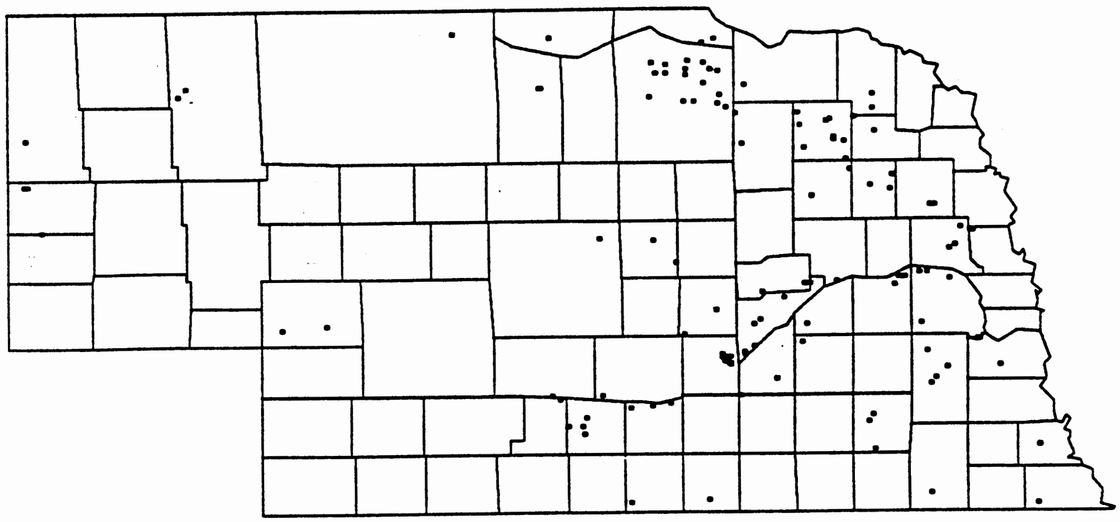


Figure 107. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 25 mg/l as NO3 but Less Than or Equal to 45 mg/l as NO3

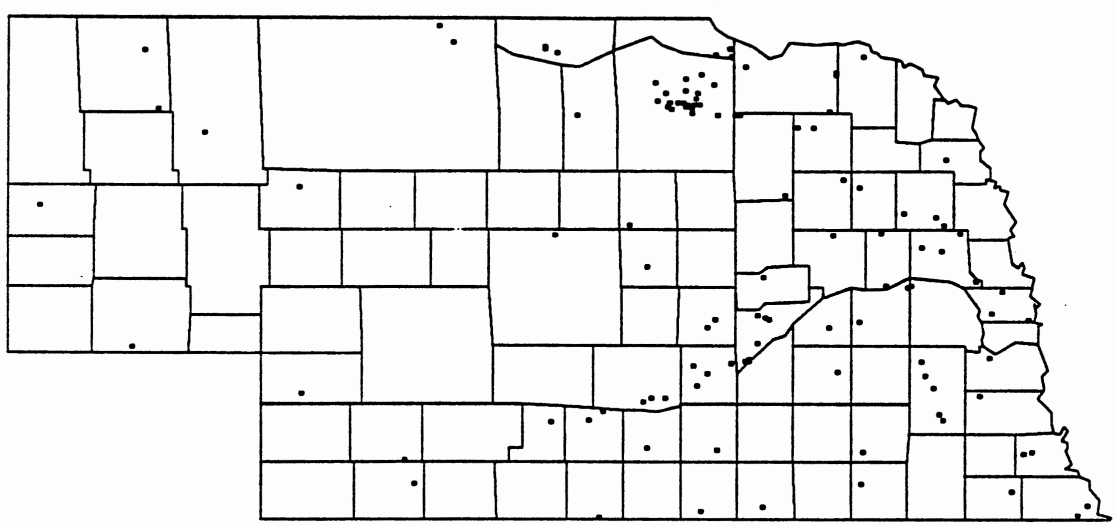


Figure 108. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 45 mg/l as NO3

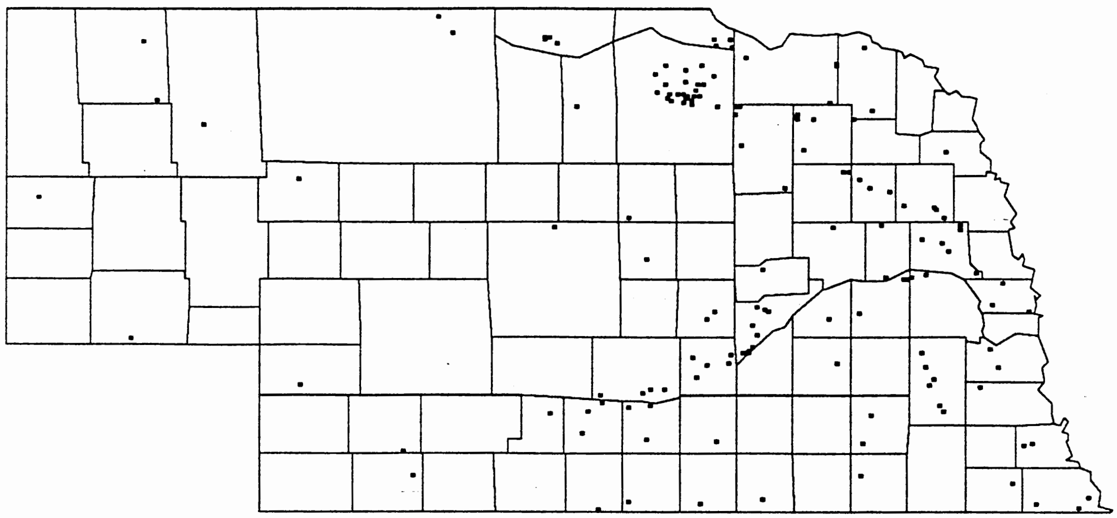


Figure 109. Nebraska: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as NO3, Equal to or Greater Than the 90th Percentile

Kansas

General Setting

Kansas contains approximately 82,000 square miles. Annual average precipitation varies from less than 16 inches in the west to approximately 40 inches in the southeast corner of the state. The northern part of the state is drained by the eastern flowing Kansas River and tributaries. The eastern to southeastern flowing Arkansas, Verdigris and Neosho River systems drain southern Kansas.

Kansas is principally underlain by Paleozoic age clastic and carbonate sequences which dip gently westward. Mississippian age limestone is the oldest exposed bedrock that outcrops in the southeastern corner of the state. The remainder of the eastern part of Kansas is underlain by Pennsylvanian and Permian age bedrock that primarily consists of limestone and shale with some sandstone beds. Cretaceous age sequences of limestone and shale units make up the bedrock that outcrops in west-central Kansas. Capping the Cretaceous strata in the western portion of the state is the unconsolidated Ogallala Formation. The western half of Kansas is mantled by a thin discontinuous veneer of Quaternary age eolian and dune sand deposits. The far northeast corner is locally overlain by glacial drift deposits. Occurring along major stream systems are terrace and alluvial deposits that consist of gravel, sand, silt and clay.

Discussion

Table 8 exhibits the number of analyses measured, the percentage of samples that exceed E.P.A. drinking water standards, and the percentage in each range of concentration. A map of the major aquifers in Kansas and their descriptions is depicted in Figures 110 and 111. Maps illustrating the location of wells and selected ground water quality in Kansas are shown in Figures 112-142.

Forty four percent of the ground-water samples analyzed for total dissolved solids in Kansas exceeded the recommended limit of 500 mg/l. These wells are distributed somewhat evenly throughout the state. Data in Table 8 suggests that high levels of dissolved solids is related to the presence of very hard water which occurs throughout the state. More than 1100 samples have been analyzed for hardness and 83 percent exceed 180 mg/l.

Over 1100 wells were sampled for chloride in the state, with 85 percent equal to or less than 125 mg/l. Only 6 percent of the samples exceed the recommended level of 250 mg/l. Figure 127 shows chloride levels equal to or greater than the 90th percentile. These locations coincide with areas where oil and gas drilling activity has occurred. This activity could be the cause for the high levels of chloride in the ground water.

Seventeen percent of the samples tested for sulfate exceed 250 mg/l. These wells are distributed somewhat evenly throughout Kansas without regard to major aquifer present. The elevated sulfate concentrations is probably related to the presence of gypsum.

About 900 samples were analyzed for nitrate as N and 750 samples were analyzed for nitrate as NO3. Both are distributed evenly throughout the state. Figures 136 and 141 show that the locations of wells where nitrate concentrations exceed the recommended levels occur predominantly in the eastern two-thirds of the state. High levels of nitrate are most likely due to agricultural activities, being derived either from fertilizers or by bringing under cultivation grasslands that previously served for grazing. The change from grazing to cultivation commonly leads to the leaching of the large quantity of nitrate stored in the unsaturated zone.

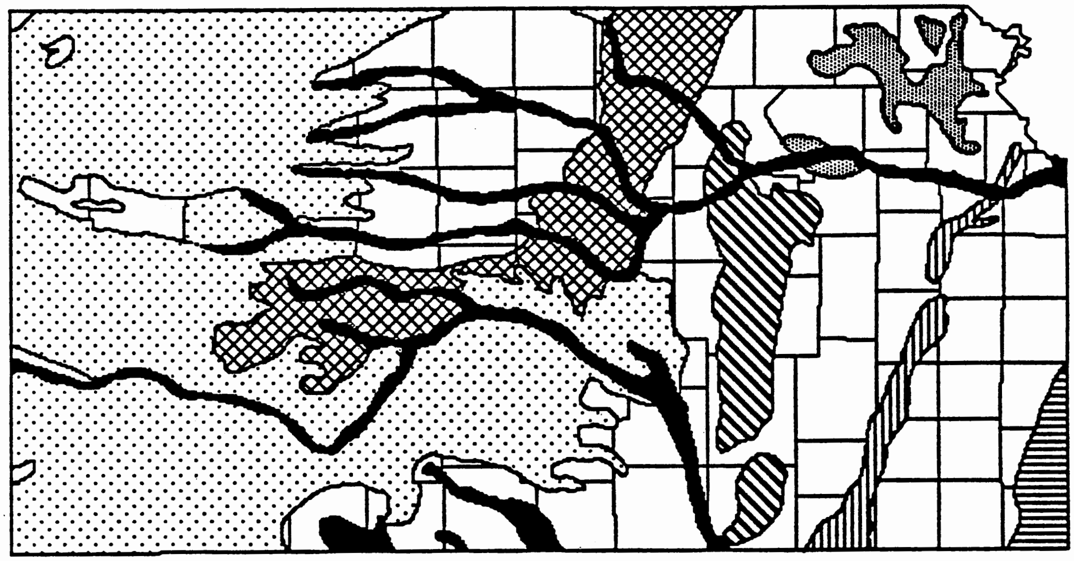
TABLE 8

KANSAS: NUMERICAL SUMMARIES
OF WATER ANALYSES

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
TDS		500*	44	•
All Samples	804		•	•
0 - 500	451		•	56
501 - 1000	295		•	37
Greater than 1000	58		•	7
Equal to or Greater Than			•	•
the 90th Percentile	84		•	10
Hardness		None	•	•
All Samples	1135		•	•
0 - 60	34		•	3
61 - 120	44		•	4
121 - 180	114		•	10
Greater than 180	943		•	83
Equal to or Greater Than			•	•
the 90th Percentile	110		•	10
Chloride		250	6	•
All Samples	1168		•	•
0 - 125	997		•	85
126 - 250	96		•	8
Greater than 250	75		•	6
Equal to or Greater Than			•	•
the 90th Percentile	117		•	10
Sulfate		250	17	•
All Samples	1170		•	•
0 - 125	788		•	67
126 - 250	183		•	16
Greater than 250	199		•	17
Equal to or Greater Than			•	•
the 90th Percentile	117		•	10

TABLE 8 (continued)

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
Nitrate as N		10	15	•
All Samples	902		•	•
0 - 5	610		•	68
6 - 10	157		•	17
Greater than 10	135		•	15
Equal to or Greater Than			•	•
the 90th Percentile	92		•	10
Nitrate as NO3		45	14	•
All Samples	755		•	•
0 - 25	524		•	69
26 - 45	123		•	16
Greater than 45	108		•	14
Equal to or Greater Than			•	•
the 90th Percentile	76		•	10



EXPLANATION

- Alluvial Aquifers
- Glacial Drift Aquifers
- High Plains Aquifer
- Great Plains Aquifer
- Chase and Council Grove Aquifers
- Douglas Aquifer
- Ozark Aquifer
- Not a Principle Aquifer

Figure 110. Kansas: Map of Major Aquifers (Modified from U.S.G.S., 1985)

[Gal/min = gallons per minute; mg/L = milligrams per liter; ft = feet. Sources: Reports of the U.S. Geological Survey and Kansas agencies]

Aquifer name and description	Well characteristics			Remarks
	Depth (ft)	Yield (gal/min)		
	Common range	Common range	May exceed	
Alluvial aquifers: Quaternary fluvial deposits of clay, silt, sand, and gravel. Generally unconfined.	10 - 150	10 - 500	1,000	Well yields in Kansas, Arkansas, Republican, and Pawnee River valleys exceed 500 gal/min. Wells in other valleys usually yield less than 100 gal/min. Locally, water from alluvial aquifers can have large concentrations of dissolved solids, chloride, sulfate, nitrate, iron, and manganese. Large concentrations of selenium and naturally occurring gross-alpha radioactivity sometimes occur in water from northern part of Great Plains.
Glacial-drift aquifer: Pleistocene glacial deposits of clay, silt, sand, and gravel. Generally unconfined.	10 - 300	10 - 100	500	Water from shallow wells generally a calcium bicarbonate type with less than 500 mg/L dissolved solids, but large concentrations of nitrate can occur. Water from deep wells can have large concentrations of dissolved solids, chloride, sulfate, iron, or manganese.
High Plains aquifer: Fluvial and eolian deposits of clay, silt, sand, and gravel of Cenozoic age. Generally unconfined.	10 - 450	500 - 1,000	1,500	Water generally a calcium bicarbonate type with concentrations of dissolved solids less than 500 mg/L, but large concentrations of fluoride and selenium can occur in northern Great Plains. Provides water supplies for Dodge City, Garden City, Great Bend, Pratt, Hutchinson, McPherson, Wichita, and most other towns in Great Plains.
Great Plains aquifer: Dakota and Cheyenne Sandstones of Cretaceous age. Generally unconfined.	20 - 200	10 - 100	1,000	Water quality variable. Calcium bicarbonate type water with less than 500 mg/L of dissolved solids produced where the aquifer is exposed. Sodium bicarbonate or sodium chloride type water with large concentrations of dissolved solids is produced west and north of the surface exposure. Large concentrations of iron occur in water from some wells. Some wells in Finney, Ford, and Hodgeman Counties can yield more than 1,000 gal/min.
Chase and Council Grove aquifer: Limestones of Chase and Council Grove Groups of Permian age. Generally unconfined.	20 - 200	10 - 20	200	Water generally a calcium bicarbonate type with concentrations of dissolved solids less than 500 mg/L. Water from some wells can have large concentrations of sulfate. Wells in Butler and Cowley Counties can produce water with large concentrations of dissolved solids. Concentrations of dissolved solids and chloride large west of the surface exposure, and water is not used.
Douglas aquifer: Channel sandstone of Pennsylvanian age. Generally unconfined.	5 - 400	10 - 40	100	Water ranges from a calcium bicarbonate type, with less than 500 mg/L of dissolved solids where aquifer is exposed, to a sodium bicarbonate or sodium chloride type, with large concentrations of dissolved solids at depth or west of surface exposure. Concentrations of fluoride may be large. Equivalent to Vamoosa-Ada aquifer in Oklahoma.
Ozark aquifer: Weathered and sandy dolomites of Arbuckle Group. Cambrian and Ordovician age. Confined.	500 - 1,800	30 - 150	500	Water generally a calcium bicarbonate type with less than 500 mg/L of dissolved solids in the Ozark Plateaus and in extreme southeast corner of the Osage Plains. Sodium bicarbonate chloride or sodium chloride type water with large concentrations of dissolved solids is produced in rest of Osage Plains. Hydrogen sulfide gas, or large concentrations of gross-alpha radioactivity or iron, can occur in water from some wells. Equivalent to Roubidoux aquifer in Oklahoma.

Figure 111. Kansas: Major Aquifer Descriptions and Well Characteristics (Modified from U.S.G.S., 1985)

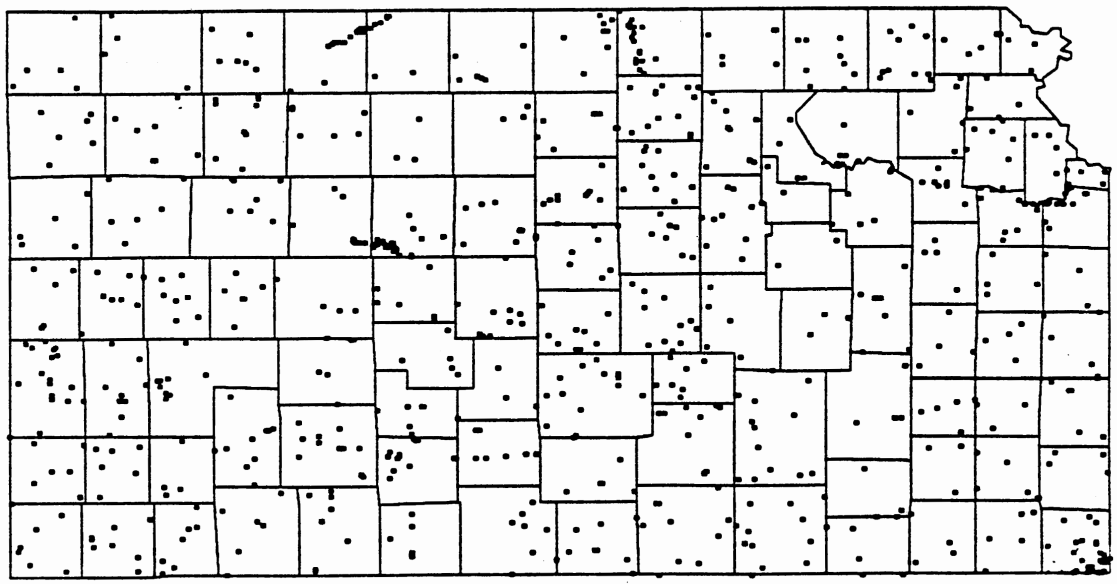


Figure 112. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed For Total Dissolved Solids.

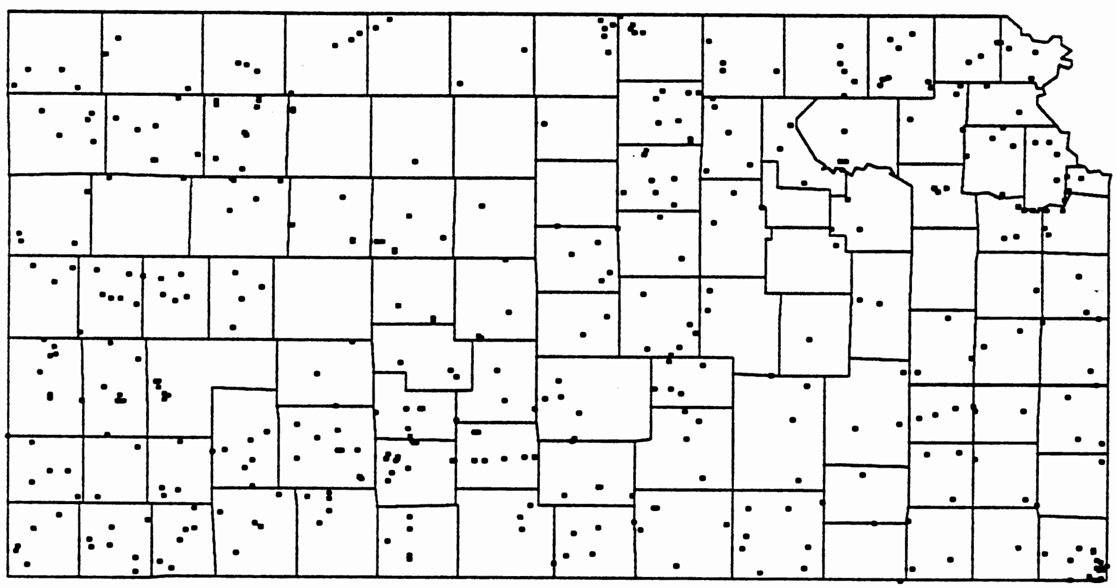


Figure 113. Kansas: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Less Than or Equal to 500 mg/l

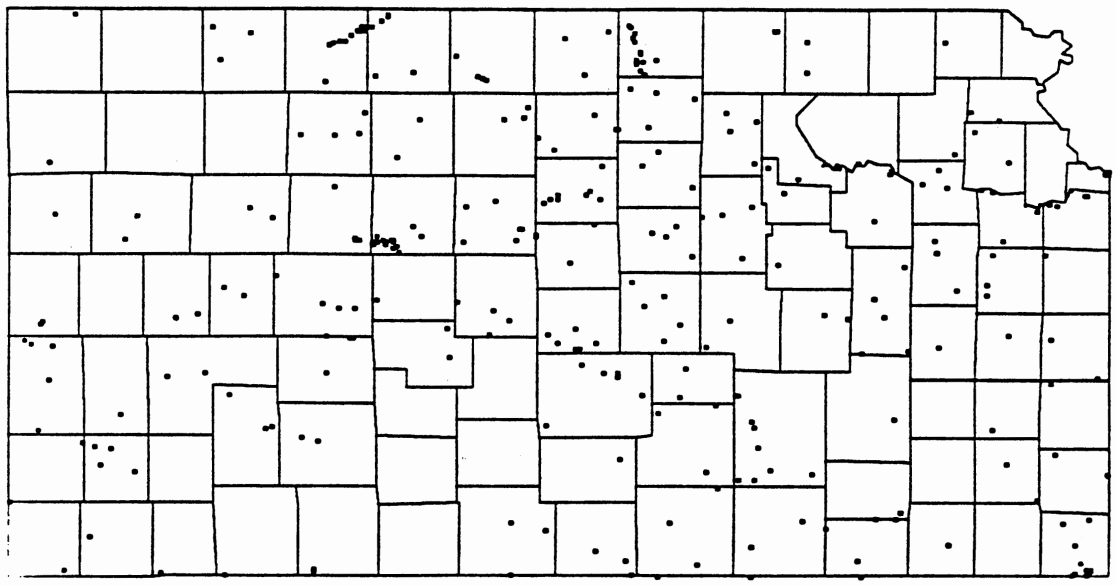


Figure 114. Kansas: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 500 mg/l but Less Than or Equal to 1000 mg/l

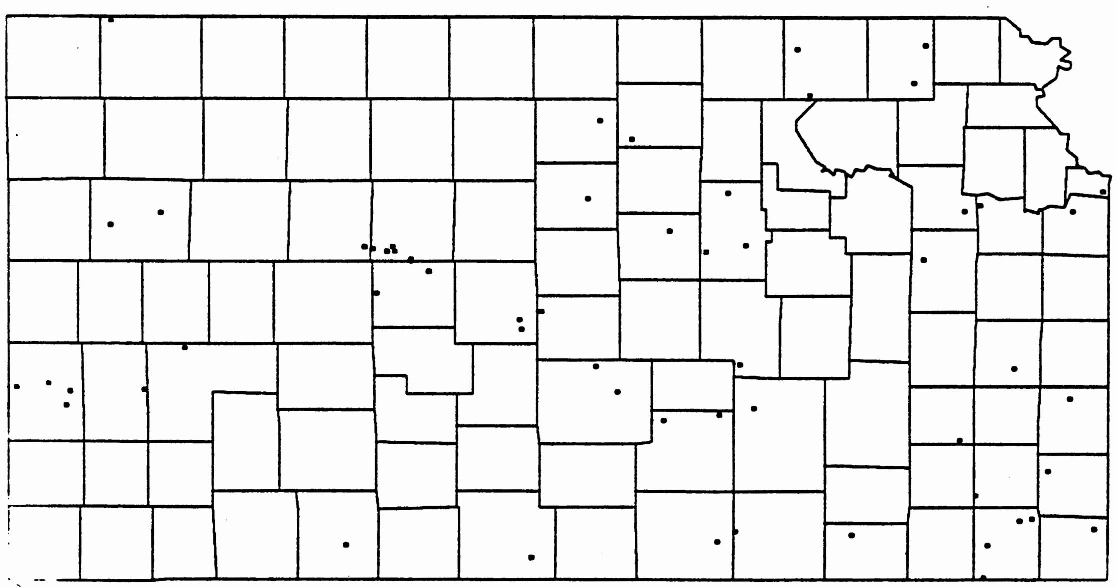


Figure 115. Kansas: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 1000 mg/l

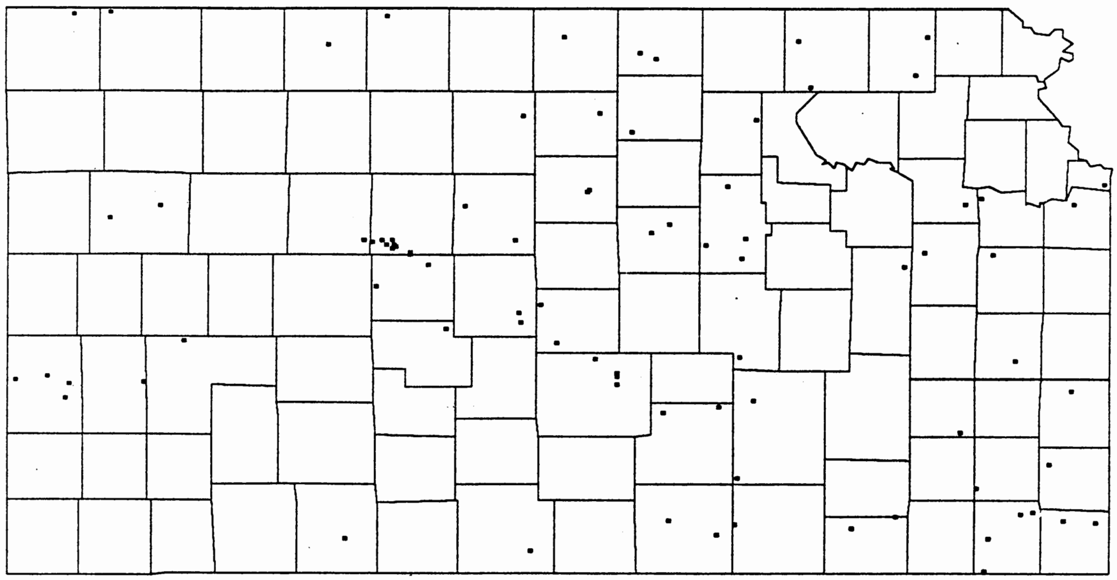


Figure 116. Kansas: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Equal to or Greater Than the 90th Percentile

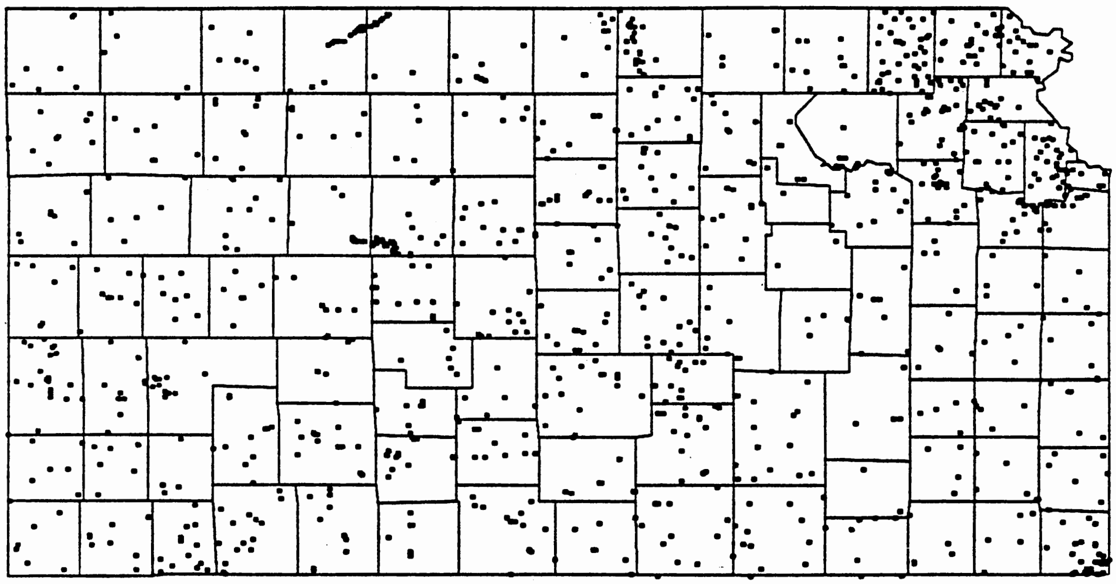


Figure 117. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed For Hardness

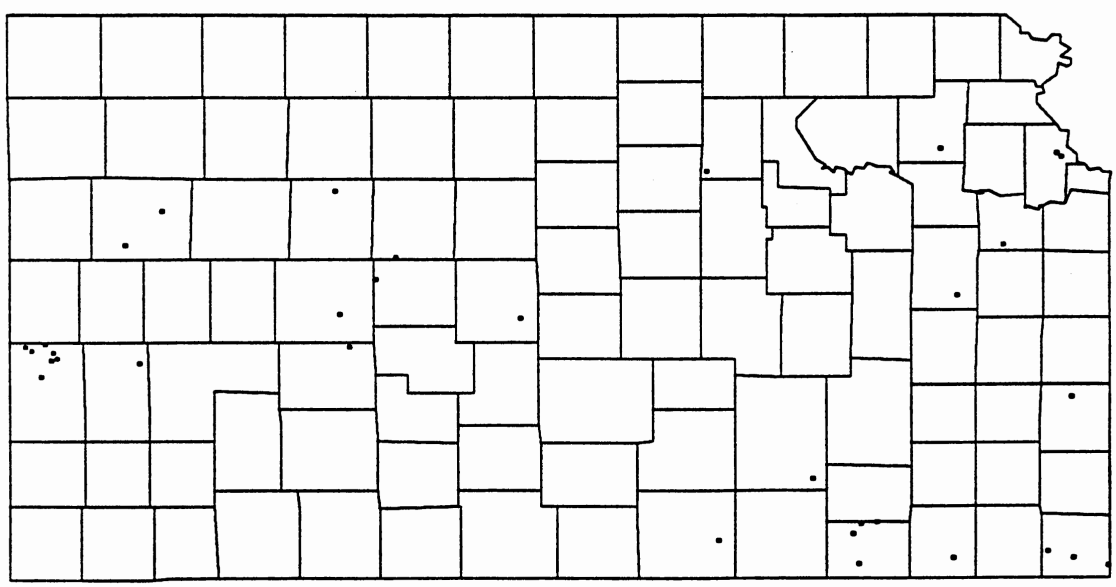


Figure 118. Kansas: Locations of Wells Where Water Contained Hardness Concentrations Less Than or Equal to 60 mg/l

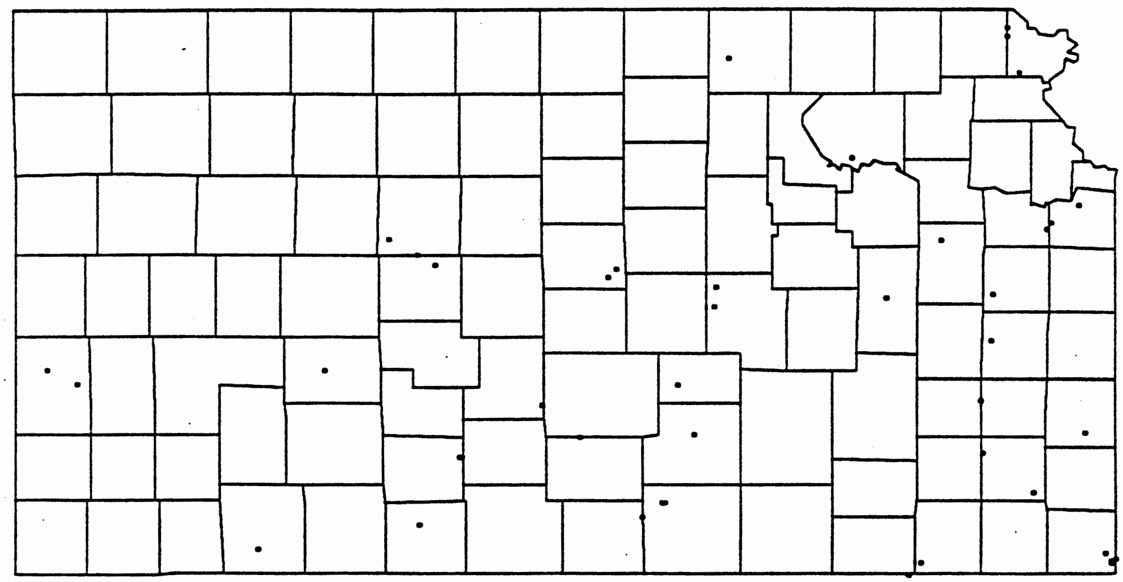


Figure 119. Kansas: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 60 mg/l but Less Than or Equal to 120 mg/l

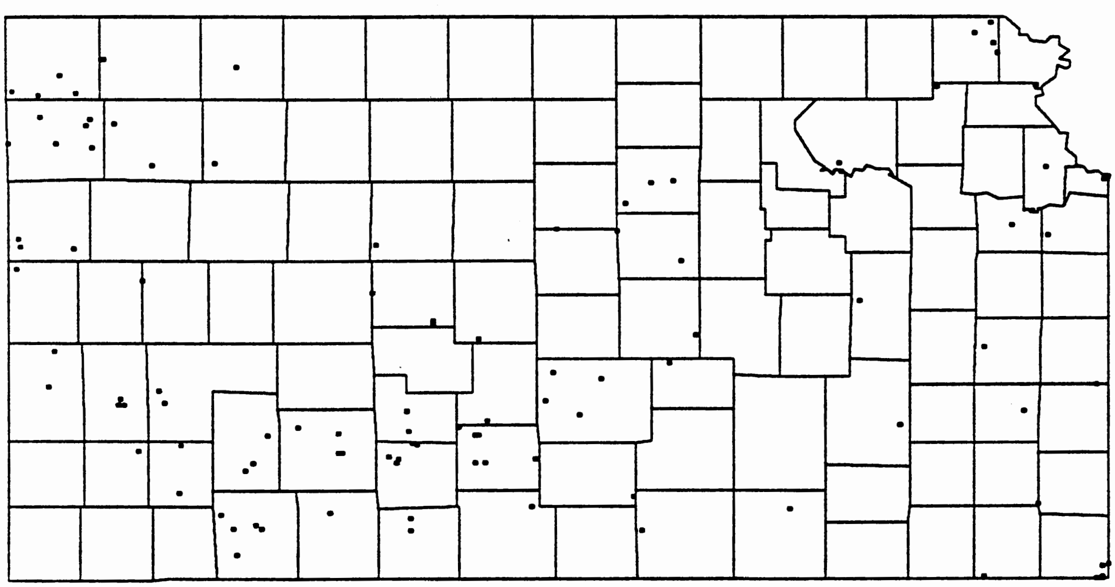


Figure 120. Kansas: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 120 mg/l but Less Than or Equal to 180 mg/l

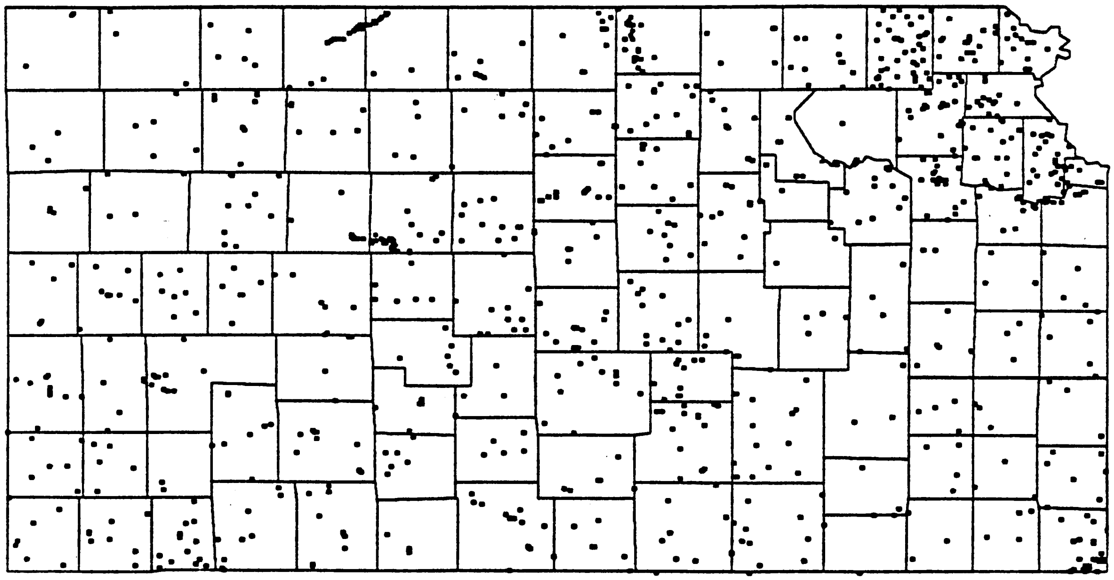


Figure 121. Kansas: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 180 mg/l

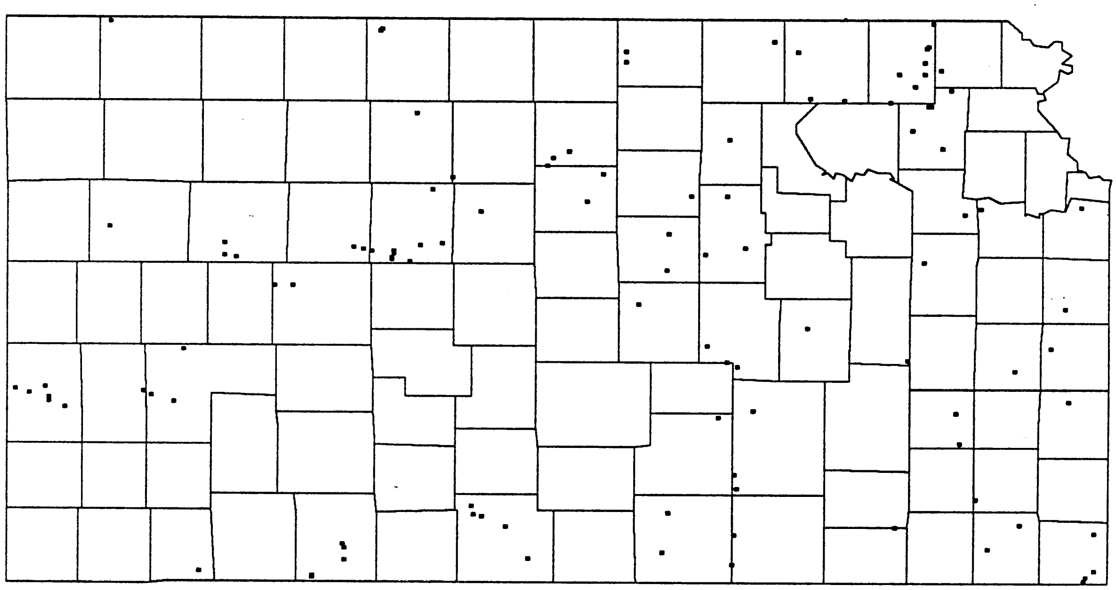


Figure 122. Kansas: Locations of Wells Where Water Contained Hardness Concentrations Equal to or Greater Than the 90th Percentile

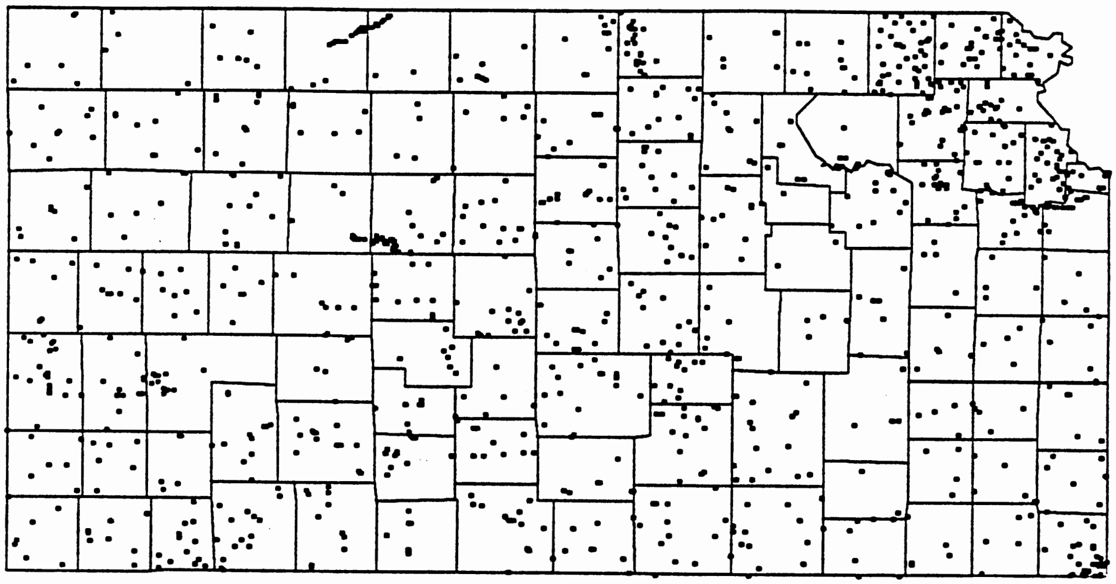


Figure 123. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed For Chloride

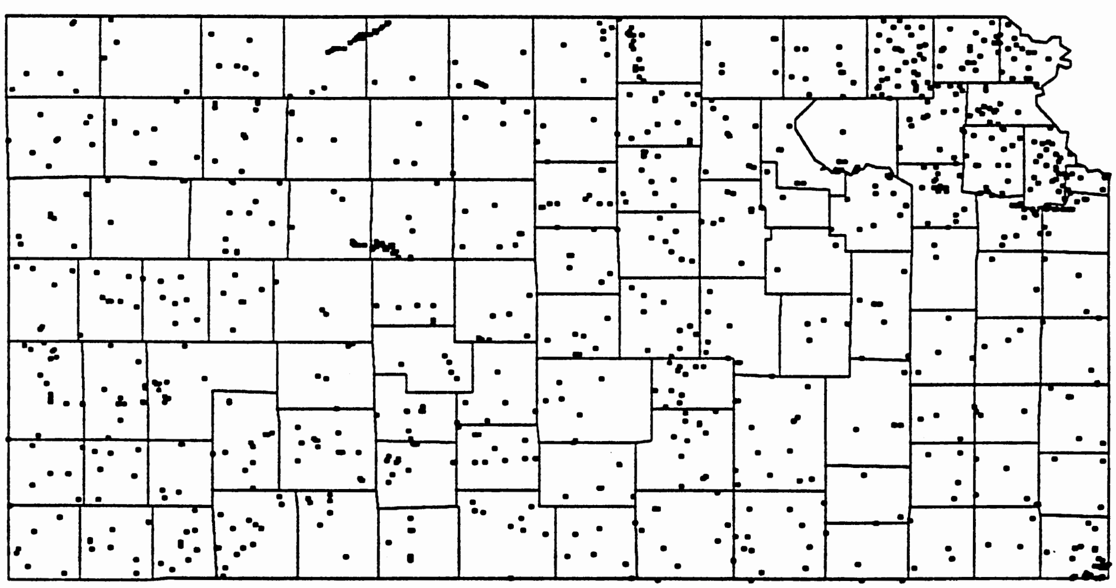


Figure 124. Kansas: Locations of Wells Where Water Contained Chloride Concentrations Less Than or Equal to 125 mg/l

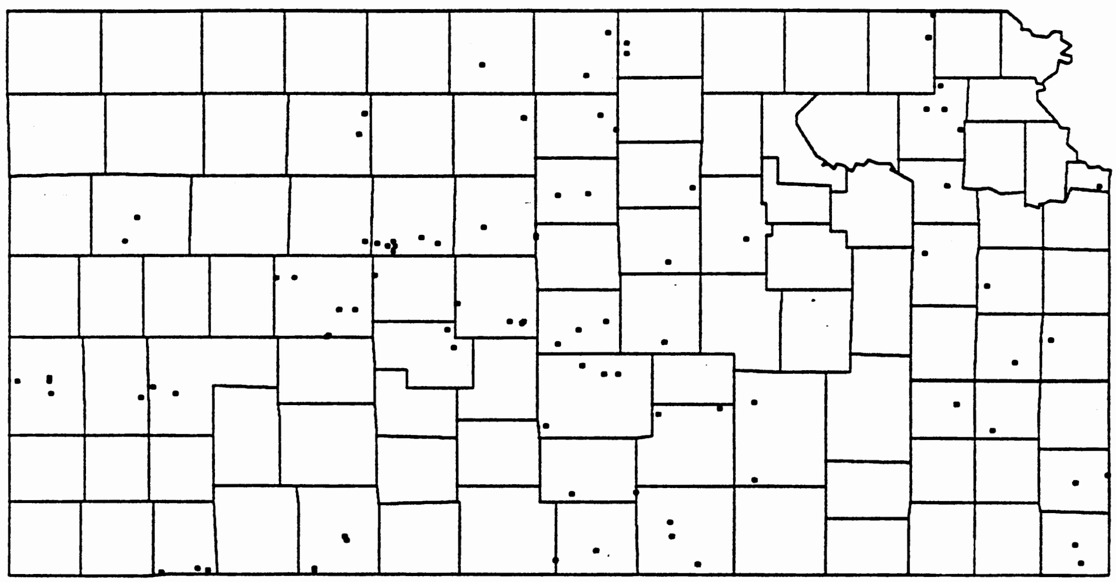


Figure 125. Kansas: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

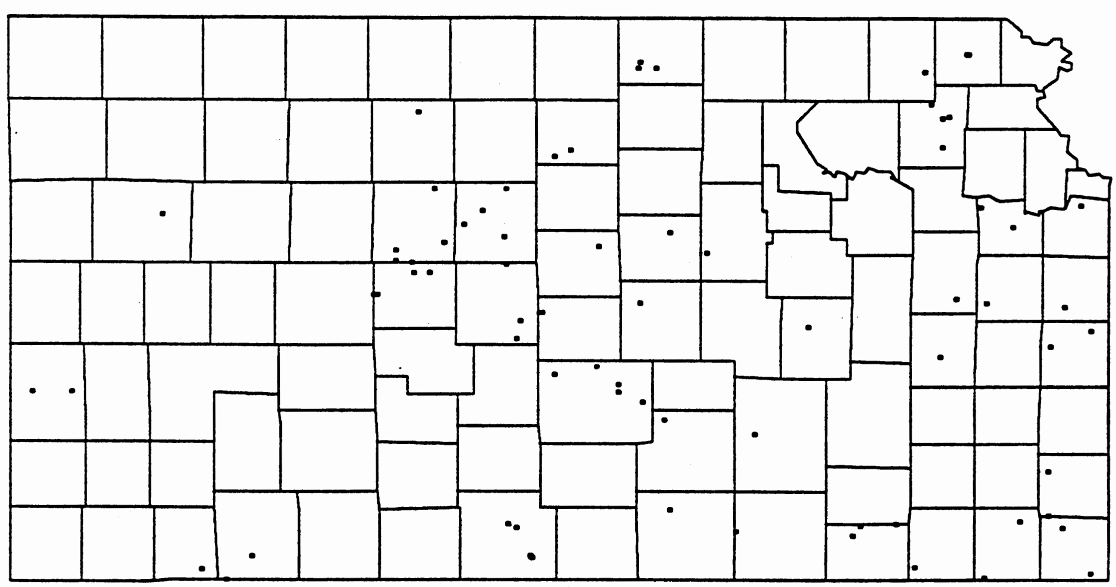


Figure 126. Kansas: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 250 mg/l

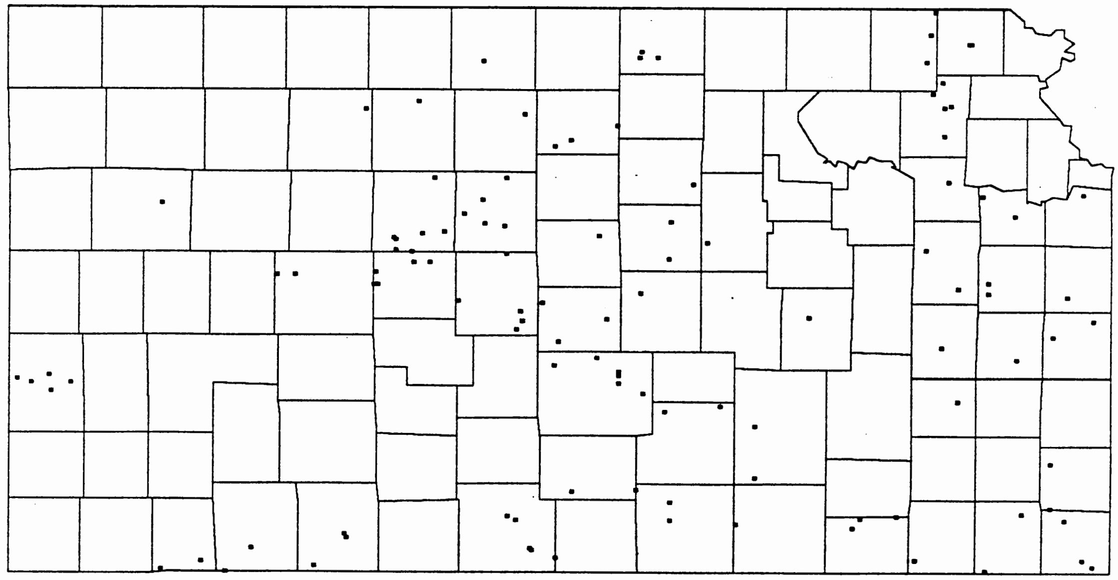


Figure 127. Kansas: Locations of Wells Where Water Contained Chloride Concentrations Equal to or Greater Than the 90th Percentile

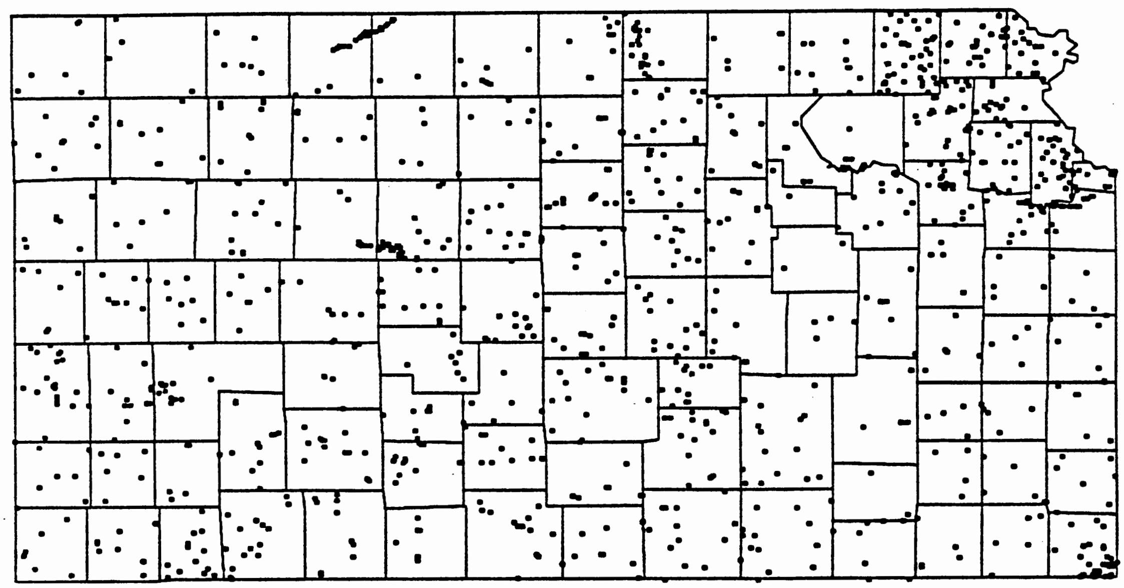


Figure 128. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed For Sulfate

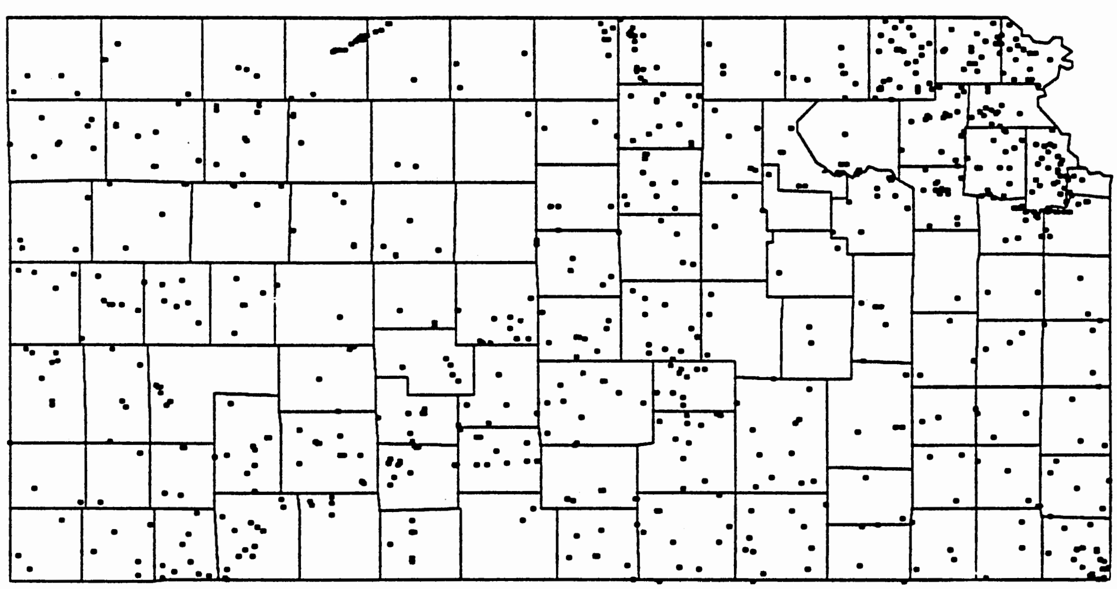


Figure 129. Kansas: Locations of Wells Where Water Contained Sulfate Concentrations Less Than or Equal to 125 mg/l

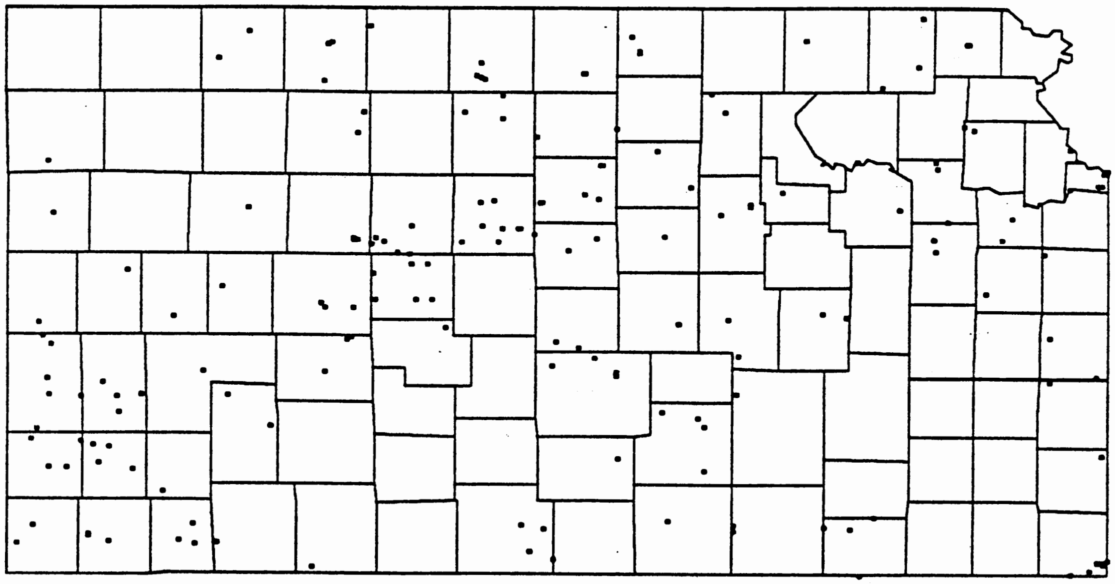


Figure 130. Kansas: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

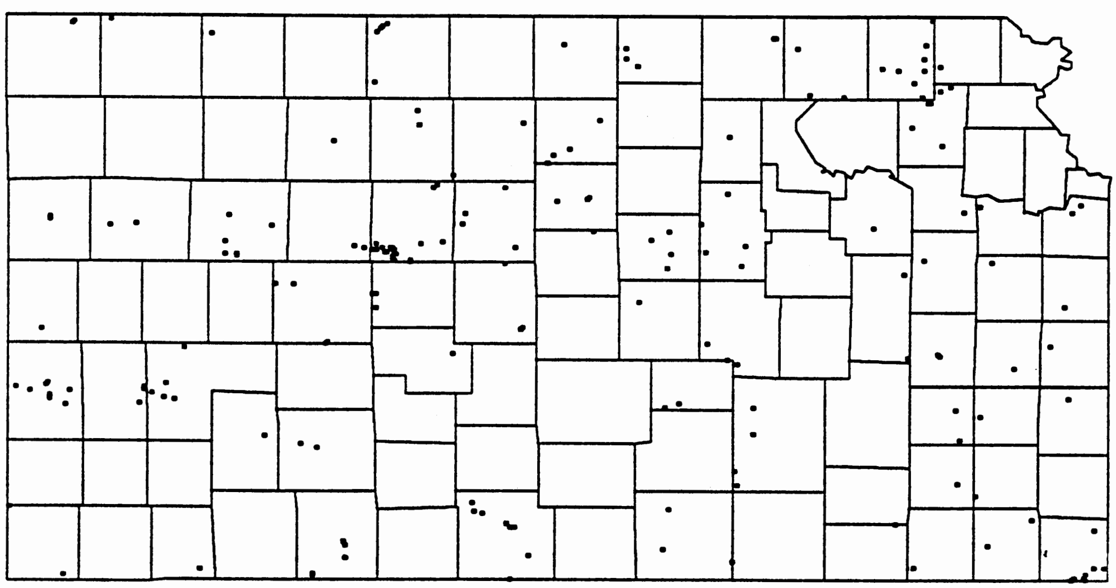


Figure 131. Kansas: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 250 mg/l

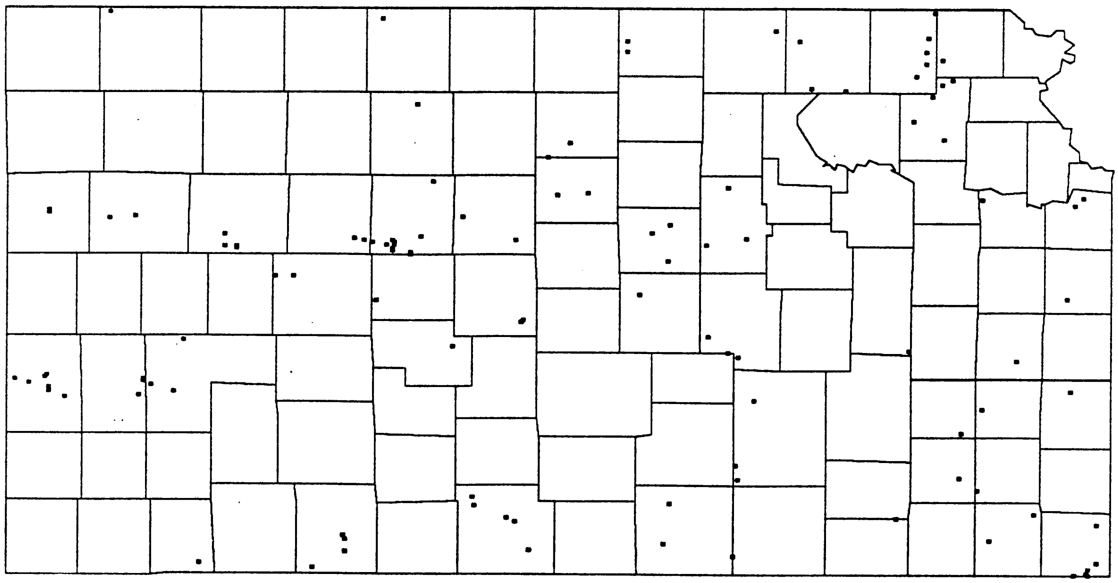


Figure 132. Kansas: Locations of Wells Where Water Contained Sulfate Concentrations Equal to or Greater Than the 90th Percentile

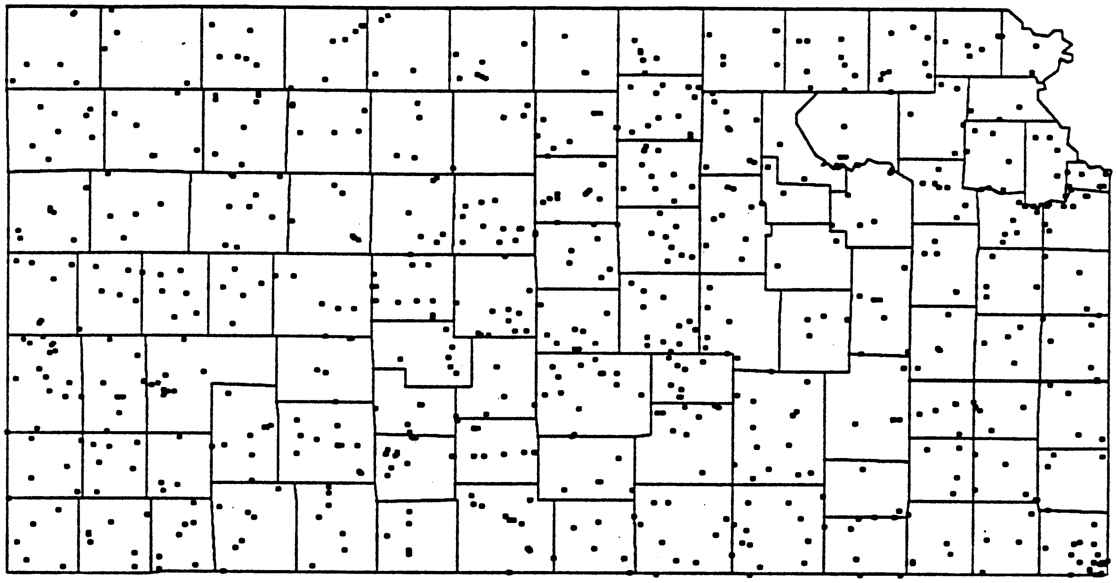


Figure 133. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate Measured as N

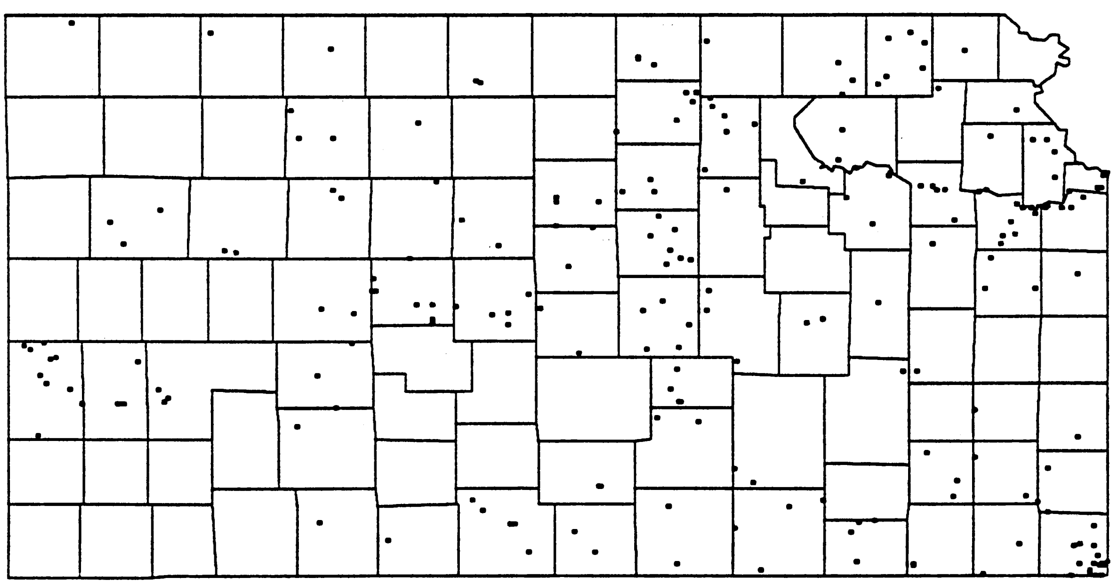


Figure 134. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 5 mg/l as N

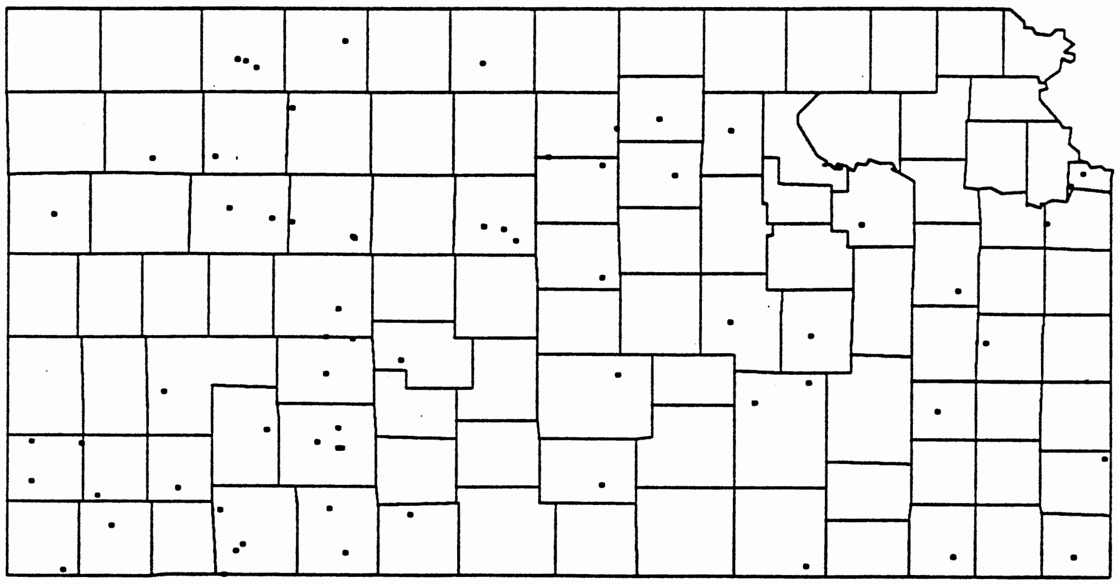


Figure 135. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 5 mg/l as N but Less Than or Equal to 10 mg/l as N

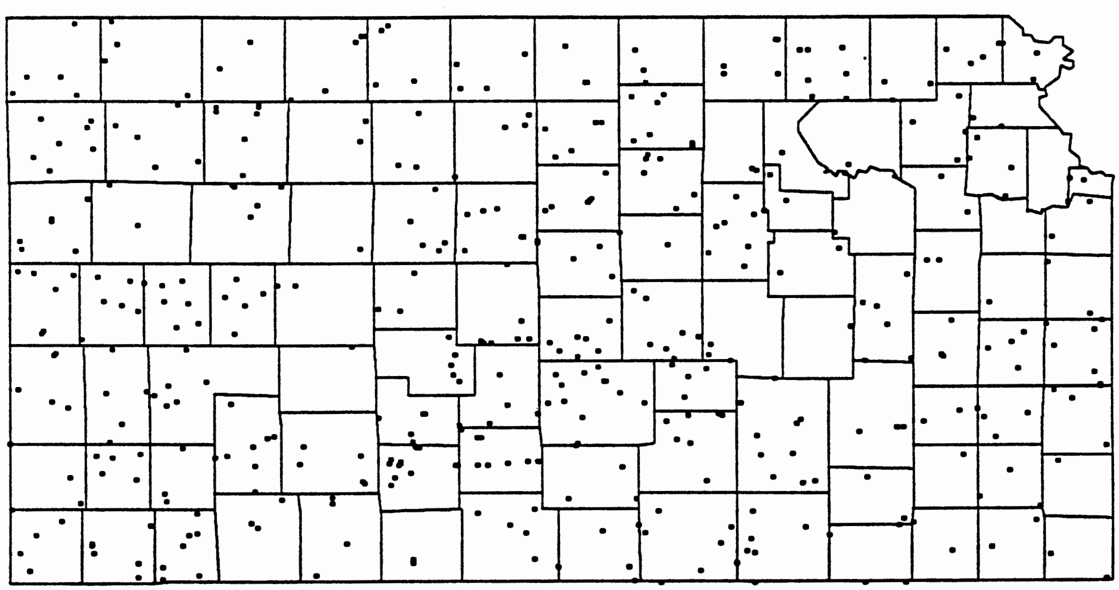


Figure 136. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 10 mg/l as N

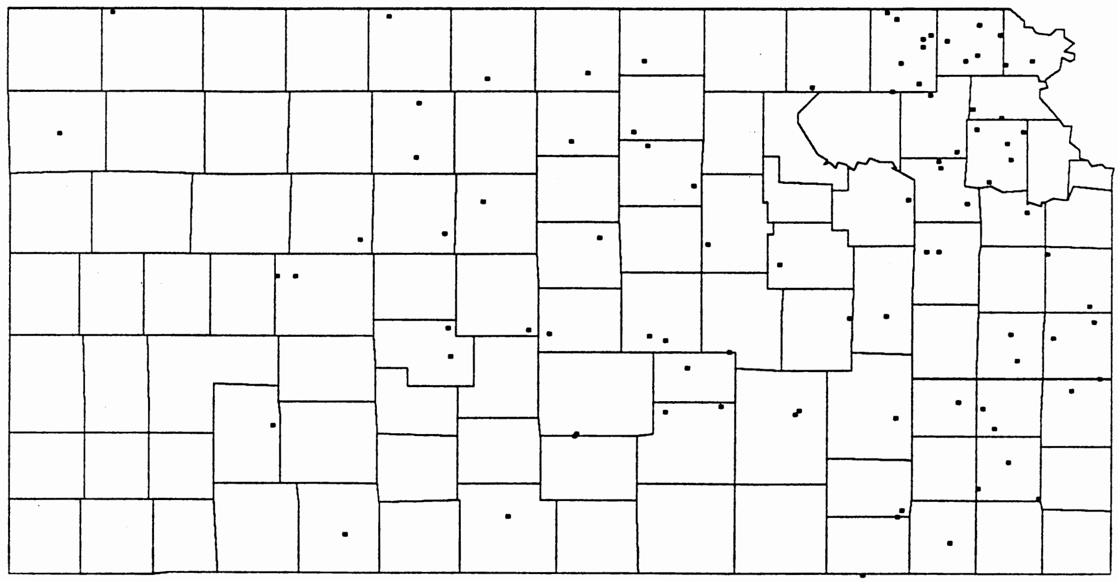


Figure 137. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as N, Equal to or Greater Than the 90th Percentile

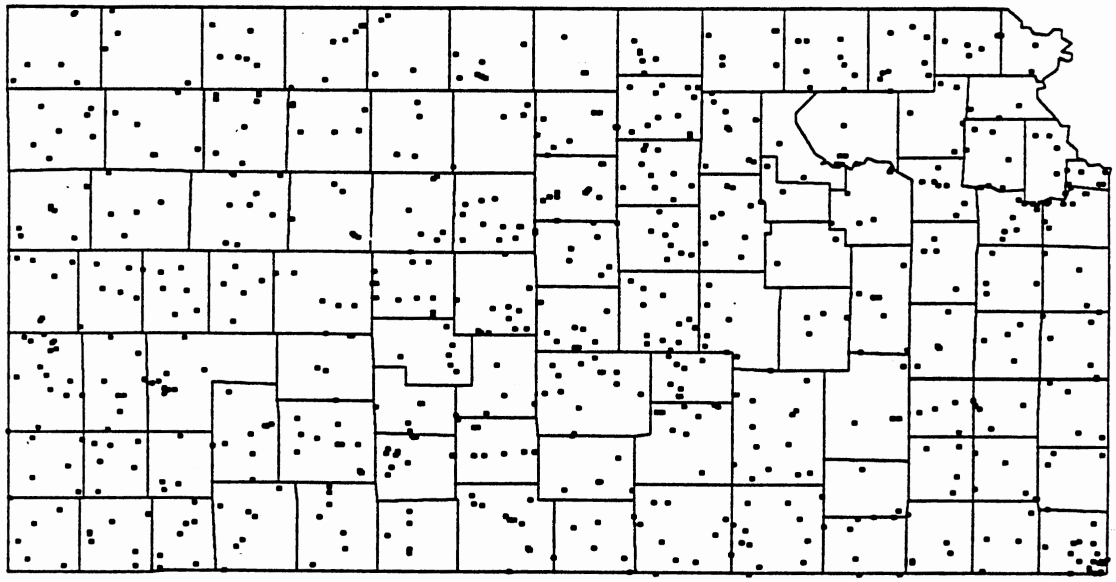


Figure 138. Kansas: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate as NO3

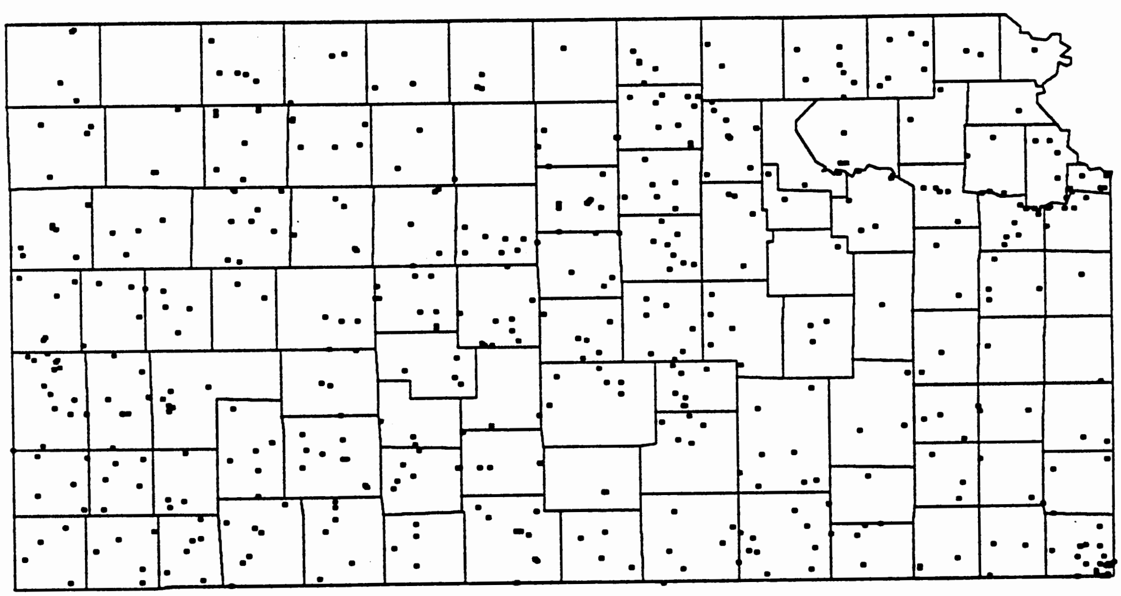


Figure 139. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 25 mg/l as NO3

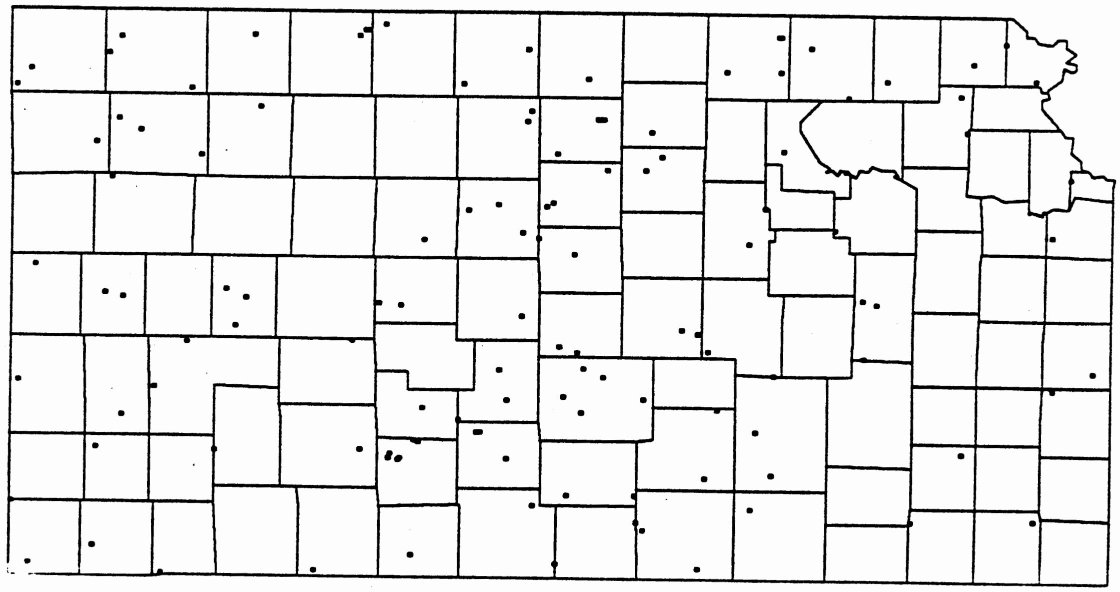


Figure 140. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 25 mg/l as NO3 but Less Than or Equal to 45 mg/l as NO3

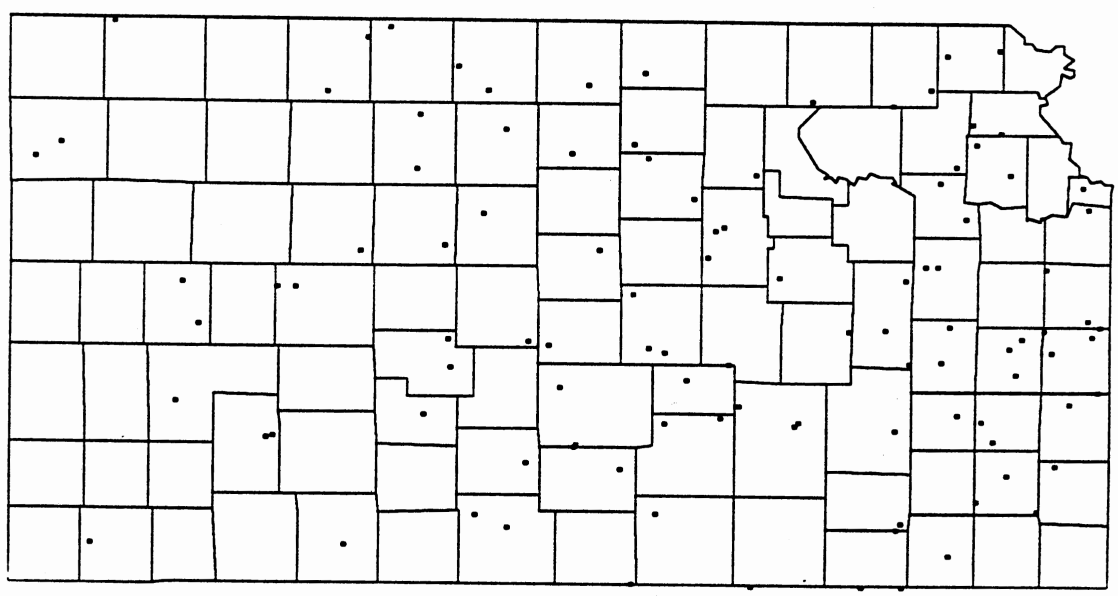


Figure 141. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 45 mg/l as NO3

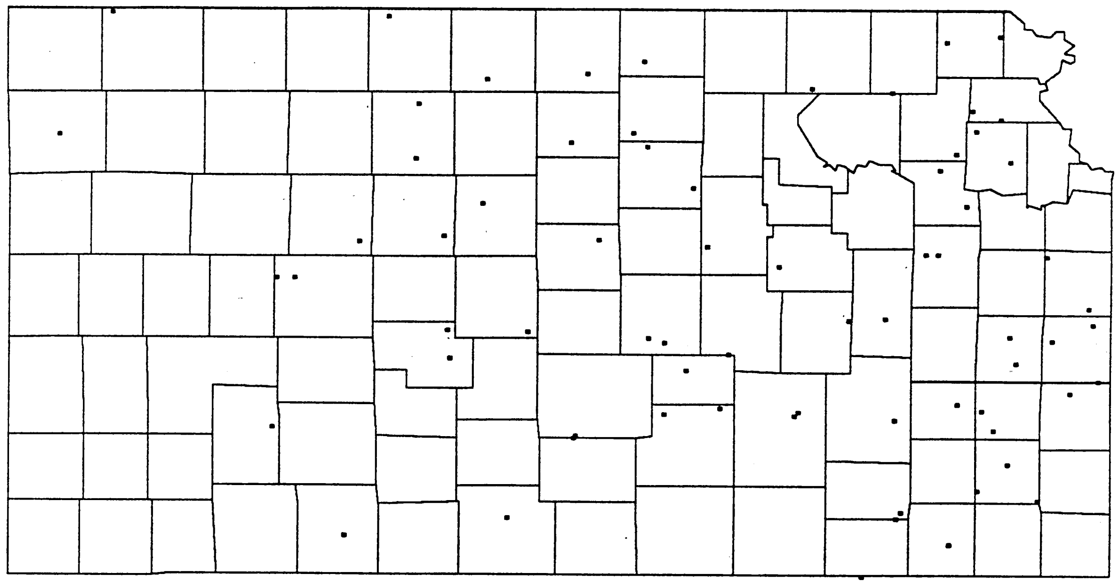


Figure 142. Kansas: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as NO3, Equal to or Greater Than the 90th Percentile

Oklahoma

General Setting

Oklahoma contains approximately 70,000 miles. Average annual precipitation ranges from 16 inches in the panhandle to over 52 inches in the southeastern corner of the state. The northern half of the state is drained by the eastern flowing Arkansas River system. This system includes the Cimarron, North Canadian and South Canadian Rivers. The southern part is drained by the Washita and Red River Systems.

The majority of Oklahoma is underlain by thick sequences of upper Paleozoic age sandstone, shale, and limestone. Precambrian crystalline rock is exposed in the Arbuckle and Wichita mountains. Outcrops of folded and faulted Paleozoic age sandstone and shale occur in the Ouachita Mountains in the southeastern part of Oklahoma. Limestone, sandstone and shale formations of Cretaceous age cover the southeastern part of the state. The northwest margin is mantled by semiconsolidated Tertiary age deposits of sand and gravel known as the Ogallala Formation. Unconsolidated terrace and alluvial deposits that consist of sand, gravel, silt and clay lie along most rivers in Oklahoma.

Discussion

Table 9 exhibits the number of analyses measured, the percentage of samples that exceed E.P.A. drinking water standards, and the percentage of samples in each range of concentration. A map of the major aquifers in Oklahoma and their descriptions is depicted in Figures 143 and 144. Maps illustrating the location of wells and selected ground water quality in Oklahoma are shown in Figures 145-175.

More than 2000 samples were analyzed for dissolved solids, 83 percent exceeded the recommended limit of 500 mg/l, and 30 percent exceed 1000 mg/l. Figures 147 and 148 shows that the wells with excessive dissolved solids are largely concentrated in central and western Oklahoma. The data and maps indicate that these high dissolved solids concentrations are due to high levels of hardness, chloride, and sulfate. The 90th percentile level of concentration for dissolved solids equals 3420 mg/l. Ten percent or 200 samples are equal to or greater than 3420 mg/l in Oklahoma. Figure 149 shows that the location of wells where these samples were obtained are located in western Oklahoma, with a concentration of wells in the far southwest corner of the state. Figures 155, 160, and 165 depict samples which are equal to or exceed the 90th percentile for hardness, chloride, and sulfate respectfully. All three show a similar cluster in the southwest corner of the state. This indicates that the high dissolved solid content in this area is due to hardness, chloride and sulfate. The major aquifer in this area is the Dog Creek-Blaine which consist of interbedded gypsum, dolomite and siltstone. This aquifer is not used for drinking water but is used intensively for irrigation in the area.

Almost 2200 samples were analyzed for hardness and 73 percent exceeded 180 mg/l. Figure 154 shows that the locations of wells containing very hard water occur extensively in central and western Oklahoma. Figure 155 indicates that the locations of wells where water contained hardness concentrations equal to or greater than the 90th percentile occur in southwestern, and to a lesser extent western Oklahoma. Hard water in the state is due to the widespread presence of carbonate and evaporite deposits.

Over 3400 samples were analyzed for chloride in Oklahoma. 76 percent are less than or equal to 125 mg/l, and 15 percent of the samples exceed the recommended limit of 250 mg/l. The highest concentration of wells is located in the southwest corner, but can be found throughout the state. High levels of chloride are likely to be due to deposits evaporite deposits as well as oil and gas drilling activity.

Sulfate was analyzed in over 3200 samples with 23 percent exceeding 250 mg/l. Figure 164 shows that the locations of wells where water contained sulfate concentrations greater than the recommended levels occur extensively in western Oklahoma. The lineation of wells which contain high levels of sulfate southeastern Oklahoma occur along a fault zone on the north side of the Ouachita Mountains.

Approximately 12 percent of the samples tested for nitrates exceed the recommended limit. High nitrates occur almost exclusively in the western half of the state. This part of Oklahoma is used extensively for irrigated agriculture. Fertilizers are the probable cause for these high levels of nitrate.

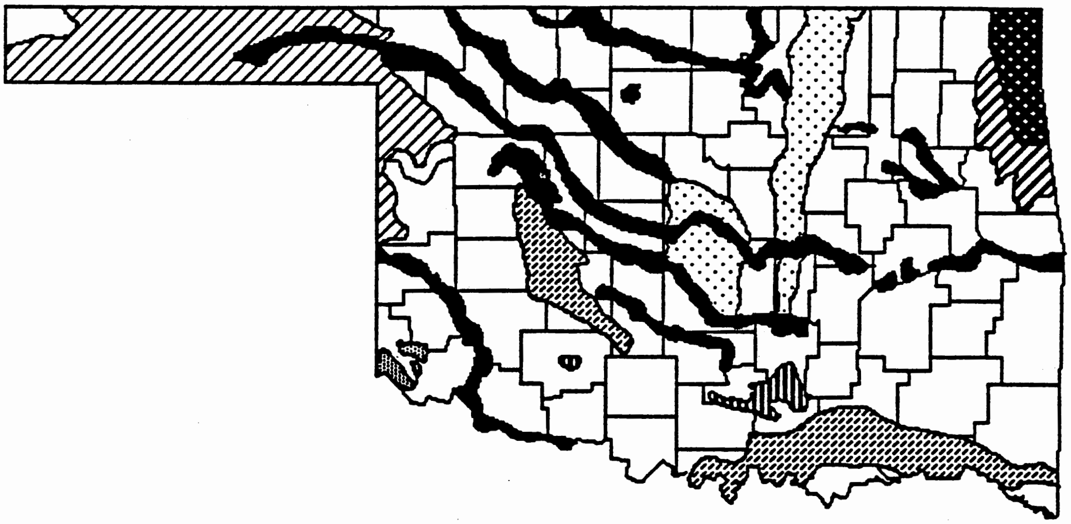
TABLE 9

OKLAHOMA: NUMERICAL SUMMARIES OF WATER ANALYSES

Chemical Constituent by Range of Concentration (mg/l)	Number of Samples	EPA Water Quality Standard (mg/l)	Percentage Exceeding EPA Standard (%)	Percentage in Each Range of Concentration (%)
TDS		500*	83	•
All Samples	2002		•	•
0 - 500	946		•	47
501 - 1000	467		•	53
Greater than 1000	595		•	30
Equal to or Greater than			•	•
the 90th Percentile	200		•	10
Hardness		None	•	•
All Samples	2191		•	•
0 - 60	185		•	8
61 - 120	131		•	6
121 - 180	268		•	12
Greater than 180	1607		•	73
Equal to or Greater than			•	•
the 90th Percentile	228		•	10
Chloride		250	15	•
All Samples	3416		•	•
0 - 125	2601		•	76
126 - 250	315		•	9
Greater than 250	500		•	15
Equal to or Greater than			•	•
the 90th Percentile	338		•	10
Sulfate		250	23	•
All Samples	3225		•	•
0 - 125	2154		•	67
126 - 250	332		•	10
Greater than 250	739		•	23
Equal to or Greater than			•	•
the 90th Percentile	318		•	10

TABLE 9 (continued)

Constituent by Range of Concentration (mg/l)	Number of Samples	Quality Standard (mg/l)	Exceeding EPA Standard (%)	in Each Range of Concentration (%)
Nitrate as N		10	11	•
All Samples	1471		•	•
0 - 5	1135		•	77
6 - 10	168		•	11
Greater than 10	168		•	11
Equal to or Greater than			•	•
the 90th Percentile	168		•	11
Nitrate as NO3		45	12	•
All Samples	1480		•	•
0 - 25	1156		•	78
26 - 45	153		•	10
Greater than 45	171		•	12
Equal to or Greater than			•	•
the 90th Percentile	157		•	11



EXPLANATION

- Alluvium and Terrace Deposits Along Major Streams
- High Plains Aquifer
- Antlers and Rush Springs Aquifers
- Dog Creek - Blaine Aquifer
- Garber - Wellington and Vamoosa - Ada Aquifers
- Keokuk - Reeds Spring (Boone) Aquifers
- Roubidoux Aquifer
- Arbuckle - Simpson and Arbuckle - Timbered Hills Aquifesa
- Not a Principle Aquifer

Figure 143. Oklahoma: Map of Major Aquifers (Modified from U.S.G.S., 1985)

[Mgal/d = millions of gallons per day; ft = feet; acre-ft = acre-feet; mg/L = milligrams per liter; gal/min = gallons per minute; Sources: Reports of the U. S. Geological Survey.]

Aquifer name and description	Aquifer withdrawals in 1980 (Mgal/d)	Well characteristics: Depth (ft) Common range	Well characteristics: Yield (gal/min) Common range	Well characteristics: Yield (gal/min) May exceed	Remarks
Alluvial aquifers:					
Arkansas River and Salt Fork Arkansas River alluvium and terrace deposits: Clay and silt in upper part grading downward into fine to coarse sand with local lenses of fine gravel. Maximum thickness 60 ft alluvium, 150 ft terrace. Saturated thickness 25 to 70 ft. Generally unconfined.	30	50 - 100	200 - 500 (alluvium): 100 - 200 (terrace):	800 400	Calcium magnesium bicarbonate type water, very hard with dissolved-solids concentrations less than 500 mg/L. Intensively pumped wells near river may induce inflow of river water with chloride concentrations of 350 to 830 mg/L.
Cimarron River alluvium and terrace deposits: Silt and clay in upper part grading downward into sandy clay, sand, and fine gravel; maximum thickness about 80 ft. Terrace deposits nearly everywhere overlain by dune sand as much as 100 ft thick. Generally unconfined.	23	50 - 150	100 - 200 (alluvium): 100 - 500 (terrace):	400 800	Water generally calcium magnesium bicarbonate type, very hard; dissolved-solids concentrations generally are less than 500 mg/L. Intensively pumped wells near river may induce inflow. During greater-than-normal precipitation dune sand and terrace deposits become saturated causing local water-logging of the lands.
North Canadian River alluvium and terrace deposits: Fine to coarse sand with minor clay and silt and local lenses of basal gravel overlain by dune sand. Thickness of alluvium averages about 30 ft; terrace maximum thickness about 300 ft. Generally unconfined.	51		300 - 600 (alluvium): 100 - 300 (terrace):	1,200 500	Water generally calcium bicarbonate type, hard to very hard; dissolved-solids concentrations less than 1,000 mg/L.
Canadian River alluvium and terrace deposits: Clay and silt in upper part grading downward into fine to coarse sand with thin lenses of basal gravel. Maximum thickness 60 ft; saturated thickness 20 to 40 ft. Generally unconfined.	8		100 - 400 (alluvium): 50 - 100 (terrace):	600 200	Water generally calcium magnesium bicarbonate type; hard to very hard; dissolved-solids concentrations generally less than 1,000 mg/L.
Washita River alluvium and terrace deposits: Silt and clay grading downward into fine to medium sand, average thickness 64 ft, maximum thickness 120 ft for alluvium. Terrace deposits silt and fine sand with maximum thickness of 50 ft. Generally unconfined.	7	50 - 100	100 - 300 (alluvium): 20 - 100 (terrace):	600 -	Water generally calcium magnesium bicarbonate type; dissolved-solids concentrations less than 1,000 mg/L.
North Fork Red River alluvium and terrace deposits (Beckham and Tillman terraces): Alluvium is silt and clay grading downward into fine to coarse sand; maximum thickness about 70 ft. Terraces about 50 percent fine to coarse sand, 50 percent silt and clay. Beckham average thickness about 70 ft; Tillman about 40 ft. Generally unconfined.	28	50 - 150	100 - 200 (alluvium): 200 - 500 (Beckham terrace): 200 - 500 (Tillman terrace):	500 900 1,100	Generally calcium magnesium bicarbonate or calcium sulfate type water, hard to very hard; dissolved-solids concentrations 1,000 to 2,000 mg/L. In Tillman terrace, water levels have declined 1 to 20 ft. Beckham terrace water levels have declined as much as 10 ft; approximately 10 percent of water in storage has been depleted.
Unconsolidated and semiconsolidated aquifers:					
High Plains aquifer: Ogallala Formation of Tertiary age and associated alluvium and terrace deposits of Quaternary age; sand, siltstone, clay, gravel, thin limestones, and caliche. Generally unconfined.	373	100 - 500	100 - 1,000	2,000	Chief source of water supplies in the High Plains of Oklahoma. Water generally hard but suitable for most uses. Water levels have declined as much as 100 ft in some areas.
Bedrock aquifers:					
Antlers aquifer: Sandstone of Cretaceous age. Friable sandstone, silt, clay, and shale; average thickness about 450 ft. Unconfined where exposed but confined toward south where overlain by less permeable rocks.	5	50 - 200 (unconfined) 200 - 800 (confined)	50 - 100 (land surface) 100 - 500 (at depth)	1,700 -	Sodium or calcium bicarbonate type water where aquifer exposed; dissolved-solids concentrations generally less than 1,000 mg/L but may be as much as 3,000 mg/L. Volume of water in storage with dissolved solids less than 1,000 mg/L estimated at 32 million acre-feet. Comparable to Trinity aquifer in Texas.

Figure 144. Oklahoma: Major Aquifer Descriptions and Well Characteristics (Modified from U.S.G.S., 1985)

Table 2. Aquifer and well characteristics in Oklahoma—Continued

Aquifer name and description	Aquifer withdrawals in 1980 (Mgal/d)	Well characteristics: Depth (ft) Common range	Yield (gal/min) Common range	Yield (gal/min) May exceed	Remarks
Rush Springs aquifer: Fine-grained sandstone with some shale, dolomite, and gypsum; 200 to 300 ft thick. Unconfined to partly confined in deeper parts of aquifer.	54	200 - 400	200 - 600	1,000	Calcium bicarbonate type water; dissolved-solids concentrations generally less than 500 mg/L. In heavily pumped areas, water levels have declined as much as 50 ft.
Dog Creek-Blaine aquifer: Interbedded gypsum, dolomite, and siltstone, 300 to 400 ft thick. Water occurs in solution openings in gypsum; generally unconfined.	25	100 - 200	100 - 500	2,500	Generally calcium sulfate chloride type water; total dissolved solids 2,000 to 6,000 mg/L. Unsuitable for drinking, but intensively used for irrigation. Water levels may decline as much as 50 ft, but aquifer is recharged by surface runoff into sinkholes and solution openings.
Garber-Wellington aquifer: Fine-grained sandstone with shale and siltstone; maximum thickness about 900 ft; saturated thickness 150 to 650 ft. Generally unconfined to partly confined where aquifer is near the surface or confined where overlain by less permeable rocks.	41	100 - 200 (unconfined) 200 - 900 (confined)	100 - 300	500	Generally calcium magnesium bicarbonate type water; dissolved-solids concentration generally less than 500 mg/L. Becomes more saline with depth and in western part of area. Underlain by salt water that may move upward in areas of heavy pumpage. Locally, the potentiometric surface has been lowered 100 to 200 ft. Contaminated by oil field brines and wastes in some areas where aquifer is near surface.
Vamoosa-Ada aquifer: Fine- to very fine-grained sandstone, siltstone, shale, and conglomerate. Thickness of water-yielding sandstone 100 to 550 ft. Unconfined where near land surface; confined in west where overlain by less permeable rocks. Equivalent to the Douglas aquifer in Kansas.	10	100 - 500	100 - 300	500	Generally sodium bicarbonate or sodium calcium bicarbonate type water; dissolved-solids concentration less than 500 mg/L, but increase to 1,000 mg/l with depth near potable-water-salt-water interface. Estimated 60 million acre-ft of potable water in storage. Most withdrawals for public and industrial use.
Keokuk-Reeds Spring (Boone) aquifer: Weathered residual chert and clay in upper part; very cherty limestone in lower part; maximum thickness 500 ft. Unconfined to confined.	3	50 - 300	1 - 10	80	Calcium bicarbonate type water, hard to very hard; dissolved-solids concentrations generally less than 500 mg/L. Because of lithology, readily susceptible to contamination from surface sources. Springs can yield 600 to 3,500 gal/min.
Roubidoux aquifer: Fractured dolomite containing two or three sandy zones; confined. Equivalent to Ozark aquifer in Kansas and Missouri.	5	800 - 1,200	150	600	Water moderately hard but suitable for most uses. Principal water supply for municipalities and industries in Ottawa County.
Arbuckle-Simpson aquifer: Limestone, dolomite, and sandstone 5,000 to 9,000 ft thick. Water occurs in solution openings and fractures; confined to unconfined.	6	100 - 2,500	100 - 500	2,000	Calcium magnesium bicarbonate type water, very hard; dissolved-solids concentration generally less than 500 mg/L. Volume of water in storage estimated to be 9 million acre-ft. Springs can yield as much as 18,000 gal/min.
Arbuckle-Timbered Hills aquifer: Limestone, dolomite, sandy dolomite, mudstone, and conglomerate; generally confined.	2	100 - 2,800	90 - 600	600	Water generally soft, but fluoride concentrations exceed 1.6 mg/L nearly everywhere and may be as much as 35 mg/L. Springs can yield as much as 200 gal/min.

Figure 144. Continued

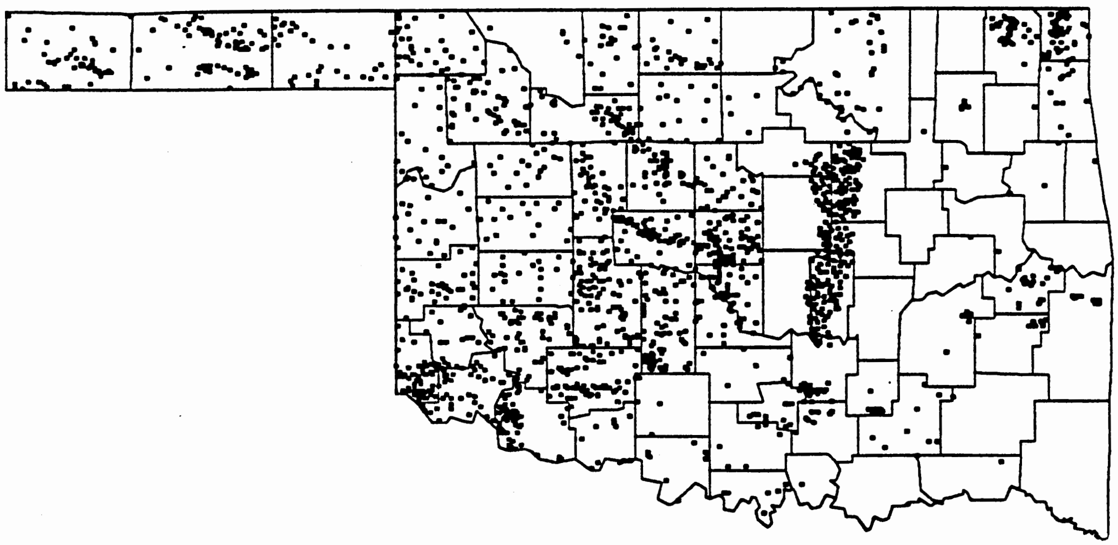


Figure 145. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed For Total Dissolved Solids.

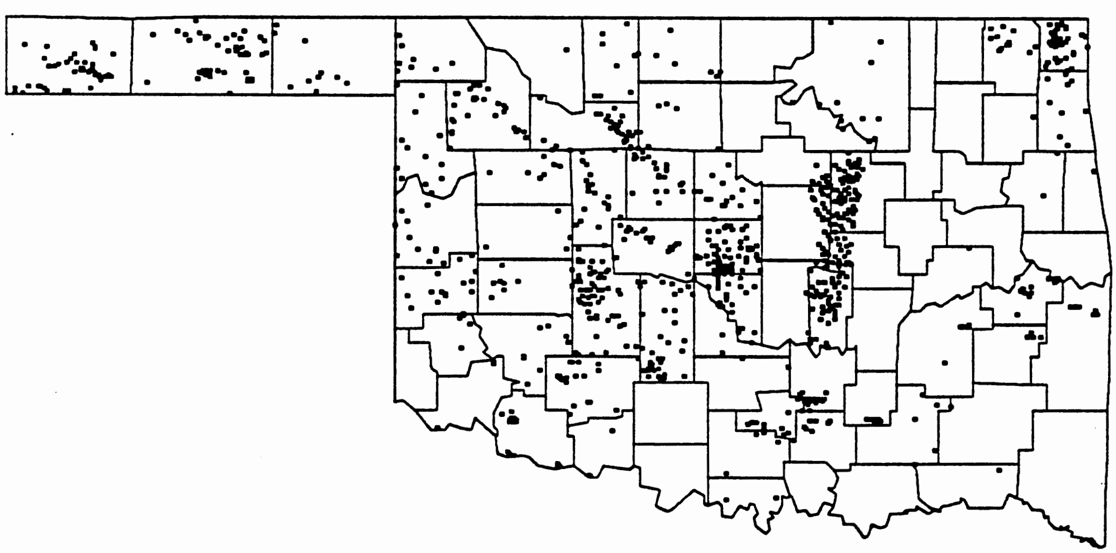


Figure 146. Oklahoma: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Less Than or Equal to 500 mg/l

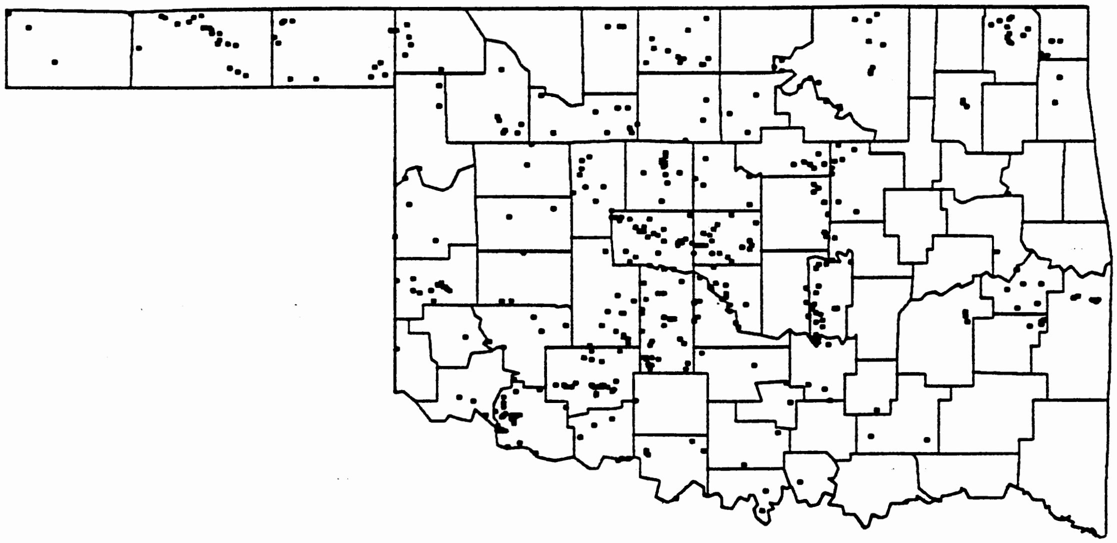


Figure 147. Oklahoma: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 500 mg/l but Less Than or Equal to 1000 mg/l

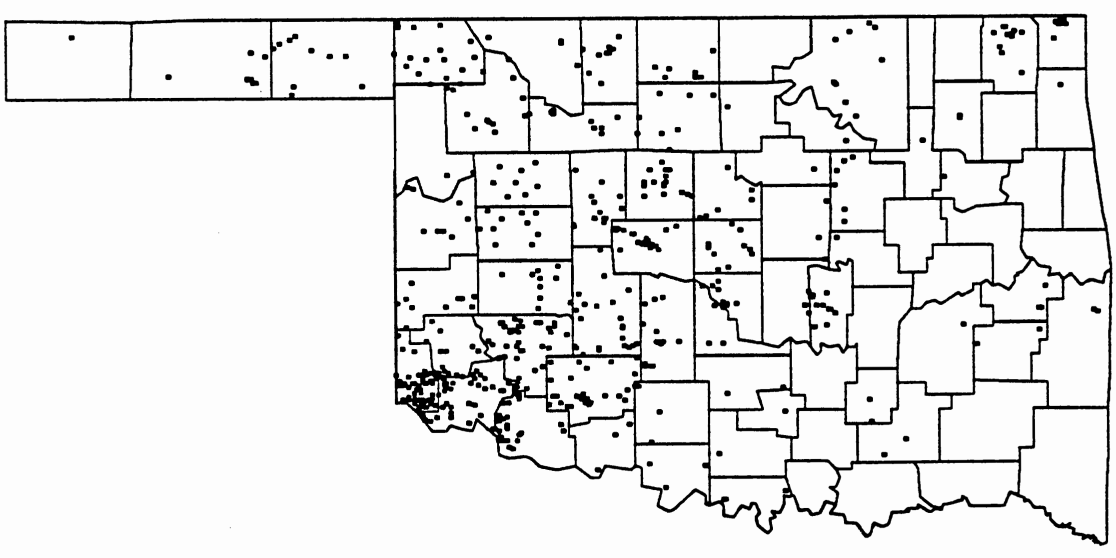


Figure 148. Oklahoma: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Greater Than 1000 mg/l

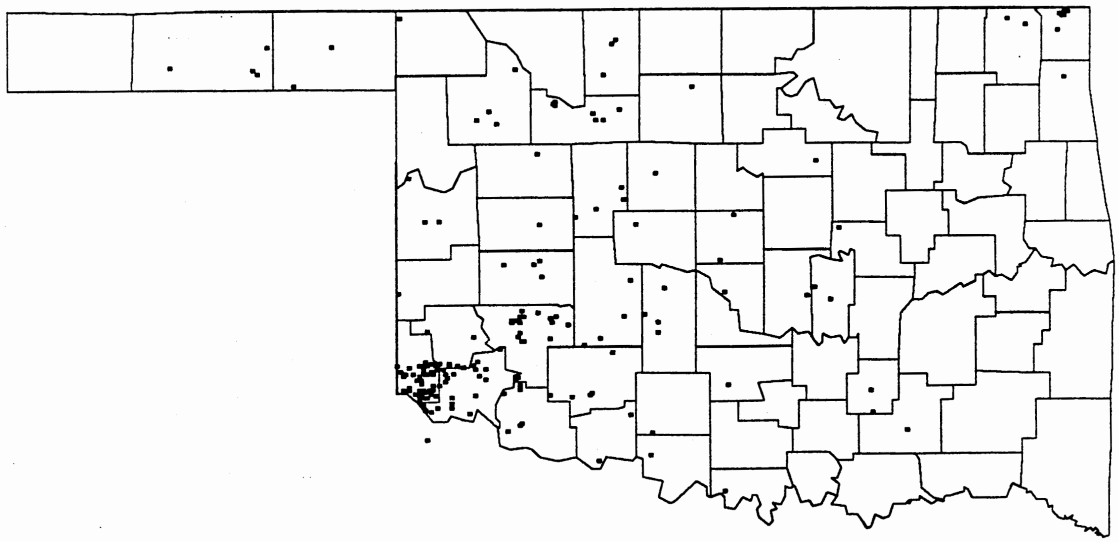


Figure 149. Oklahoma: Locations of Wells Where Water Contained Total Dissolved Solids Concentrations Equal to or Greater Than the 90th Percentile

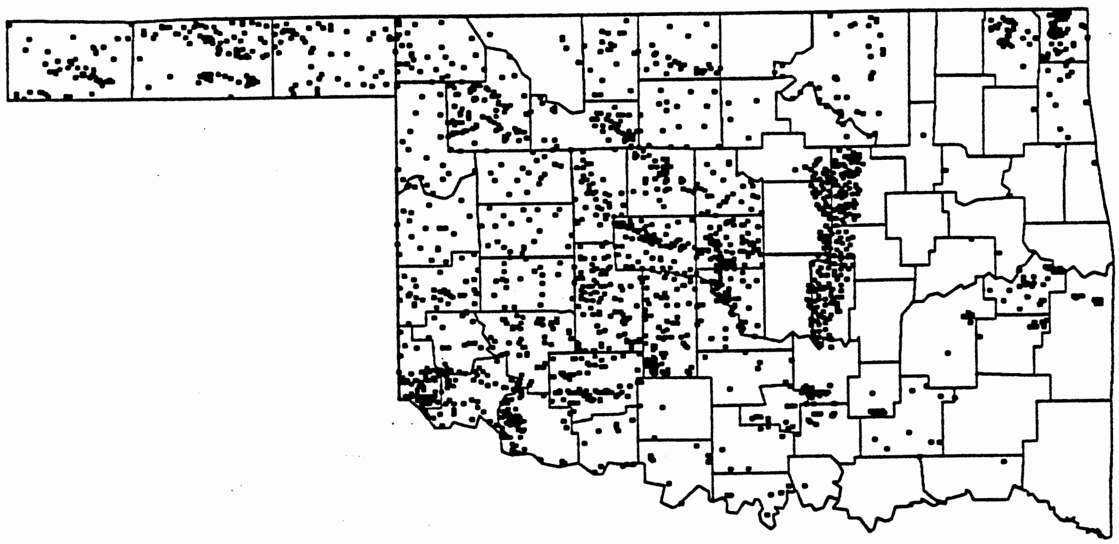


Figure 150. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed For Hardness

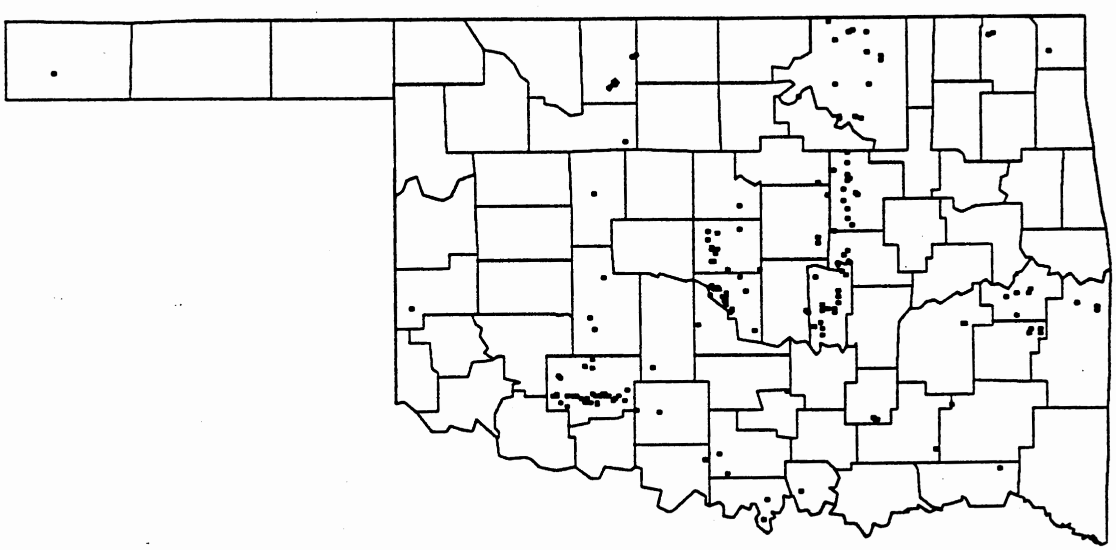


Figure 151. Oklahoma: Locations of Wells Where Water Contained Hardness Concentrations Less Than or Equal to 60 mg/l

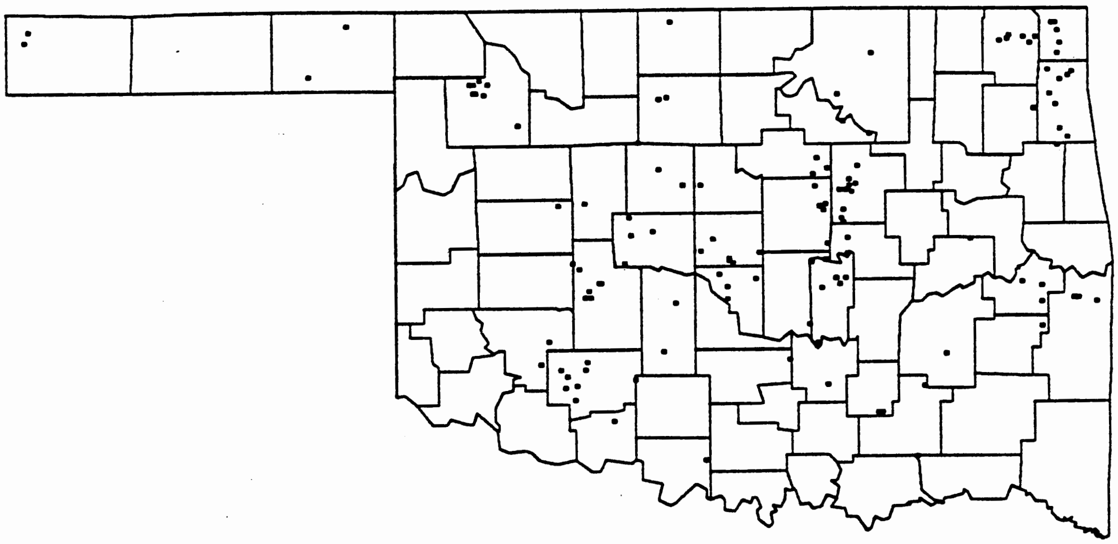


Figure 152. Oklahoma: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 60 mg/l but Less Than or Equal to 120 mg/l

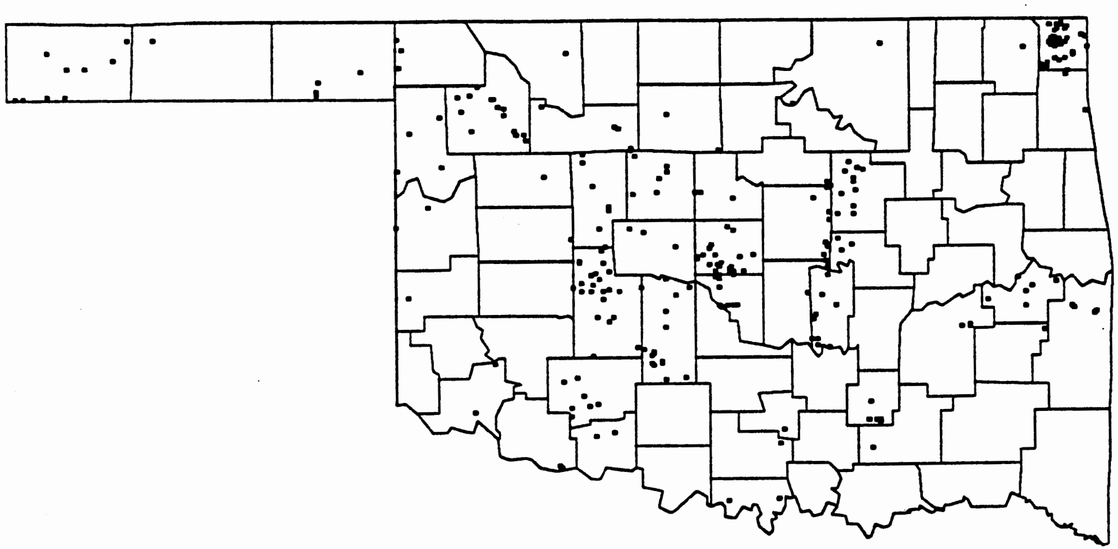


Figure 153. Oklahoma: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 120 mg/l but Less Than or Equal to 180 mg/l

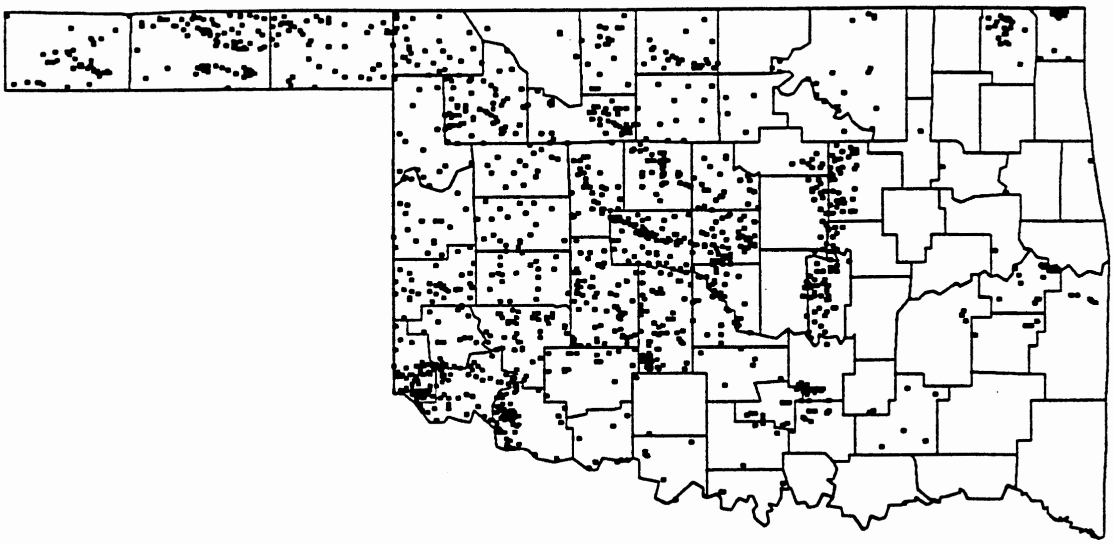


Figure 154. Oklahoma: Locations of Wells Where Water Contained Hardness Concentrations Greater Than 180 mg/l

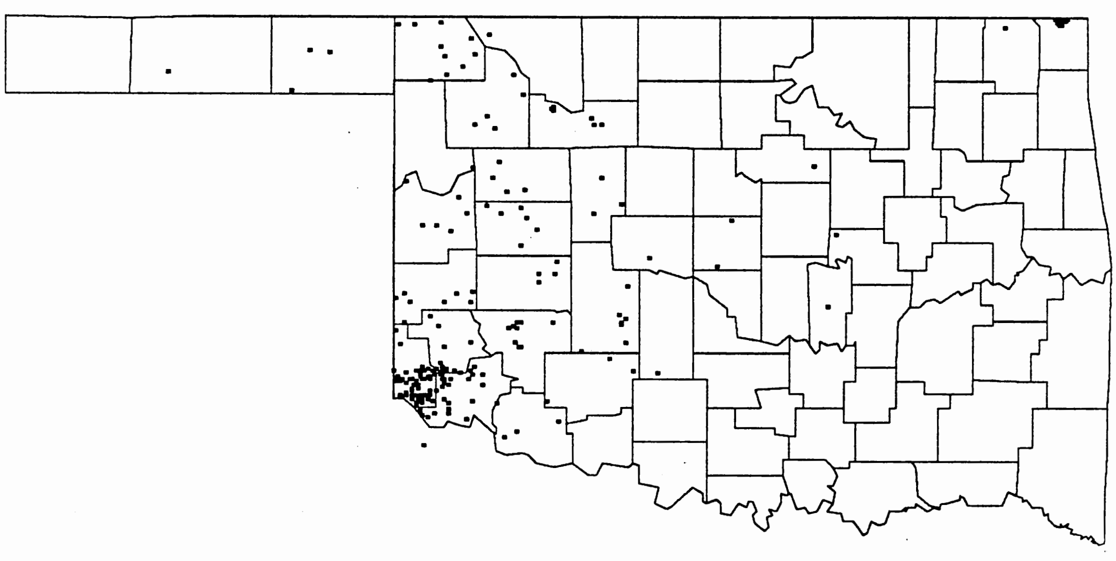


Figure 155. Oklahoma: Locations of Wells Where Water Contained Hardness Concentrations Equal to or Greater Than the 90th Percentile

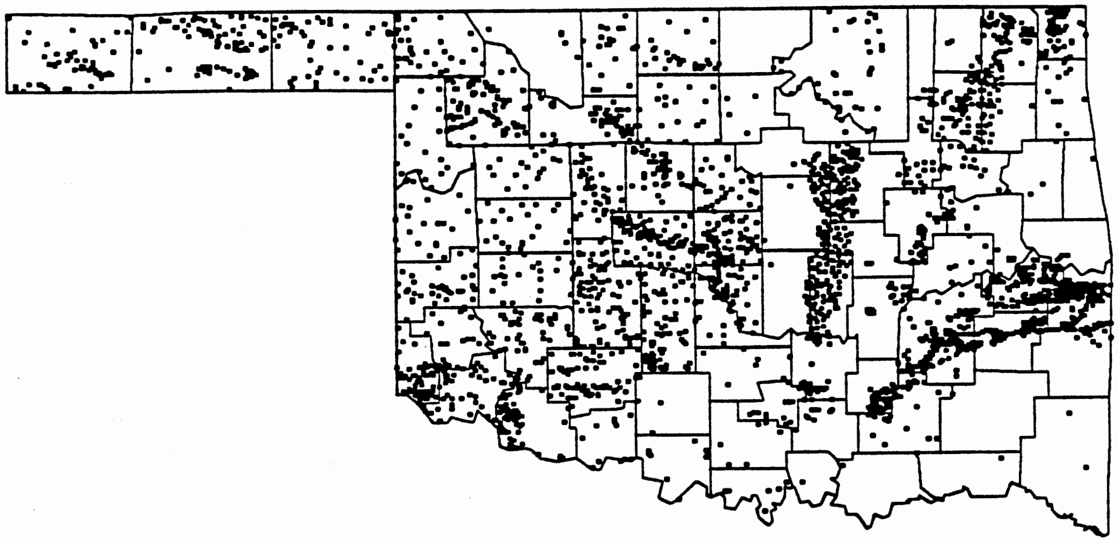


Figure 156. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed For Chloride

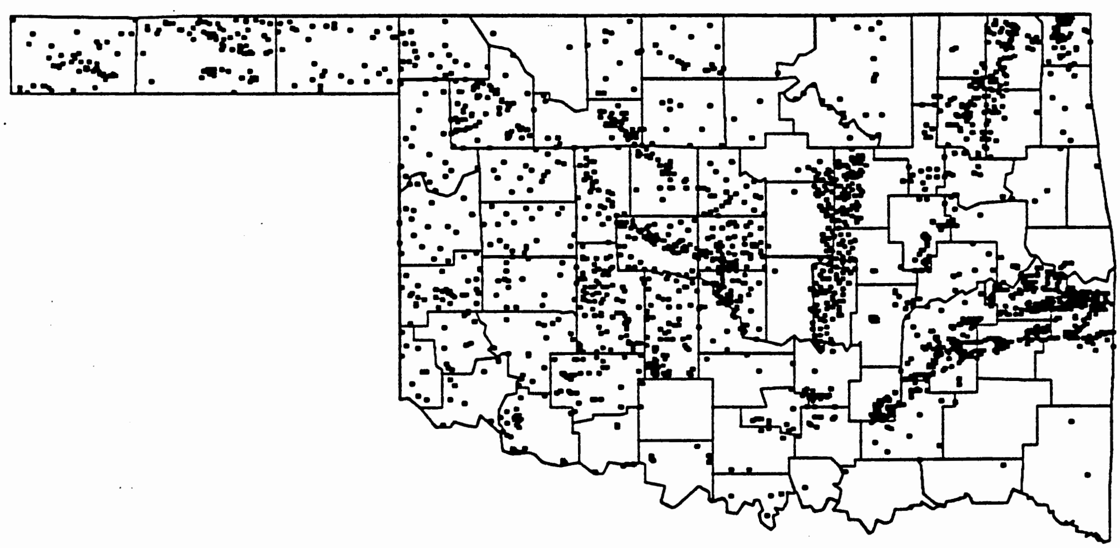


Figure 157. Oklahoma: Locations of Wells Where Water Contained Chloride Concentrations Less Than or Equal to 125 mg/l

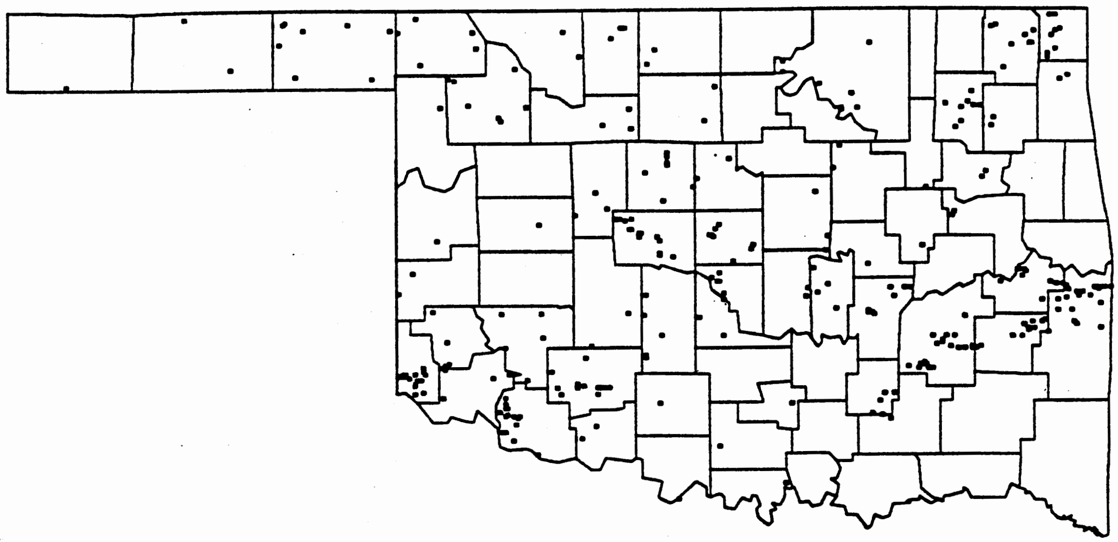


Figure 158. Oklahoma: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

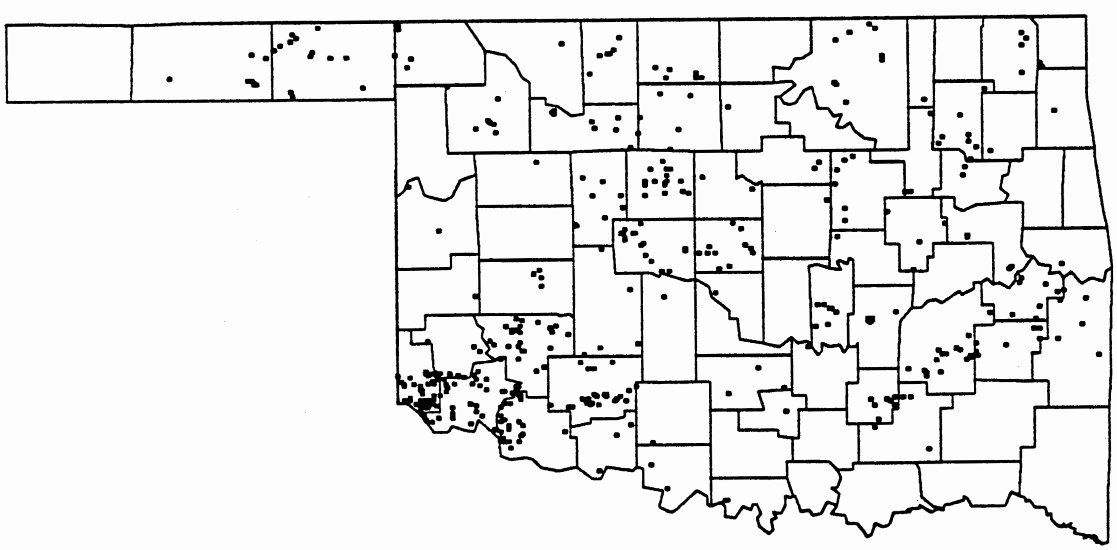


Figure 159. Oklahoma: Locations of Wells Where Water Contained Chloride Concentrations Greater Than 250 mg/l

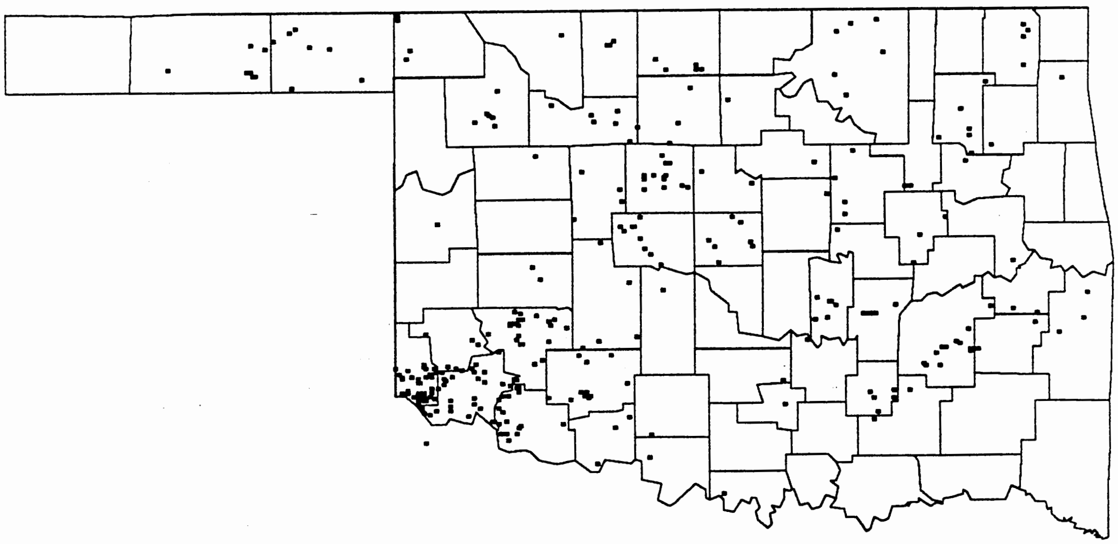


Figure 160. Oklahoma: Locations of Wells Where Water Contained Chloride Concentrations Equal to or Greater Than the 90th Percentile

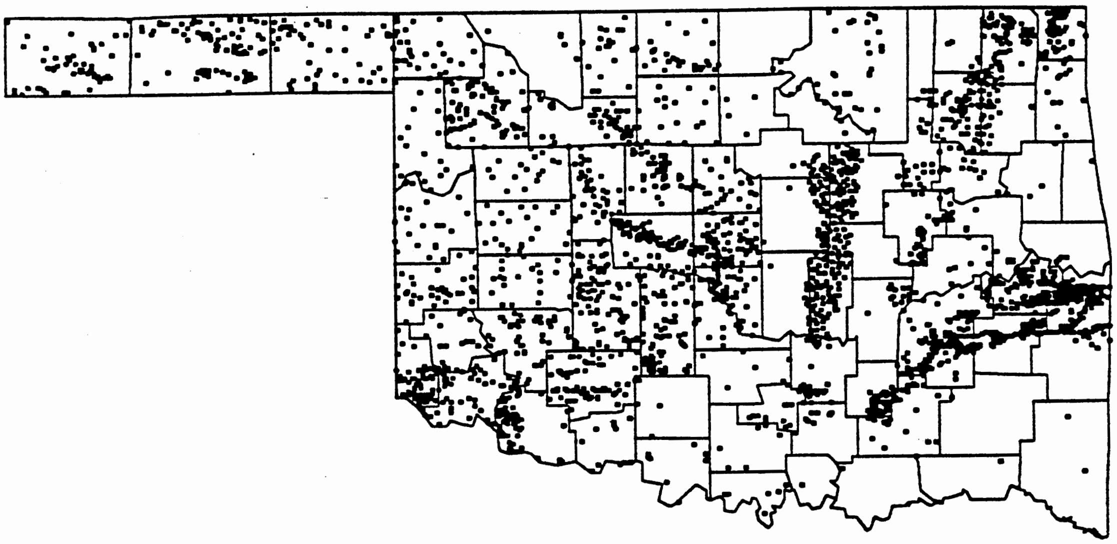


Figure 161. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed For Sulfate

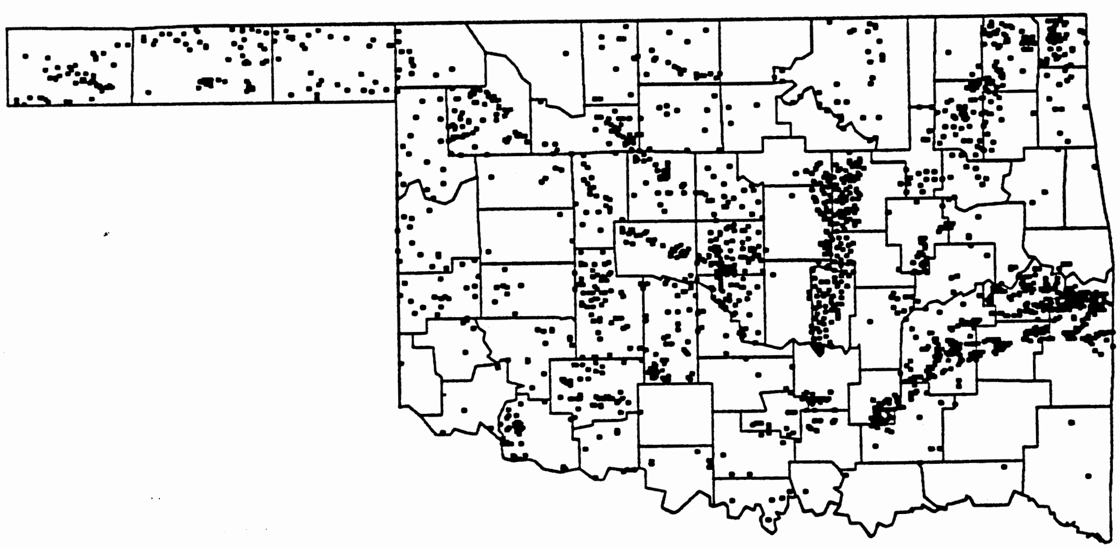


Figure 162. Oklahoma: Locations of Wells Where Water Contained Sulfate Concentrations Less Than or Equal to 125 mg/l

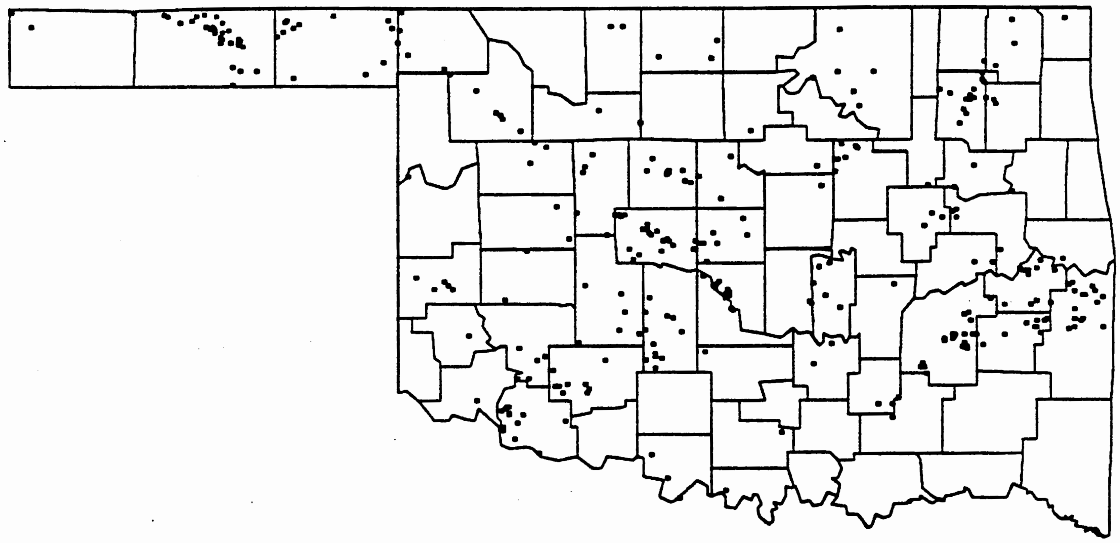


Figure 163. Oklahoma: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 125 mg/l but Less Than or Equal to 250 mg/l

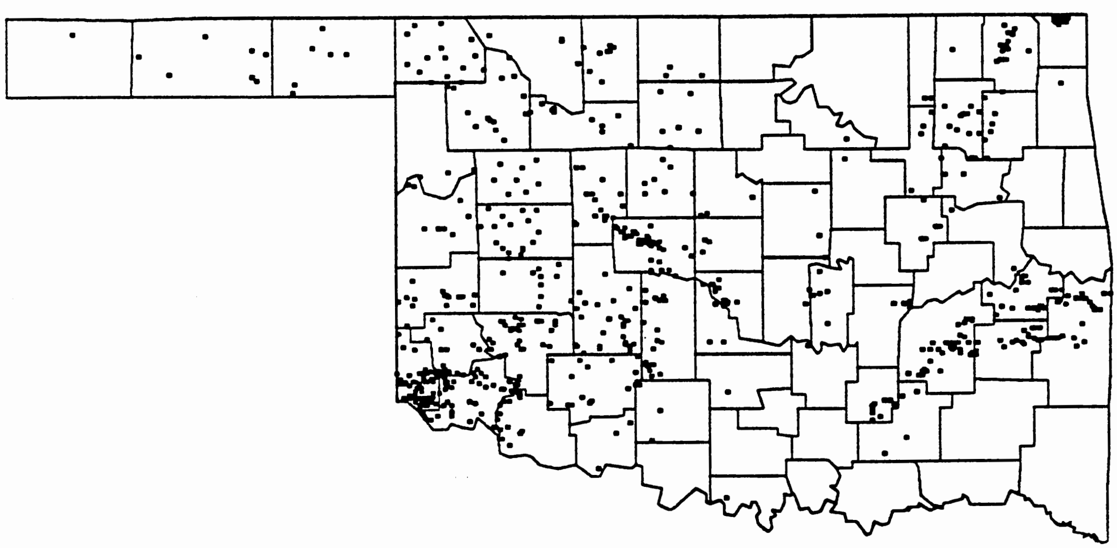


Figure 164. Oklahoma: Locations of Wells Where Water Contained Sulfate Concentrations Greater Than 250 mg/l

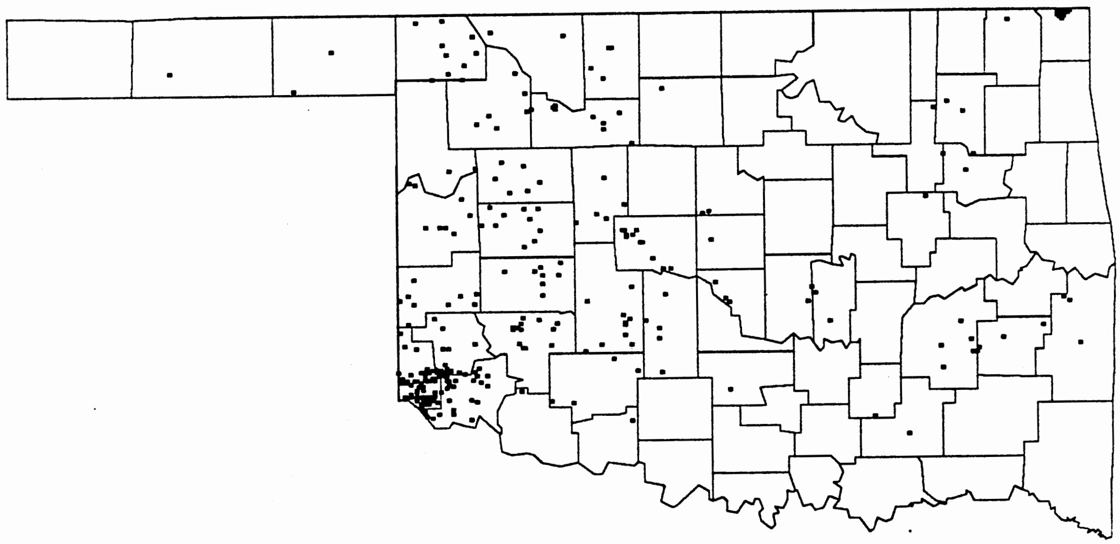


Figure 165. Oklahoma: Locations of Wells Where Water Contained Sulfate Concentrations Equal to or Greater Than the 90th Percentile

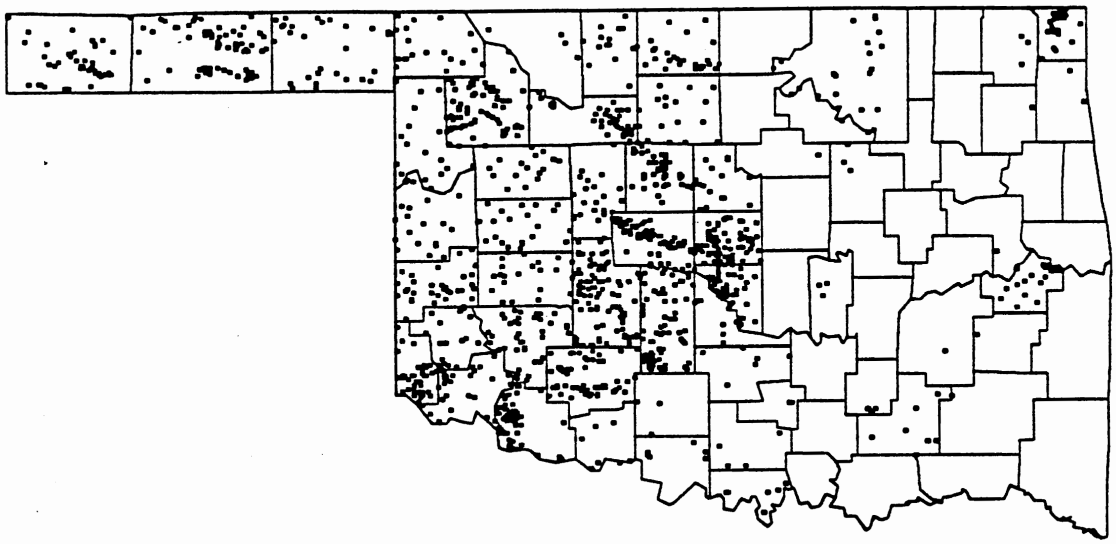


Figure 166. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate Measured as N

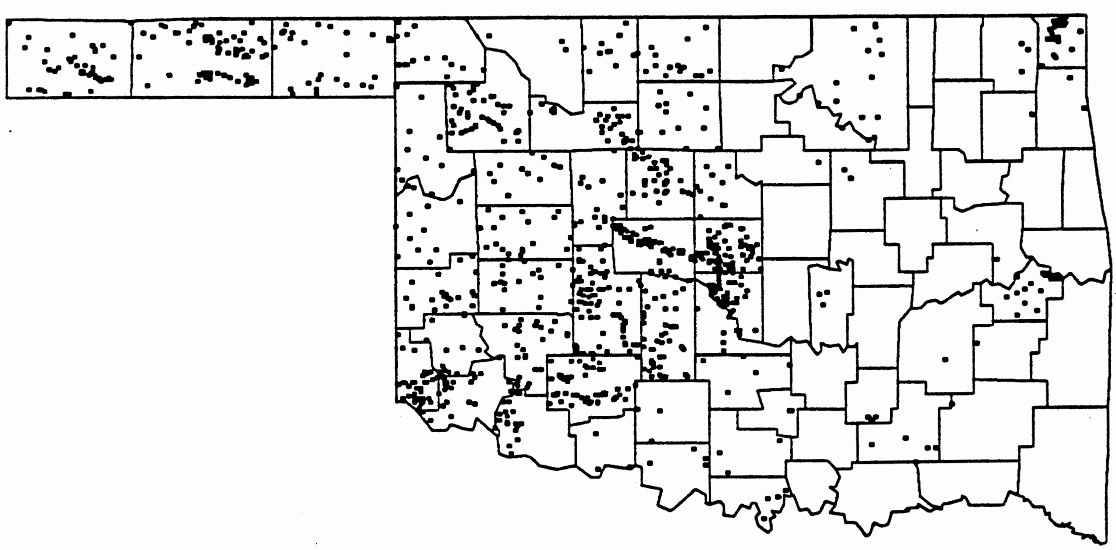


Figure 167. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 5 mg/l as N

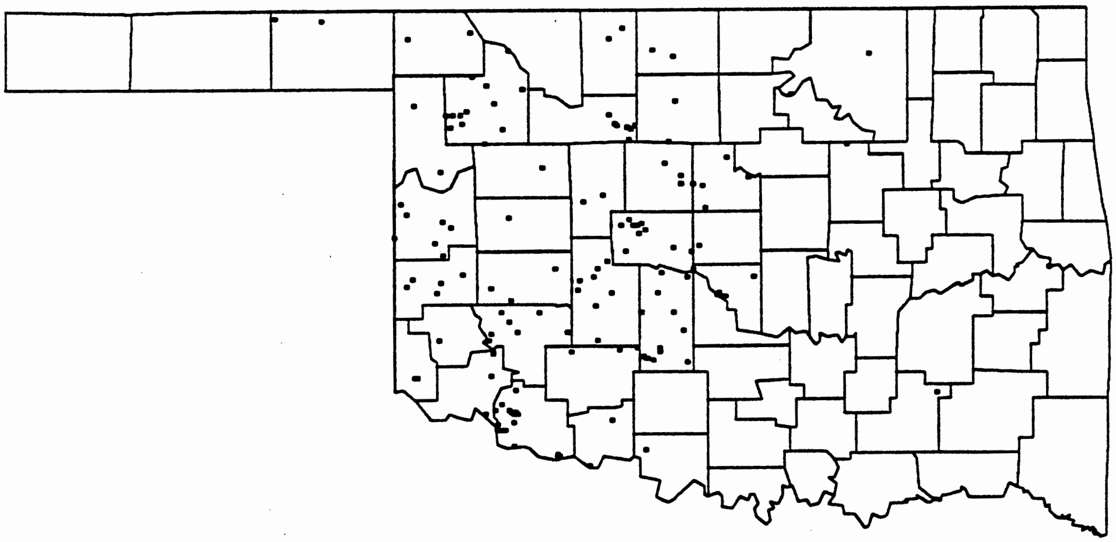


Figure 168. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 5 mg/l as N but Less Than or Equal to 10 mg/l as N

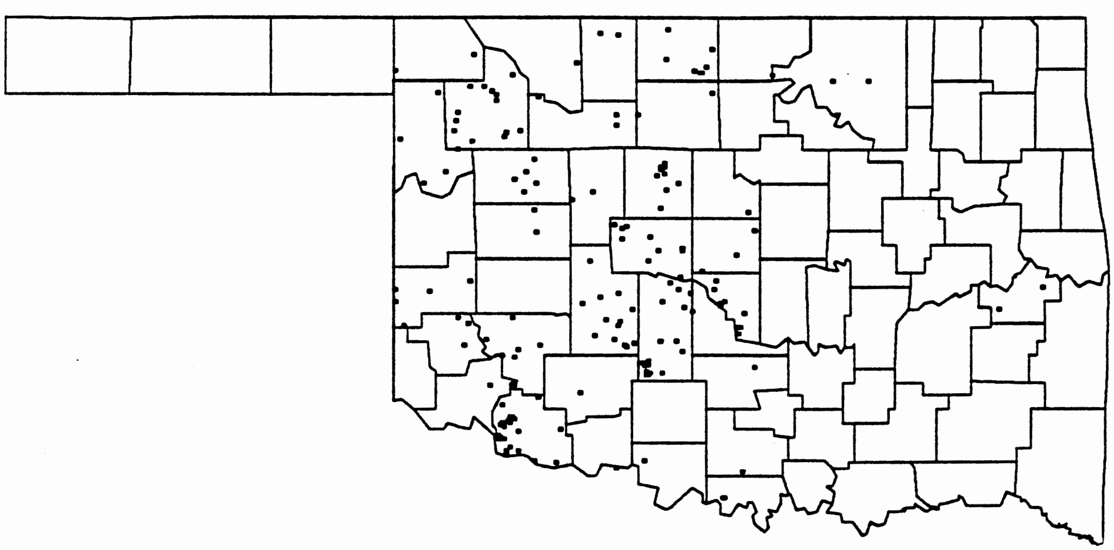


Figure 169. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 10 mg/l as N

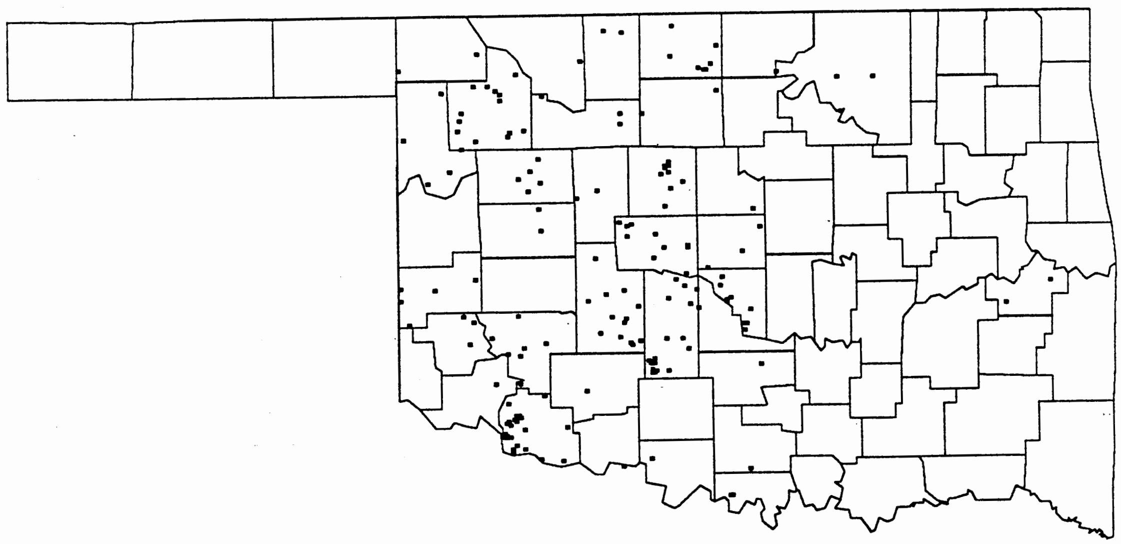


Figure 170. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as N, Equal to or Greater Than the 90th Percentile

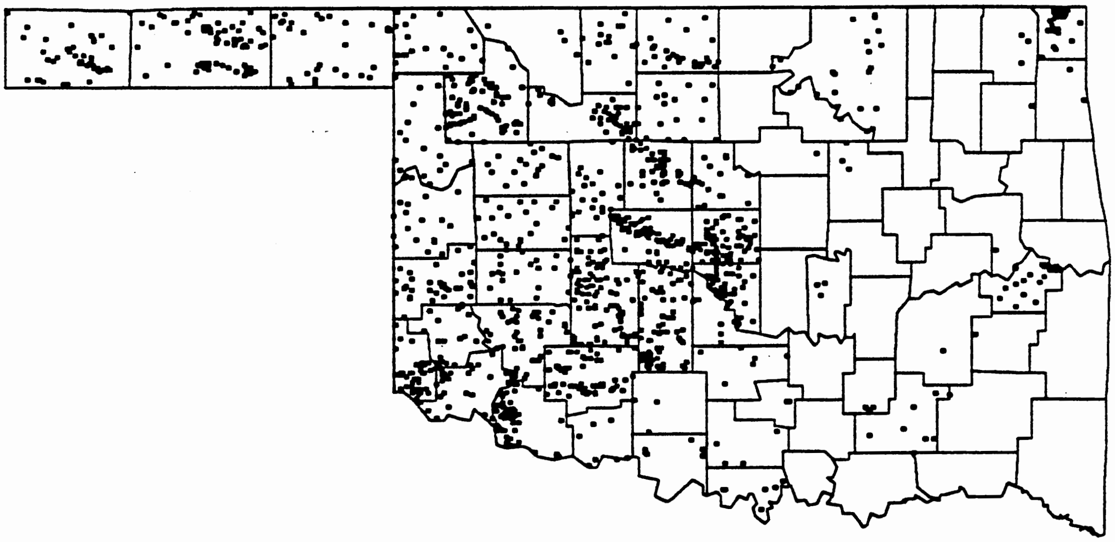


Figure 171. Oklahoma: Locations of Wells From Which Samples Were Collected and Analyzed for Nitrate as NO3

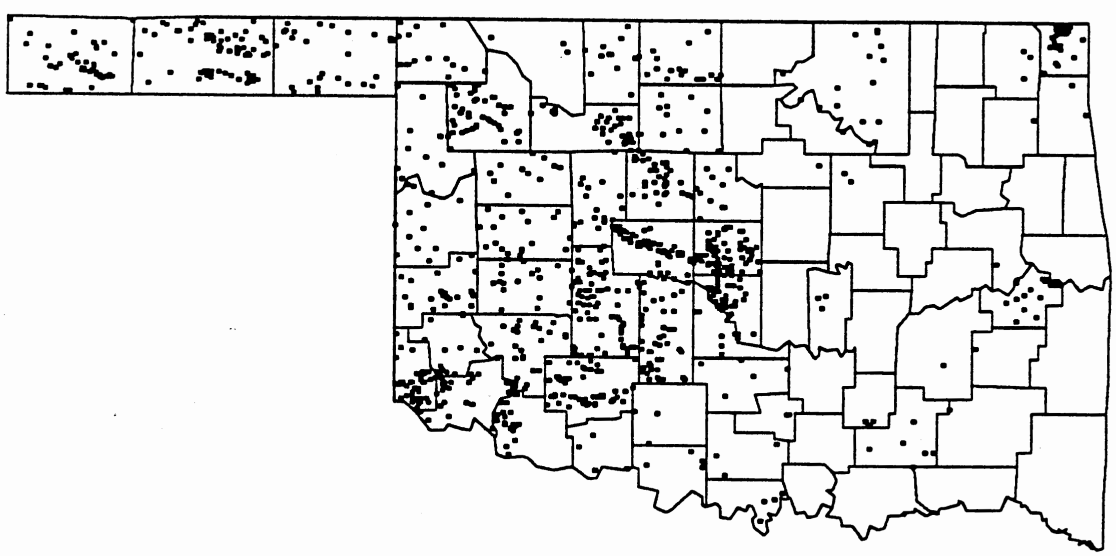


Figure 172. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Less Than or Equal to 25 mg/l as NO3

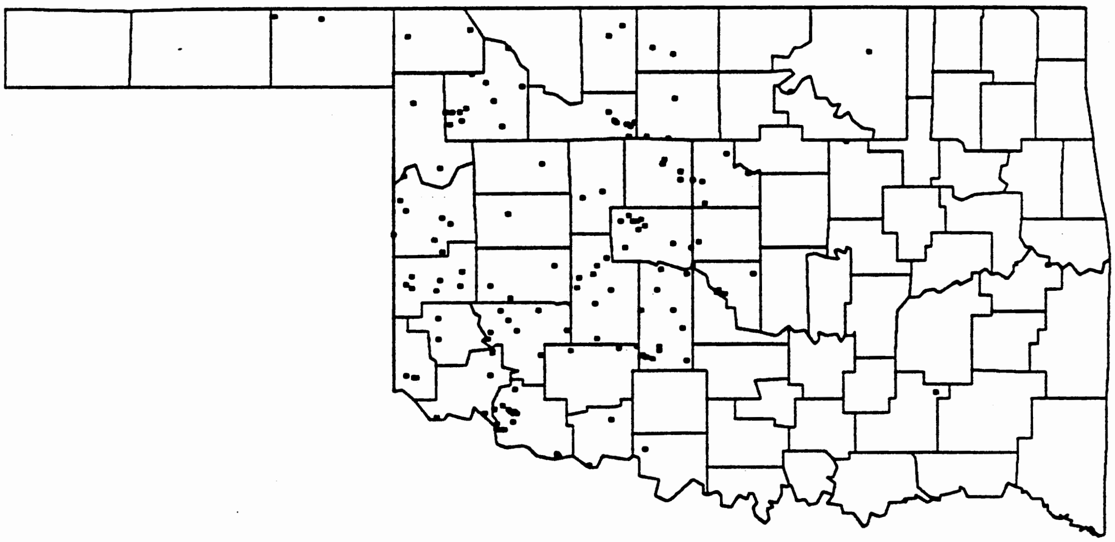


Figure 173. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 25 mg/l as NO3 but Less Than or Equal to 45 mg/l as NO3

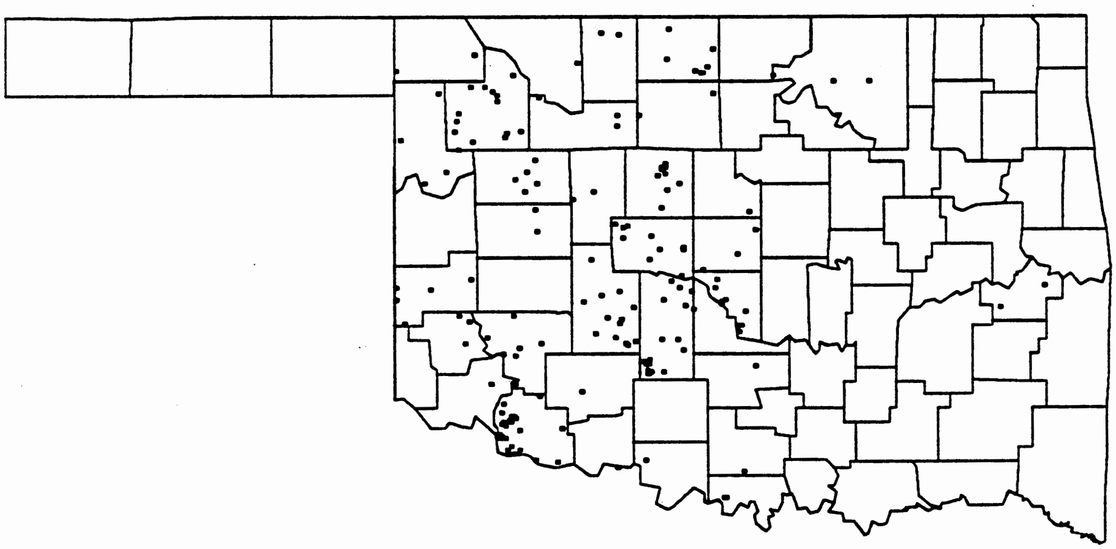


Figure 174. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations Greater Than 45 mg/l as NO3

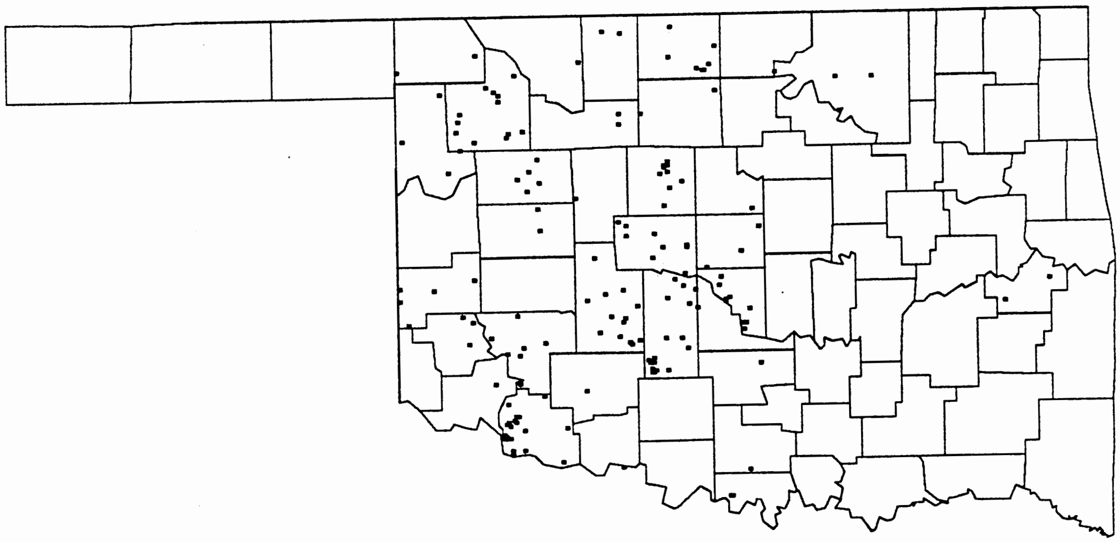


Figure 175. Oklahoma: Locations of Wells Where Water Contained Nitrate Concentrations, Measured as NO3, Equal to or Greater Than the 90th Percentile

CHAPTER VI

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to develop a practical method of obtaining and mapping ground water quality on a regional scale and to use this method to map selected ground water quality in North Dakota, South Dakota, Nebraska, Kansas and Oklahoma. The water analyses used for this investigation was obtained from the computer program Hydrodata QW. This program contains water quality data from the U.S. Geological Survey's National Water Data Storage and Retrieval System. This data base is widely considered to be one of the largest and accurate available. Once the data was accessed from Hydrodata QW, it was edited and mapped with the aid of desktop computers. The chemical parameters selected to represent the quality of the ground water was total dissolved solids, hardness, chloride, sulfate, and nitrate. All analyses were mapped by geographic location, by range of concentration in mg/l. Due to the relatively large aerial extent of the study area and vast quantity of data, the mapping scale of approximately 1: 5,000,000 was used. Since this study is most likely to used as a quick and general reference, this scale was selected because it will fit on commonly published standard letter size paper.

Conclusions

Based on the results of this the following conclusions may by made:

1) The Hydrodata QW program is considered to be an acceptable data base due principally to the relatively large number of analyses it contains and the quality control for accuracy instituted by the U.S. Geological Survey. Another attribute of the program is that water quality data can be obtained via a personal computer.

2) Deficiencies in the data base do exist. There are many analyses that do not include all major cations and anions, or measurements for organics or trace elements. A few well station locations are not accurately identified by the appropriate longitude and latitude. The number of analyses varies greatly from state to state.

3) The maps provide a general representation of the selected ground water quality in North Dakota, Nebraska, Kansas and Oklahoma. Due to the small number of analyses in South Dakota one can not gain a meaningful understanding of the ground water quality in that state.

4) A good understanding of basic DOS commands and fundamental operational procedures of both the PC and Macintosh computers is essential for timely execution for this type of data gathering and mapping

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APPENDIX

COMPUTER COMMANDS AND COMMENTS

Introduction

The following appendix itemizes the the steps and commands that were used in this investigation. Also included are pertinent comments. This procedure is divided into three main steps: (1) data base search, (2) analyses editing, and (3) mapping.

Computer Hardware

The computer hardware used for this investigation is as follows: (1) 386 IBM compatible personal computer (hereafter referred to as PC), with 40 megabyte hardrive and an optical disk drive (CD-ROM), (2) Macintosh IIci desktop computer (hereafter referred to as Mac) with a removable hardrive, and (3) Laser Writer II printer.

Computer Software

The computer programs used on the PC are as follows: (1) Hydrodata QW by Earthinfo, (2) Wordstar release 4 by MicroPro, and (3) SEP 100 by Kelly Goff. Programs used on the Mac are Apple File Exchange by Apple and Atlas MapMaker 4.5 by Strategic Mapping. It is assumed that all software is properly loaded on the appropriate hardrives.

General Information

The following table relates each step with the appropriate hardware and software.

Step	Software	Hardware
Data base search	Hydrodata QW	PC
Analyses editing	SEP 100	PC
Analyses editing	Wordstar	PC
Analyses editing	Apple File Exchange	Mac
Mapping	MapMaker	Mac

The following excerpt from the user's manual describes the a typical sequence with this program:

"Example: you start by selecting items from the Station, Analysis, and Parameter menus that define the set of data you want. When this query is set up, you start the program to search and filter the data with the criteria in your query. You review the resulting data, scrolling through the Long or Short report form. After deciding what further use you want to make of the information, you export the data from the optical disc to a hard-disk file, and quit the program to analyze it" (EarthInfo, 1989).

This program is relatively user friendly because it is operated by the selection of menu options. A single line message located at the bottom of monitor presents a status message, such as "parsing query" or "retrieving data." This status line states what input is expected by the program, or gives other useful information. When you choose a menu item, a selection box opens below it. Knowledge of some basic commands are required for use. It is recommended to consult the users manual for complete operation of this program. The following commands will allow one basic use of the program:

/	Accesses the menu bar.
Enter	Moves one down to a lower level.
ESC	1) Takes one out of the menu that one is in and moves one back 1 level. 2) Once at the main menu, ESC will return one to the menu screen one just came from.

	3) "ESC to abort" will appear in the message line when appropriate.
TAB	Moves between data windows in the Long and Short reports.
F1	Gets you to the help screen.
F5	Marks a selection.
F6	Unmarks a selection.
Arrow Up, Down Left, Right	Allows one to move about the menu and the Results list.

Computer commands are in bold face type. Comments are in regular type. "Selection" of an item is done by using the arrow keys. One can see that an item has been "selected" because it will be highlighted. One can see that an item has been marked because the letters will be white in color instead of black. The "open" command is done by striking the enter or return key. Items in quotation marks are words that actually appear on the screen when the program is in use.

Data Base Search

This Hydrodata QW program is written on compact discs (CD-ROM), therefore, the PC must have an optical disc drive. The following commands will access the Hydrodata QW program.

Turn on the PC computer
Turn on monitor
Turn on optical disc drive
Insert the CD containing ground water analyses for ND, SD, NB, KS, and OK

C> will appear, type the following:

C>CD CDSYS
C>MSCDEX /D:CDROM /L:L /M:2
C>CD
C>CD\CD\QUALITY
C>QUALITY

Enter
Enter

The Hydrodata QW title page will appear, then the menu will appear. The File menu will be highlighted.

How to set up a query.

Select the Station menu (by striking the arrow right key)
Open the Station menu (by striking the enter key)
A selection box will appear on the screen.
Select the Site Code category (by striking the arrow down key)
Open the Site Code category
A selection box will appear.
Select the Well (Groundwater) category
Mark the Well (Groundwater) category (by striking the F5 key)
Note: The program will search the data base for samples only taken from wells, not streams or springs or other sources.
Strike the (/) key
This will access the menu. The File menu will always be highlighted, after the (/) key is struck simply because it is the first one listed.
Select the Parameter menu
Open the Parameter menu
A selection box will appear.
Select the Parameter category
Open the Parameter category
The parameter list will appear, with both the parameter number and its description. The parameters are listed in order by parameter number.
The following is a list of the 20 parameters searched for in the data base.

Parameter Number	Parameter Description
00011	Temperature (degrees Fahrenheit)
00095	Specific Conductance (micromhos)
00440	Bicarbonate (mg/l)
00403	pH (standard units)
00618	Nitrate, dissolved (mg/l as N)
00900	Hardness, total (mg/l as CaCO3)
00915	Calcium, dissolved (mg/l as Ca)
00925	Magnesium, dissolved (mg/l as Mg)
00930	Sodium, dissolved (mg/l as Na)
00935	Potassium, dissolved (mg/l as K)
00940	Chloride, dissolved (mg/l as Cl)
00945	Sulfate, dissolved (mg/l as SO4)
00950	Fluorine, dissolved (mg/l as F)
00955	Silica, dissolved (mg/l as Si02)
01020	Boron, dissolved (mg/l as B)
01046	Iron, dissolved (ug/l as Fe)
70300	Dissolved Solids, residue on evaporation at 180 degrees C (mg/l)

71851	Nitrate, dissolved (mg/l as NO3)
72008	Depth of Well, total (ft)
72019	Depth Below Land Surface, water level (ft)

There are hundreds of parameters to choose from in this program. One can scroll through the list by using the arrow or page down keys. A simple and fast method of locating the desired parameters is by using the Locate menu.

After you have accessed the parameter list, get back to the menu by following command.

/

Select the Locate menu

Open the Locate menu

A selection box will appear.

Select the Find by Code (F3) Category

Open the Find by Code (F3) Category

A "Search Window" box will appear.

Type in the the parameter number for temperature, degrees F., which is 00011, Enter

The program will quickly search for the number and the parameter will appear highlighted on the screen.

Mark the temperature, degrees F. parameter (by striking the F5 key)

The letters will now be white, indicating a Marked parameter.

Access the menu

/

Select the Locate menu

Open the Locate menu

Select the Find by Code (F3) Category

Open the Find by Code (F3) Category

A "Search Window" box will appear.

Type in the the parameter number for specific conductance, which is 00095, Enter

Mark the specific conductance parameter

Continue repeating this process until all remaining parameters have been marked

Once all parameters have been marked access the menu

/

How to Save a Query

One data base file is to be constructed for each state in the study area. In order to save time this query containing samples obtained from wells and the 20 parameters listed above will be saved in the program and recalled to be ran in conjunction with a specific state. By saving this query one does not have reconstruct it five separate times. That is one time for each of the five states.

Select the File menu (it should already be highlighted when the menu was accessed)
Open the File Menu
Select the Save category
Open the Save category
A "Save" box will appear.
One can save a query or one can save a query and results.
The arrow key acts as a toggle switch for the two choices
Select the Query option
Strike the tab key to access the Filename window
Type in a filename for this query (PAR is one suggestion)
Note: Write this down. This is done so that you will know which query filename is associated with which query, if you have more than one.
Strike the Enter key
A box will appear stating the approximate size in kilobytes of the query.
Select yes and strike enter to save the query
The query containing samples obtained only from well and the 20 parameters are now saved to the program under the filename PAR.

How to Load a Saved Query

Select the File menu
Open the File menu
Select the Load category
Open the Load category
A "Load " box will appear.
One has the option of loading a query or one can load a query and results.
The arrow key acts as a toggle switch for the two choices.
Select the Query option
Strike the tab key to access the Filename window
Type in the filename, PAR
Strike Enter
The PAR query is now loaded.

Adding to the Query

Now that the PAR query is loaded we can add a geographic location filter such as Oklahoma. That is construct a query so that it will search for analyses that have been obtained from wells only located in Oklahoma and contain one or more of the 20 parameters selected.

Select the Station menu
Open the Station menu

A selection box will appear
Select the State category
Open the State category
The following states will appear: Alaska, Hawaii, Idaho, Kansas, Montana, Nebraska, North Dakota, Oklahoma, Oregon, South Dakota, Texas, and Washington.
Select Oklahoma (Do not strike Enter, just highlight Oklahoma)
Mark Oklahoma by striking F5
Access the menu.
/
The new query is complete.

How to Start a Query Search

Now that the query has been established, one can search the program for the desired analyses.

Select the Locate menu
Open the Locate menu
A selection box will appear
Select the Begin Search category
Strike Enter to start the search
The program will search the data base for the analyses that were defined by the query. This process will take about 26 hours for the state of Oklahoma. When the search is complete a message box will appear in the center of the screen stating, "The database search has completed, strike any key to continue".
Also on the screen a Results list will appear. The Results List contain the station name, station ID, number of analyses, and number of parameters.

Strike any key
Access the Menu
/
Select the File menu
Open the File menu
Select the Export category
Open the Export category
An Export box will appear.
The Export box will have four subcategories: "Export Results, File Type, Data Format, and Filename".
In the "Export Results" subcategory one has the option of exporting all the Results or only Marked Results.
Select "All"
In the "File Type" subcategory one has the option of ASCII, Binary, Card, dBase, or Lotus file formats.

Select "Card"
In the "Data Format" subcategory on has the option of Long Report, Short Report, or Results List.
Select "Long Report"
In the "Filename" subcategory type in the filename that will identify the analyses.
Type in C:OKLA
Strike Enter
A box will appear stating the approximate size of the file in kilobytes and a question asking if you wish to export this file.
Select yes
Strike Enter
The file has now been exported to the hardrive. Make sure that there is enough room on the hardrive to store this information.
Access the menu
/
Select the File menu
Open the File menu
Select the Quit category
Strike Enter
A box will appear asking if you wish to exit the program
Select yes
Strike Enter
The program has now been exited.
C> will appear.

Since these state files are so large (approximately 10 kilobytes) they must be edited and transfered to a floppy disk before the next state file can created.

Analyses Editing

SEP 100

The state file OKLA has been created on Hydrodata QW and transferred to the hardrive (drive C). The file must be edited and condensed.

With C> appearing on the screen, access SEP 100 by the following command:
C>SEP 100
The following question will appear on the screen: "Enter File Name?"
Type in OKLA
The program will locate and edit the file. Actually, two new files will be created; OKLA.ll and OKLA.dat.
C> will appear on the screen when this editing process is complete.

WordStar

The OKLA.ll and OKLA.dat files contain spaces that will not allow the MapMaker program to read them. With the use of WordStar these unwanted can be easily removed from the files.

With C> appearing on the screen, access WordStar by the following command:
C>WS

Editing the OKLA.ll file

The first step is to open a nondocument, by the following command:
Type in N
The following question will appear: "Nondocument to open?"
Type in OKLA.ll
Strike Enter
Type in ^QA
The following question will appear: "Find What?"
Strike the spacebar
Strike Enter
The following question will appear: "Replace with?"
Strike Enter
The following question will appear: "Option(s)?"
Type in GN
Strike Enter
The program will begin editing.
After the editing is complete,
Strike ESC
Strike Enter
Type in ^KD
This will save the edited OKLA.ll file
After the file has been saved the main menu will appear.

Editing the OKLA.dat file

The first step is to open a nondocument, by the following command:
Type in N
The following question will appear: "Nondocument to open?"
Type in OKLA.dat
The file will appear
Arrow down one line
Type in ^QA
The following question will appear: "Find What?"
Strike the spacebar
Strike Enter

The following question will appear: "Replace with?"
Strike Enter
The following question will appear: "Option(s)?"
Type in RN
Strike Enter
The program will begin editing.
After the editing is complete,
Strike ESC
Strike Enter
Type in ^KD
This will save the edited OKLA.dat file.
After the file has been saved the main menu will appear.
Strike X to exit WordStar
The OKLA.ll and OKLA.dat files have now been edited.

Transferring the OKLA.ll and OKLA.dat Files From the Hardrive to a Floppy

The files are now properly edited and are of a size so that they can be copied to a high density 3.5 inch floppy disk. The disk must be formatted in the usual manner.

Insert the formatted disk into drive B.
With C> appearing on the screen, type the following command:
C>COPY C:OKLA.ll B:
After this process is complete, type the following command:
C>COPY C:OKLA.dat B:
Both the OKLA.ll and OKLA.dat files should now be on the floppy disk.

Apple File Exchange

The OKLA.ll and OKLA.dat files were created on the PC, in a MS-DOS format. The MapMaker program is ran on a Macintosh computer. The Apple File Exchange program makes a MS-DOS file readable on a Macintosh computer.

Turn on the Macintosh computer
Access the Apple File Transfer program
A box titled "Apple File Exchange" will appear on the screen.
Insert the floppy containing the OKLA.ll and OKLA.dat files
The Macintosh HD (hardrive) directory will be on the left and the floppy disk directory will be on the right.
Select Text transaction from the MS-DOS to Mac menu
A box titled "For converting MS-DOS to Mac" will appear.
Select OK
A box titled "Apple File Exchange" will appear on the screen.
Select the OKLA.ll file from the floppy disk directory

Select Translate
Select the OKLA.DAT file from the floppy disk directory
Select Translate
The OKLA.ll and OKLA.dat files should now be in the Macintosh directory and ready for use on the Macintosh.
Select Quit from the Edit menu
The floppy disk should automatically eject.
The main menu should appear.

Mapping

MapMaker

The files are now readable on the Macintosh. The locations of the wells where the samples were taken are now ready to be mapped.

Access the MapMaker program
The menu will appear.

How to Convert a Text File to a Boundary File

Select Convert Boundary Files from the File Menu
A box titled "What do you want to convert?" will appear.
Select Text to MapMaker Boundary
Select OK
A box titled " In what form are your coordinates?" will appear.
Select Latitude/Longitude
Select OK
A box titled " What projection method do you want to use?" will appear.
Select None - use actual Lat/Long
Select OK
The Macintosh HD directory will appear.
Select OKLA.ll
Select Open
A box titled "MapMaker Boundary File:" will appear.
A box to type in a new file name is also on the screen.
Type in CONV-OKLA.ll
This will allow one to distinguish a converted .ll file and one that is not.
Select Save
The main MapMaker menu will appear.
There is no need to convert the OKLA.dat file because it is data file.

How to Create a Map

Select New under the File

A box titled "Specify the way you would like to use the map boundary files to create your map" will appear.
Select Combine Several Complete Files
Select OK
A box with the Macintosh HD directory will appear.
Select the MapMaker file
Open the MapMaker file
A box with the MapMaker directory will appear.
Select US Cnty Bndy
Open the US CNTY BNDY file
A box with the US County Boundary directory will appear.
Select OK Cnty LL Bndy
Open the OK CNTY LL BNDY file
A box titled "Select the layer to which you want to add boundaries" will appear.
Select the Based Map option (it should be highlighted)
Select Add Boundary
A box with the Macintosh HD directory will appear.
Select the CONV-OKLA.ll file
Open the CONV-OKLA.ll file
A box titled "Select the layer to which you want to add boundaries" will appear.
Select Done
A box will titled "Specify map size and position" will appear.
Select OK. use Rectangle
A county map of Oklahoma with all locations of wells that were sampled for the 20 parameters will appear.
Select Import Data from the File menu]
A box titled "Base map category and data values import options" will appear.
Select Category Names and Data Values option
A box with the Macintosh HD directory will appear.
Select the OKLA.dat file
Open the OKLA.dat file
The program will read the file and a map will appear.

As an example, the following commands will produce a map of Oklahoma with the locations of the wells where water contained chloride of less than or equal to 500 mg/l.

Select chloride under the Category menu
Select Data Divisions under the Assign menu
A box will titled "Assign data divisions" will appear.
In the Number of Divisions (1 - 35) category type in 1
In the Classification Method category select the Manual Entry option
A box titled "Specify Data Range for Division 1 of 1" will appear.
In the Minimum category type in 0

In the Maximum category type in 500
Select OK
The map will appear.
Select save from the File menu
Name the file OK GW Quality
The file contains all parameters. To map other parameters just select this file and change categories and/or concentration levels.

How to Print a Map

Select Page Setup under the File menu
A box titled "LaserWriter page setup will appear"
In the reduce or enlarge category type in 75
Select OK
Select Print under the File menu
A box titled "LaserWriter" will appear.
Select OK
The map will be printed.

Creating Data Base Files for Other States

Once one is assured that the edited .ll and .dat files contain the information desired and function properly, these files can be deleted from the PC hardrive. This will create the needed space to create the data base for another state.

VITA 2

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Candidate for the Degree of

Master of Science

Thesis: GROUND-WATER QUALITY OF NORTH DAKOTA, SOUTH DAKOTA, NEBRASKA, KANSAS AND OKLAHOMA

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