TEXAS DEPARTMENT OF WATER RESOURCES

REPORT 226

THE SEYMOUR AQUIFER

Ground-Water Quality and Availability in Haskell and Knox Counties, Texas

Volume I

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THE SEYMOUR AQUIFER

GROUND-WATER QUALITY AND AVAILABILITY IN HASKELL AND KNOX COUNTIES, TEXAS

VOLUME I

CONCLUSIONS

The Seymour Formation contains an important water-bearing unit in an irregularly shaped area in northwestern Haskell and southern Knox Counties, Texas. The Seymour aquifer is the only source of moderate to large supplies of fresh ground water within the area. No alternative fresh supplies exist from deeper formations. The aquifer underlies 274,500 acres and furnishes water to over 2,000 irrigation wells. Municipal, domestic, and stock supplies are also dependent on the Seymour.

The geologic and hydrologic character of the Seymour is quite variable. Typically, wells are 40 to 60 feet deep and are completed in the lower part of the formation which normally consists of sand and gravel. Well yields average 270 gallons per minute and are as high as 1,300 gallons per minute. Specific capacities of wells average over 50 gallons per minute per foot of drawdown. Saturated thicknesses are typically between 20 and 40 feet. Transmissivities range from 20,000 to over 300,000 gallons per day per foot and average 100,000 gallons per day per foot. Ground-water movement rates, unaffected by pumping, average between 800 and 1,200 feet per year.

Nearly all recharge to the Seymour is by direct infiltration of precipitation on the land surface. Analysis of pumpage, water levels, and precipitation over the past 20 years indicates that nearly 50,000 acre-feet per year is available for pumping by wells. Annual pumpage in recent years has ranged from about 25,000 acre-feet to about 65,000 acre-feet, averaging 40,600 acre-feet.

Water quality in the Seymour is variable. The dissolved solids content of natural water from individual wells ranges from about 300 milligrams per liter to 3,000 milligrams per liter. Most values are between 400 and 1,000 milligrams per liter. The best quality water is found in and adjacent to the more important recharge areas. Generally, water quality is satisfactory for irrigation purposes. Most water quality meets state standards for public supplies, except for nitrate content which commonly exceeds the limit of 45 milligrams per liter. Nitrate contents of Seymour water are typically from 30 to 90 milligrams per liter. Available chemical analyses and nitrogen isotope analyses indicate most of the nitrate in the Seymour results from leaching of natural soil nitrate due to cultivation.

The Seymour aquifer is susceptible to pollution from both surface and near surface sources. Over 3,200 past and present, actual and potential pollution sources exist on the Seymour. Most are only potential sources; actual sources are believed to number a few hundred. Existing pollution is due mainly to past pollution sources and activities, and not to current practices. Most existing pollution has been due to oil field brines and septic tank discharge.

It is estimated that about 2 percent of the water in the Seymour aquifer is affected by pollution. About 75 percent of the existing pollution is estimated to be due to the former disposal of oil field brine into unlined surface pits. An estimated 20 percent has been caused by leaky injection wells and unplugged, abandoned holes. About 4 percent of the existing pollution results from septic tanks, while miscellaneous sources are responsible for 1 percent. Little effect on water quality results from return flow of irrigation water, evapotranspiration, or agricultural application of fertilizers and pesticides.

The portions of the aquifer affected currently by pollution are relatively localized. The portions of the aquifer affected by pollution will increase in the future due to the natural movement of ground water and to the spreading effects caused by pumping wells. However, portions of the aquifer affected by significant pollution will not become extremely large in the future. Significant future pollution problems will be confined mostly to individual properties as opposed to large areas of the aquifer.

Correcting existing pollution can take years, or even decades, and can be very costly. Thus, prevention rather than correction is most important in dealing with ground-water pollution. For past pollution sources, it is possible only to control the resulting pollution plumes either by removal or avoidance measures. Pollution removal measures involve pumping by wells to remove the pollutants from the aquifer. Typically, this is impractical because of the large volumes of water that must be pumped, the relatively long periods of time required, and problems regarding disposal of the pumped water. Avoidance methods include relocating wells affected by pollution or selective pumping and blending to obtain a quality of water that can be used. These can be effective methods if the pollution is not severe or if the property involved is large, and sufficient quantities of unpolluted water can be obtained.

INTRODUCTION

Purpose

This report describes the ground-water resources of the Seymour aquifer in Haskell and Knox Counties, Texas. Emphasis is on water quality, but important availability information is included. The investigation began in 1975 at the request of the Texas Department of Water Resources and citizens of Haskell and Knox Counties. The primary objective of the investigation was to gain a comprehensive understanding of:

1) the water quality in the Seymour aquifer;

2) the past, present, and potential sources of pollution to the aquifer due primarily to mineralized water; and,

3) the future quality and availability of water from the aquifer.

Volume I contains text and related illustrations and tables describing the quality and quantity of the ground-water resources of the Seymour aquifer. It includes an explanation of the geology as related to the occurrence of ground water, the ground-water conditions in the Seymour, ground water in other formations, and pollution in the Seymour. Provided in Volume I is information intended to aid in obtaining maximum benefits from the Seymour aquifer and to assist regulatory agencies in protecting the aquifer from pollution.

Volume II contains supporting basic data consisting of maps and tables including: 15 well location maps; records of 2,058 water wells; records of water levels in 93 wells; results of chemical analyses of 2,197 water samples plus 11 tables containing results of over 200 additional chemical analyses on various specialized samples; 240 drillers' logs; descriptions of geologic samples from 16 surface localities and 4 wells; results of sieve analyses of formation samples; a cross-index of previously published well numbers; a list of available aerial photographs; and information on production and disposal of oil field brines.

Scope

Compilation of Previous Data

The first phase of the investigation consisted of compiling previous geologic and hydrologic reports for the area. These were obtained from many sources, but primarily from the U.S. Geological Survey, Texas Department of Water Resources, Bureau of Economic Geology, and Texas Railroad Commission. The work included compilation of unpublished data on water wells, oil tests, and fluid injection wells, primarily from the files of the Texas Department of Water Resources, U.S. Geological Survey, Texas Department of Health, and Texas Railroad Commission. Climatic data including temperature, precipitation, and evaporation records were obtained from the National Weather Service.

Literature Survey on Effects of Nitrate

A survey of the more readily available literature on the effects on humans and livestock of consuming water with high nitrate levels was conducted. Over 150 published reports and articles were reviewed for this phase of the investigation. The results of the survey are included as an appendix to Volume I.

Water Well Inventory

A field inventory was made to obtain information on water wells and to update existing information where necessary. Approximately 1,200 previous well schedules were updated, and approximately 800 wells were scheduled which had not been inventoried previously. Special efforts were made to locate all wells for which important previous data were available. Many of the earlier records were found to be particularly significant because they include historical water quality data and water-level information. Only a small percentage of those wells previously scheduled could not be located during the field work.

Wells inventoried include all public supply and industrial wells. In addition, selected wells used for irrigation, stock, and domestic supply were scheduled to provide representative coverage. All wells scheduled were located and assigned elevations based on 7½-minute topographic quadrangles with 5-foot or 10-foot contour intervals. In addition, all irrigation wells were located on 7½-minute topographic maps, and the type of power used for each irrigation well was noted. This step provided information on the number and distribution of irrigation wells powered by electricity, butane, or natural gas.

Geology

The surface geology of the Seymour and Permian rocks adjacent to the Seymour was inspected in the field, and descriptions were prepared for the outcrops studied. Also, drillers were interviewed regarding the subsurface conditions encountered in the Seymour and in underlying zones. The drilling of four Seymour wells was observed, and geologic descriptions of the sediments encountered were prepared. Formation samples from the 4 drilling sites and from 12 outcrop localities were collected, and sieve analyses were made on 27 samples. Drillers' logs for 240 wells were reviewed. To study the geology of the Permian rocks underlying the Seymour aquifer, 23 electric logs and 6 sample logs were obtained for selected oil tests.

Hydrology

In order to determine 1-hour specific capacity, transmissivity, and permeability, 11 pumping tests were conducted, and 13 prior test results were analyzed. Records of pumpage were obtained, and estimates were made of the groundwater withdrawals from the Seymour. Records of municipal and industrial pumpage were obtained from the Texas Department of Water Resources or from well owners. Irrigation pumpage was estimated by field counts of electrically-powered and gas-powered wells, by obtaining power figures from three electric utility companies which serve the area, and by tests on 45 wells to determine the amount of water pumped per unit of power consumed. Estimates were made of pumpage for rural, domestic, and livestock use.

Records of past water levels in wells were obtained from the Texas Department of Water Resources, the U.S. Geological Survey, well owners, and drillers. Water-level measurements were made on approximately 450 wells during January 1977 to define conditions. Seasonal water-level fluctuations were investigated through the use of two continuous water-level recorders operated during the period 1975–1977. One of the recorders was in the vicinity of Munday; the other in the vicinity of Rochester. Records for 93 water-level observation wells were obtained and evaluated.

The direction and rate of ground-water movement in the Seymour aquifer were estimated. Also, maps of the water table, the base of the aquifer, and the saturated thickness were prepared. The amount of water in storage in 1977 was estimated and compared to the amount in storage 20 years ago. Also, estimates of the annual availability of water were made.

Water Quality

Extensive sampling of water wells was done to obtain representative water quality for both Seymour and Permian wells. Over 1,100 water samples from wells and springs were collected and analyzed. In addition, the results of approximately 1,100 previous chemical analyses were obtained, primarily from records of the Texas Railroad Commission, the Texas Department of Health, the Texas Department of Water Resources, and the U.S. Geological Survey. Also, approximately 200 samples were obtained for analysis of special constituents such as pesticides, nitrogen cycle, and nitrogen isotope, or for analysis of water from special sources such as springs, creeks, bailed samples from wells, consecutive samples from wells, sewage effluent samples, oil field brine samples, and formation sample extracts.

The water quality section of this report presents the current water quality in the Seymour, includes comparisons useful in identifying water pollution, and provides a basis for detecting future changes in water quality.

Man's Effects on Water Quality

An important part of this investigation was an appraisal of the effects of man's activities on the water quality in the Seymour aquifer. An extensive pollution source inventory was made. Past pollution sources were located with the aid of aerial photographs of varying dates from 1939 to 1970, pollution complaint files of state agencies, and Texas Railroad Commission files on saltwater disposal and fluid injection operations. Existing pollution sources were located from these same sources, as well as from topographic maps, ownership maps, and visual field inspections. Over 3,200 past and present, actual and potential pollution sources on the Seymour were inventoried and located on 7½-minute topographic maps.

From the information obtained, the more significant past and present sources of mineralized water pollution to the Seymour were evaluated. The indicated areal extent, severity, and probable sources of the present pollution were studied. Future movement and effects of past pollution sources were evaluated. Also, methods to control and deal with pollution of the aquifer are presented.

Planning Sessions

Periodic planning sessions were held during this investigation with personnel from state agencies and a seven-member citizens' advisory committee. The state agencies involved included the Texas Department of Water Resources (and its predecessor agencies, the Texas Water Quality Board and Texas Water Development Board), the Texas Railroad Commission, and the Texas Department of Health. The progress of the investigation was reviewed during the meetings, and ideas for data collection and analysis were discussed. The meetings helped tailor the investigation to correspond to the needs of the citizens of Haskell and Knox Counties and to the planning and regulatory functions of the state agencies involved.

Area of Investigation

The investigation focused on that part of the Seymour Formation located principally in southern Knox and northwestern Haskell Counties as shown on Figure 1. Very small portions of southwestern Baylor County and eastern Stonewall County were covered, also. The area represents a single hydrologic unit of the Seymour aquifer covering approximately 274,500 acres.

The area is approximately 60 miles north of Abilene and 75 miles southwest of Wichita Falls. It is located in the Brazos River Basin; the Brazos River is located immediately to the north and west of the area studied.

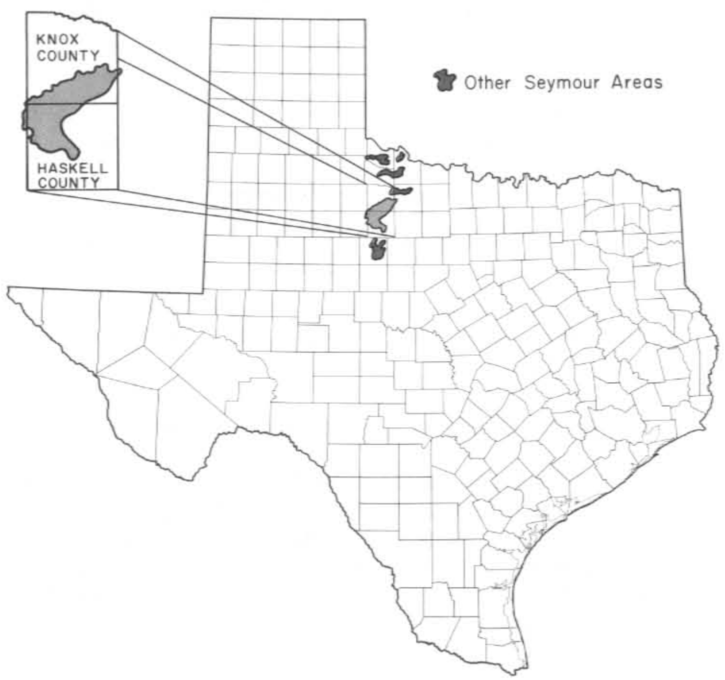

Figure 1. Location of Area

The area immediately surrounding the Seymour aquifer in Haskell and Knox Counties was studied also during the investigation. The surrounding area was investigated principally from geologic and water quality standpoints to better understand the water quality in the Seymour aquifer, to help determine the extent to which fresh water is present in the Permian formations, and to determine the relationship of the Permian formations to the Seymour aquifer.

Population

The Seymour aquifer is of major importance to the population and economy of the area. It is the only available source of large quantities of fresh water. Throughout the 1900's, people have depended on the Seymour for fresh water for domestic and stock use and, more recently, as a supplemental irrigation supply.

The estimated population living on the Seymour Formation from 1890 to 1973 is shown in Figure 2, together with a comparison of rural and urban population. The population figures are estimates, based on city and county population data obtained from the U.S. Bureau of Census and adjusted to the area of the Seymour aquifer.

Small groups of pioneers began settling the area in the mid-1800's, but the area remained sparsely populated until the very early 1900's. Between 1900 and 1910, the population rose rapidly. Approximately 10,000 people moved into the area during this period. The population peaked at about 14,000 in the 1950's, and is currently slightly less than 11,000.

The communities and towns on the Seymour include:

	1973 Population
Goree	538
Haskell	3,650
Knox City	1,750
Munday	1,925
O'Brien	250
Rhineland	196
Rochester	529
Rule	1,024

Except for Rhineland, which does not have a public water supply, all the towns listed obtain their municipal supplies from the Seymour aquifer, currently. Three other towns, Aspermont, Benjamin, and Weinert, receive their municipal water supplies from the area, also.

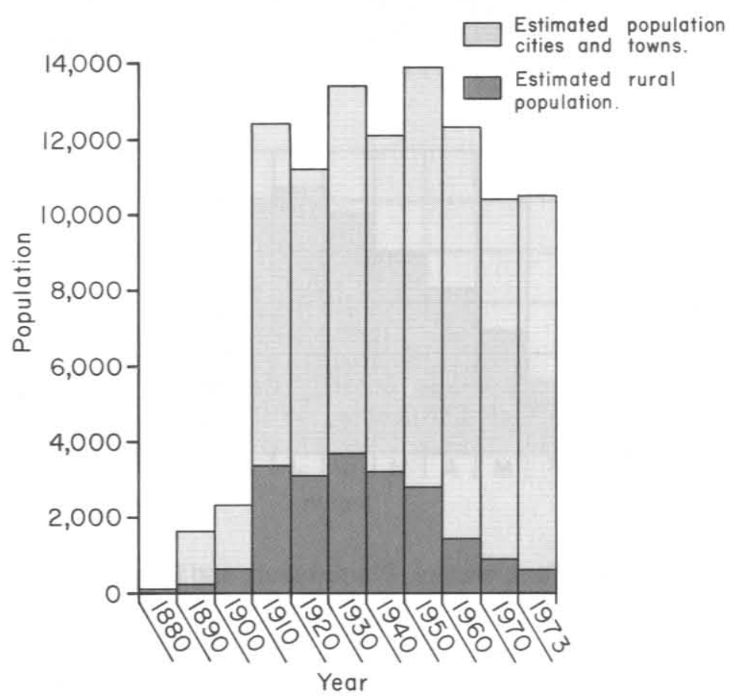

Figure 2. Estimated Population on Seymour Formation

Recently, the North Texas Water Authority constructed Millers Creek Reservoir. The reservoir will yield approximately 5,000 acre-feet per year and will be the source of water for Munday, Goree, Haskell, and Knox City.

Economy

The primary income in Haskell and Knox Counties comes from farming and ranching (See Figure 3). In 1976, $48,000,000 or 69 percent of the total annual income was attributed to farming and ranching (*Dallas Morning News*, 1975). Mineral production, primarily oil and gas, accounted for 20 percent or $14,000,000 of the total income in 1976. Small businesses, mostly associated with agriculture such as grain, fertilizer, and farm equipment, and other businesses associated with urban activities such as food, clothing, real estate, and insurance, comprised the remaining 11 percent of the total income of Haskell and Knox Counties in 1976.

Climate

The Seymour area is in the eastern half of the Low Rolling Plains. The area is characterized by precipitation maximums

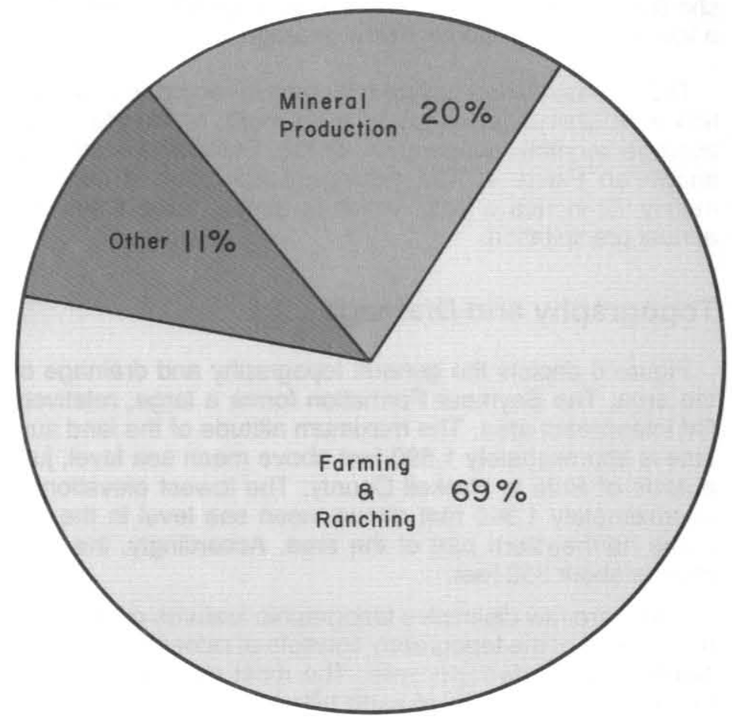

Figure 3. Income Sources in Haskell and Knox Counties

in late spring and early fall, mild winters, and very warm summers. Figure 4 shows the average monthly temperature at Munday, the average monthly precipitation at Haskell and Munday, and the monthly evaporation at Chillicothe. The average monthly temperature reaches a maximum in July of 85 degrees Fahrenheit (°F). The growing season in Knox County lasts approximately 217 days from approximately April 3 to November 6. Haskell County has one of the longest growing seasons in the northwestern half of Texas of approximately 232 days. The average date of the first freeze in the fall is November 15.

Figure 5 shows the annual precipitation at Munday and Haskell since the early 1900's. The average annual precipitation is 24.7 inches at Munday and 24.3 inches at Haskell. The annual precipitation is quite variable, ranging from a maximum in 1942 of almost 50 inches to a minimum in 1956 of approximately 10 inches.

More than 75 percent of the precipitation occurs typically during the period of April through October, coinciding with the growing season in the area. The heaviest rainfall occurs typically in May when between 3 and 4 inches fall. During winter months, the precipitation averages between 1 and 2 inches per month.

Figure 5 illustrates past precipitation trends for the area. Some of the wetter and drier periods are indicated on the graph. The 1944–1955 period was very dry, especially after 1950. The precipitation was above average in only three years of the 11-year period. The period 1957–1976 was characterized by average or above average rainfall with only a few years being slightly below average.

The closest station having a long-term record of evaporation is at Chillicothe about 55 miles north of Munday. The average monthly evaporation at the Chillicothe station is shown on Figure 4. The average evaporation is approximately 72 inches a year, which is almost three times the annual precipitation.

Topography and Drainage

Figure 6 depicts the general topography and drainage of the area. The Seymour Formation forms a large, relatively flat interstream area. The maximum altitude of the land surface is approximately 1,690 feet above mean sea level, just outside of Rule in Haskell County. The lowest elevation is approximately 1,340 feet above mean sea level in the extreme northeastern part of the area. Accordingly, the total relief is about 350 feet.

There are few distinctive topographic features on the Seymour. Most of the topography consists of rather flat surfaces sloping 8 to 10 feet per mile. The most prominent feature in the area is a group of sand hills located in the western part of the area in 1-degree quadrangle 21–41 and adjoining parts of adjacent quadrangles. Also, there is normally a significant topographic drop along the border of the Seymour.

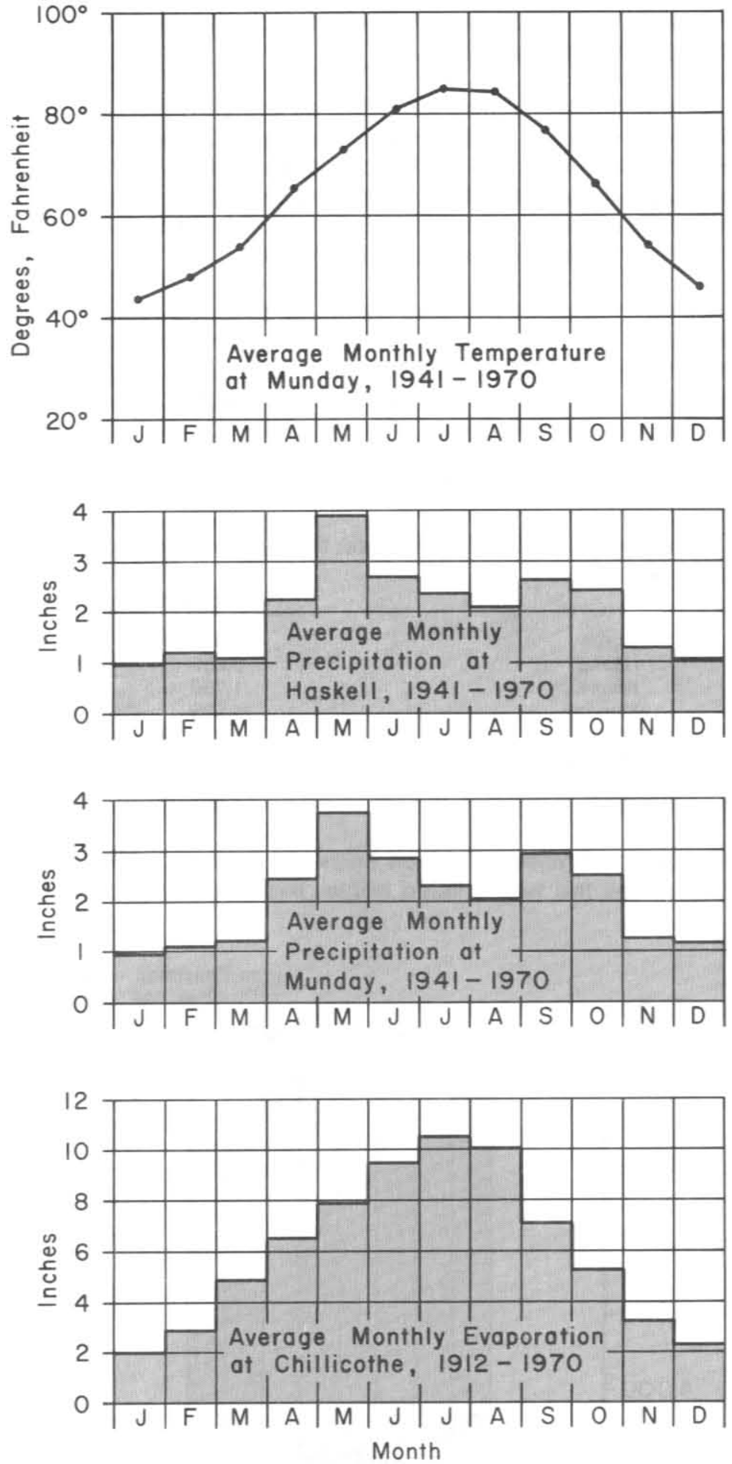

Figure 4. Temperature, Precipitation, and Evaporation

Another significant, but more subtle feature is a small topographic break which separates the Seymour into two sections as shown on Figure 7. The topographic break separates older Seymour deposits to the south and east from younger Seymour deposits to the north and west. The break represents an episode of valley deepening which was followed subsequently by alluviation. The younger deposits occur beneath a terrace extending along the northern and northwestern edge of the area in a belt approximately 4 miles wide.

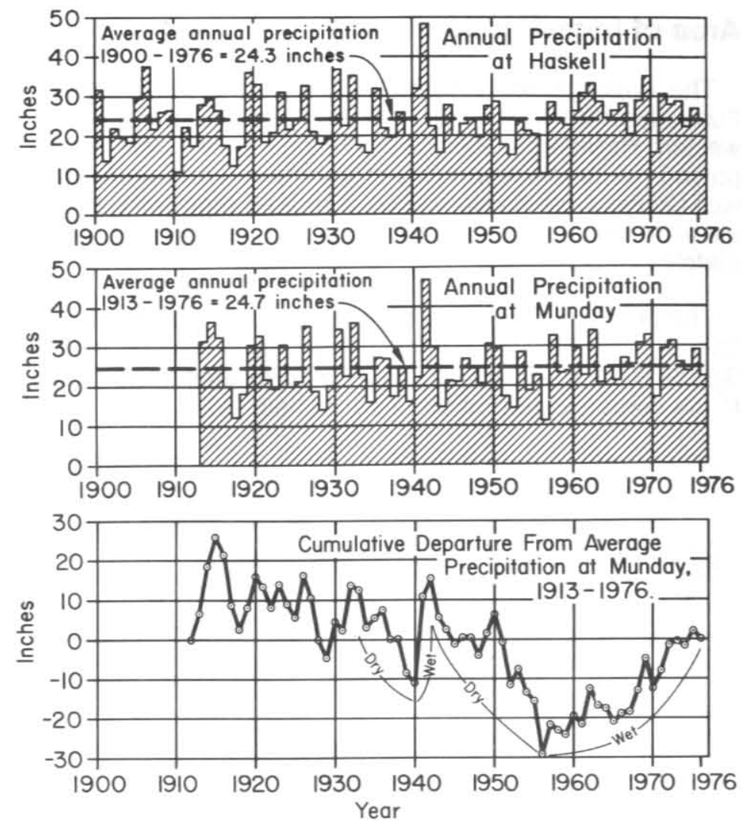

Figure 5. Precipitation at Munday and Haskell

The outcrop of the Seymour is characterized by a general lack of surface drainage. A few drainages are located near the edge of the formation. These are mapped on Figure 6. Most of the creeks in the area are intermittent with the exception of a few such as Wild Horse Creek. Wild Horse Creek, which is spring-fed, flowed several hundred gallons per minute during the summer of 1976. Other spring-fed creeks include Union Creek and China Branch in the northwestern part of the area and Rice Springs Branch at Haskell. Each flowed only a few gallons per minute in the summer of 1976. Results of chemical analyses of water from creeks are given in Table 21.

Land Use

Figure 8 illustrates the land use on the Seymour Formation. Of approximately 274,500 acres comprising the Seymour Formation, an estimated 265,000 acres (97 percent)

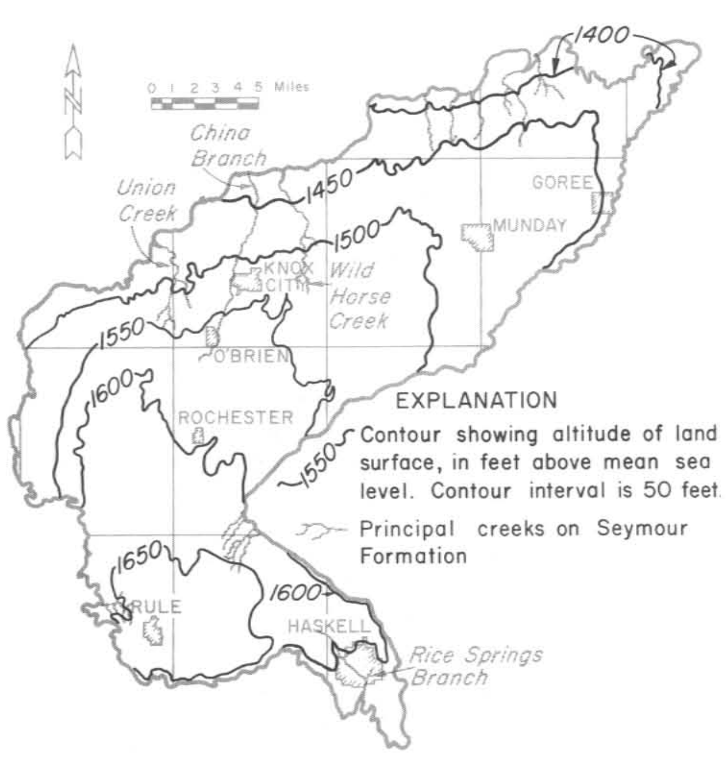

Figure 6. General Topography and Drainage

are used for farming. Approximately 105,000 acres (39 percent) are used for irrigation farming. In many instances, only supplemental irrigation is practiced. About 160,000 acres are used for dryland farming. Approximately 2,800 acres are used for ranching. The remaining 6,700 acres include homesteads, roads and other transportation facilities, and areas associated with oil production.

Until the late 1800's, the land use on the Seymour Formation was limited to ranching. Local residents report that originally the area was a treeless grassland with thick native, "stirrup high" grasses. Brush and trees occurred only along the principal creeks and along those edges of the Seymour bordering the Brazos River and Lake Creek.

Beginning in approximately 1890 and continuing until 1910, farming became a major activity in the area. Most all of the land was cultivated initially during this period and essentially has been cultivated continuously to the present. The major crops harvested in Haskell and Knox Counties in 1976, according to the Texas Department of Agriculture (1975 and 1976), included:

Crop	Yield
Wheat	4,013,000 bushels
Oats	221,100 bushels
Sorghum	2,305,000 bushels
Guar	2,866,000 pounds
Cotton	66,200 bales

Melons, potatoes, and other vegetables are grown in the area, also.

Two types of irrigation are used in the area. Row irrigation is prevalent on the flatter, gently sloping land. Sprinkler irrigation systems are used on sandier land and on the rolling topography.

Previous Investigations

The earliest report containing information on ground-water conditions for the Seymour is by Gordon (1913). Well records and chemical analyses of water are included in the Gordon report for a few wells. Later, Huggins and Turner (1937) conducted an extensive well inventory of Knox County. Their report includes records of 550 wells and test holes, approximately 185 chemical analyses of water, and logs of 22 test holes.

A preliminary report on ground-water resources by Broadhurst and Follett (1944) contains records of wells, chemical analyses, and water-level data for an area between Rochester, Rule, and Haskell. Public water supplies at Haskell, Rochester, Rule, Goree, Knox City, and Munday were investigated a few years later by Sundstrom, Broadhurst, and Dwyer (1947).

Ogilbee and Osborne reported on the ground-water resources of Haskell and Knox Counties in 1962. Their report contains records for over 1,100 wells, describes conditions as of 1957, and contains chemical quality data on 163 wells in Haskell and Knox Counties.

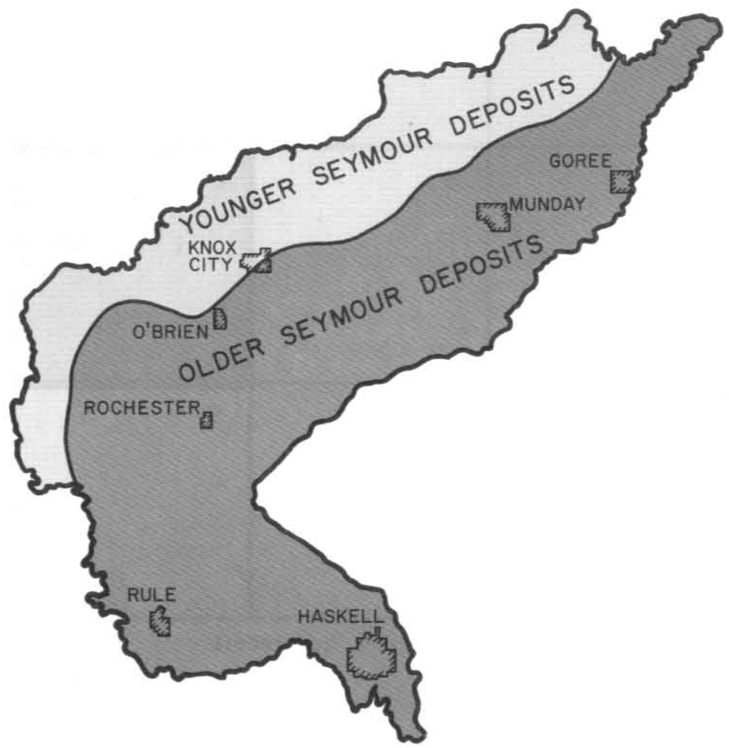

Figure 7. Seymour Units

Several other brief or specialized reports have been made on parts of the area. These include reports on water-level measurements and reports dealing with poor quality or contaminated water in the Seymour. All of these are listed in the bibliography of this report.

Basic data on wells from all past reports were incorporated into this report if it was possible to locate the wells in the field during this investigation. Table 31 is an index of identifying numbers for such wells.

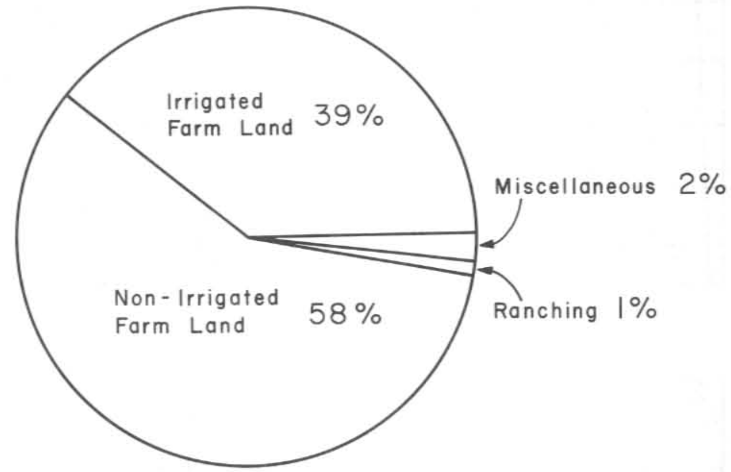

Figure 8. Land Use for Seymour Formation

Well-Numbering System

The well-numbering system used in this report is one adopted by the Texas Department of Water Resources. The system, as shown in Figure 9, is based on longitude and latitude. It facilitates the location of wells and prevents duplication of well numbers. Each well is assigned a seven-digit number which is derived as follows.

The State is divided into 1-degree quadrangles of latitude and longitude. There are 89 such quadrangles numbered 01 through 89. Each 1-degree quadrangle is subdivided into 7½-minute quadrangles numbered 01 through 64. Finally, each 7½-minute quadrangle is subdivided into 2½-minute quadrangles numbered 1 through 9. Within these 2½-minute quadrangles, each well is assigned a two-digit number beginning with 01.

The first two digits of each well number identify the 1-degree quadrangle. The third and fourth digits indicate the 7½-minute quadrangle. The fifth digit identifies the 2½-minute quadrangle. Together, the sixth and seventh digits identify the well within the 2½-minute quadrangle.

In addition to the seven-digit well number, a two-letter prefix is used to identify the county in which the well is located. The county prefixes used in this report are:

Prefix	County
AU	Baylor
LP	Haskell
RS	Knox
XR	Stonewall

For example, well RS 21-35-609 is in Knox County (RS); 1-degree quadrangle 21; 7½-minute quadrangle 35; 2½-minute quadrangle 6; and was the ninth well (09) inventoried in that 2½-minute quadrangle.

The area studied in this report is in that part of Texas covered by 1-degree quadrangles 21 and 22. Figure 10 shows the 1-degree and 7½-minute quadrangles within the primary study area. Well locations within each 7½-minute quadrangle are shown on Figures 58 through 72. On the location maps, the 2½-minute quadrangles are not shown, but their notation occurs as the first digit of the three-digit number adjacent to each numbered well location.

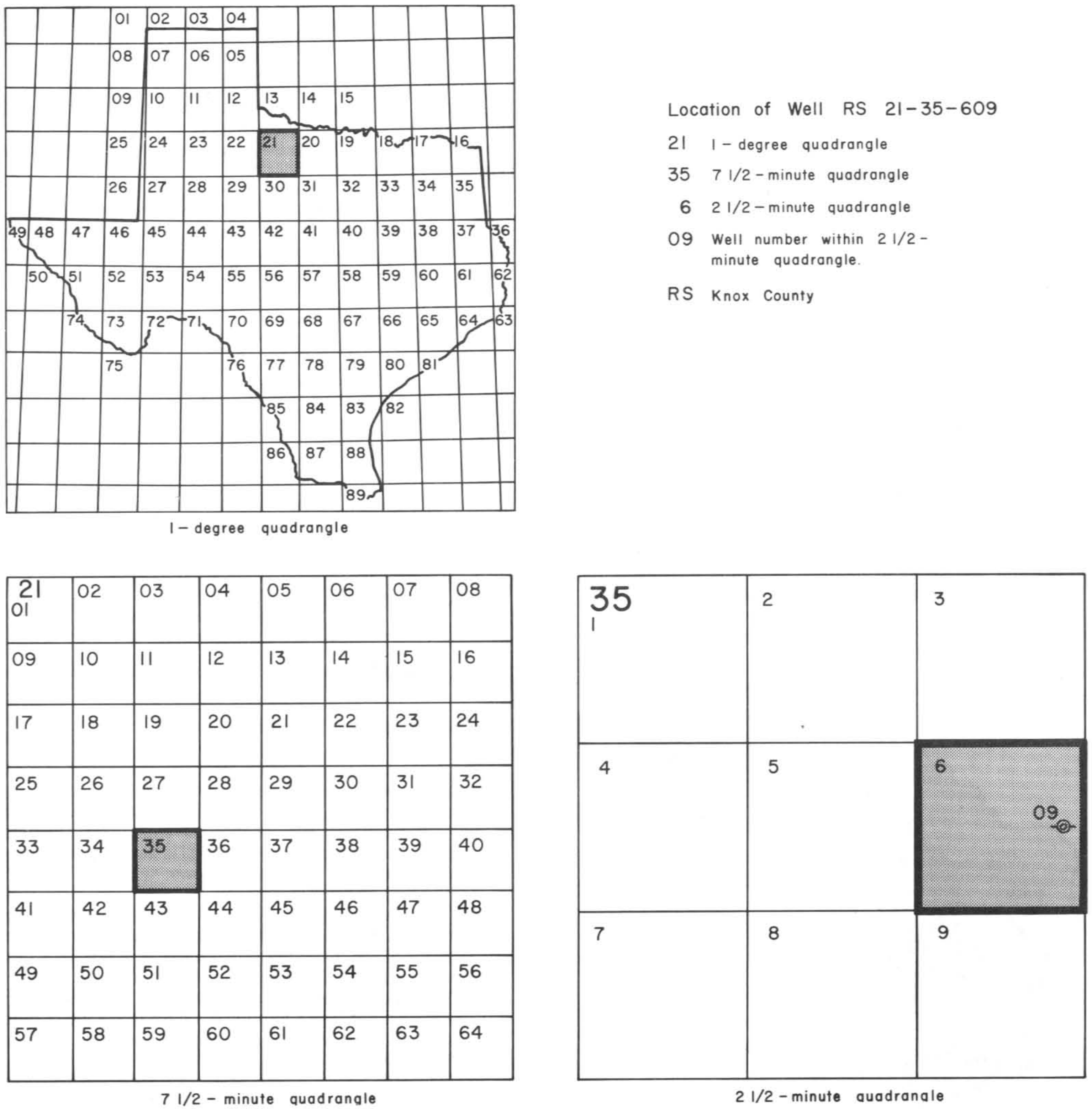

Figure 9. Well-Numbering System

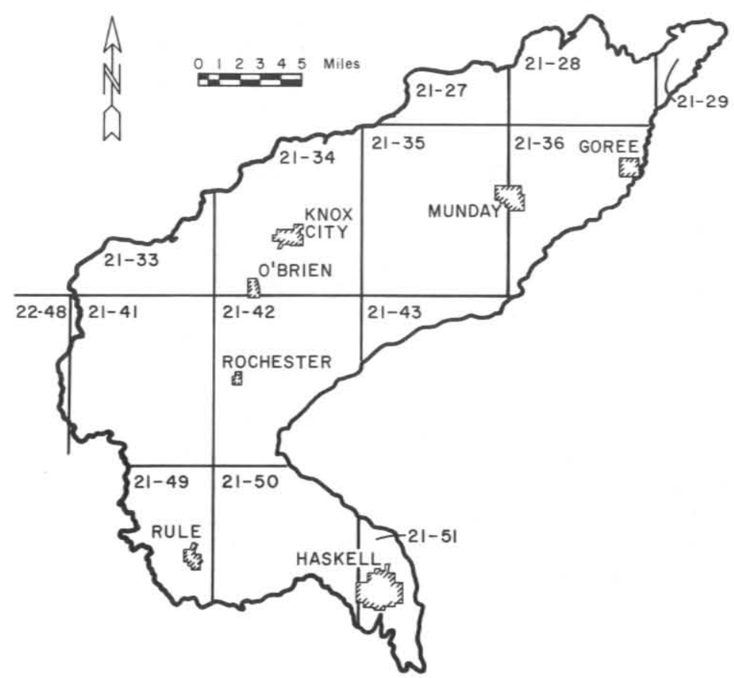

Figure 10. 7½-Minute Quadrangle Numbers

Acknowledgements

Sincere thanks are extended to the landowners, farmers, and municipal officials of Haskell and Knox Counties for their assistance and cooperation in providing information concerning the ground-water conditions and for allowing access to property in order that sampling and testing could be performed.

Particular recognition is due the Citizens' Advisory Committee for their continuing interest and helpful advice throughout this project. The committee included M. L. Wiggins, Callie Ann Combs, Clint Norman, Calvin Christian, Ted Alexander, A. A. Cox, and Joe Cloud.

Special thanks are given to Helen McClure, Clarence Brown, Wayne Speck, and Earl Avis for permitting the construction and maintenance of water-level recorder stations on their property.

Finally, appreciation is expressed to those individuals in the following organizations who provided assistance, data, and expertise in their respective fields: Texas Department of Water Resources, Austin; Texas Highway Department, Austin; U. S. Geological Survey, Austin; Texas A&M University, College Station; Texas Department of Health, Austin; Bureau of Economic Geology, University of Texas, Austin; Texas Railroad Commission, Austin, Wichita Falls, and Abilene; Environmental Protection Agency, Dallas; University of Texas Southwestern Medical School, Dallas; West Texas Utilities, Stamford; B-K Electric Cooperative, Seymour; Stamford Electric Cooperative, Stamford; Federal Land Bank Association, Haskell; Soil Conservation Service, Haskell and Knox Counties; Agricultural Stabilization and Conservation Service, Haskell and Knox Counties; Texas A&M Vegetable Research Center, Munday; and Hise Welding and Drilling Company, Haskell.

GENERAL GEOLOGY AS RELATED TO THE OCCURRENCE OF GROUND WATER

Those geologic units important to the occurrence of fresh ground water include rocks of Permian age and sediments of Pleistocene and Recent age. Figure 13 shows the general surface extent of the units. A summary of the important units and their water-bearing properties is included in Table 1. The relationship of the Clear Fork Group, the Seymour Formation, and the younger terrace and alluvial deposits is shown on Figures 11 and 12.

Rocks belonging to the Clear Fork Group of Permian age underlie the entire area. The Clear Fork consists predominately of red shales and silty shales with a very few, thin beds of dolomite, sandstone, siltstone, and gypsum. Typically, shales of the Clear Fork are referred to as "red beds" by drillers, but sometimes they are described as "birds-eye clay" due to the presence of green spots, caused by iron reduction, in the otherwise red shales.

Table 1. Geologic Units and Their Water-Bearing Properties

Unit	Area of Occurrence	Maximum Thickness	Principal Composition	Number of Wells in Unit According to Table 11	General Water-Bearing Properties
Younger terrace deposits and river alluvium	Along and in the present valley of the Brazos River at altitudes lower than the Seymour Formation	40 feet	Gravel, sand, silt, and clay	4	Yields small to moderate quantities of fresh to mineralized water.
Younger Seymour deposits	See Figure 7	65 feet	Gravel, sand, silt, and clay	1,913	Important aquifer with well yields ranging up to 500 gpm. Water is of satisfactory chemical quality for most purposes.
Older Seymour deposits	See Figure 7	94 feet	Gravel, sand, silt, and clay		Principal aquifer in Haskell and Knox Counties. Well yields range up to 1,300 gpm. Water is of satisfactory chemical quality for most purposes.
Clear Fork Group	Adjacent to and beneath Seymour and younger deposits	300 feet in extreme eastern part of area, but over 1,100 feet in northwestern part of area	Called "red beds" by drillers. Consists mostly of red shales and silty shales. Contains a few beds of siltstone, sandstone, dolomite, and gypsum.	75	Yields small quantities of water which is locally potable, but is typically of poor chemical quality.

The Clear Fork beds dip to the west-northwest at 40 to 50 feet per mile. Progressing westward across the area, successively younger Permian beds occur at the surface and beneath the Seymour and younger deposits. No large amounts of water are available from the Clear Fork. Only meager supplies of mostly mineralized water are available. Studies of electric logs of oil tests indicate no fresh water occurs in the Clear Fork or in deeper zones beneath the Clear Fork.

Prior to deposition of the Seymour sediments, the rocks of the Clear Fork were subjected to a long period of erosion resulting in a well-developed drainage pattern. Generally, this erosional surface slopes to the northeast, east, and southeast at an average rate of about 8 feet per mile. Locally, valleys exist which slope toward the southeast or northeast. The Clear Fork surface was covered later by Seymour and younger sediments deposited by eastward flowing streams.

The Seymour and the younger terrace and alluvial sediments occur in patterns controlled by successive cycles of terrestrial erosion and alluviation due to climatic cycles caused by successive advances and retreats of glaciers. The Seymour deposits in the area of this investigation represent at least two of these successive cycles; the deposits younger in age than the Seymour represent other such cycles. The areas of occurrence of the two Seymour units are shown in Figure 7, and they are termed in this report the "older Seymour deposits" and the "younger Seymour deposits."

Terrace deposits and river alluvium of more recent origin than the Seymour deposits occur principally between the

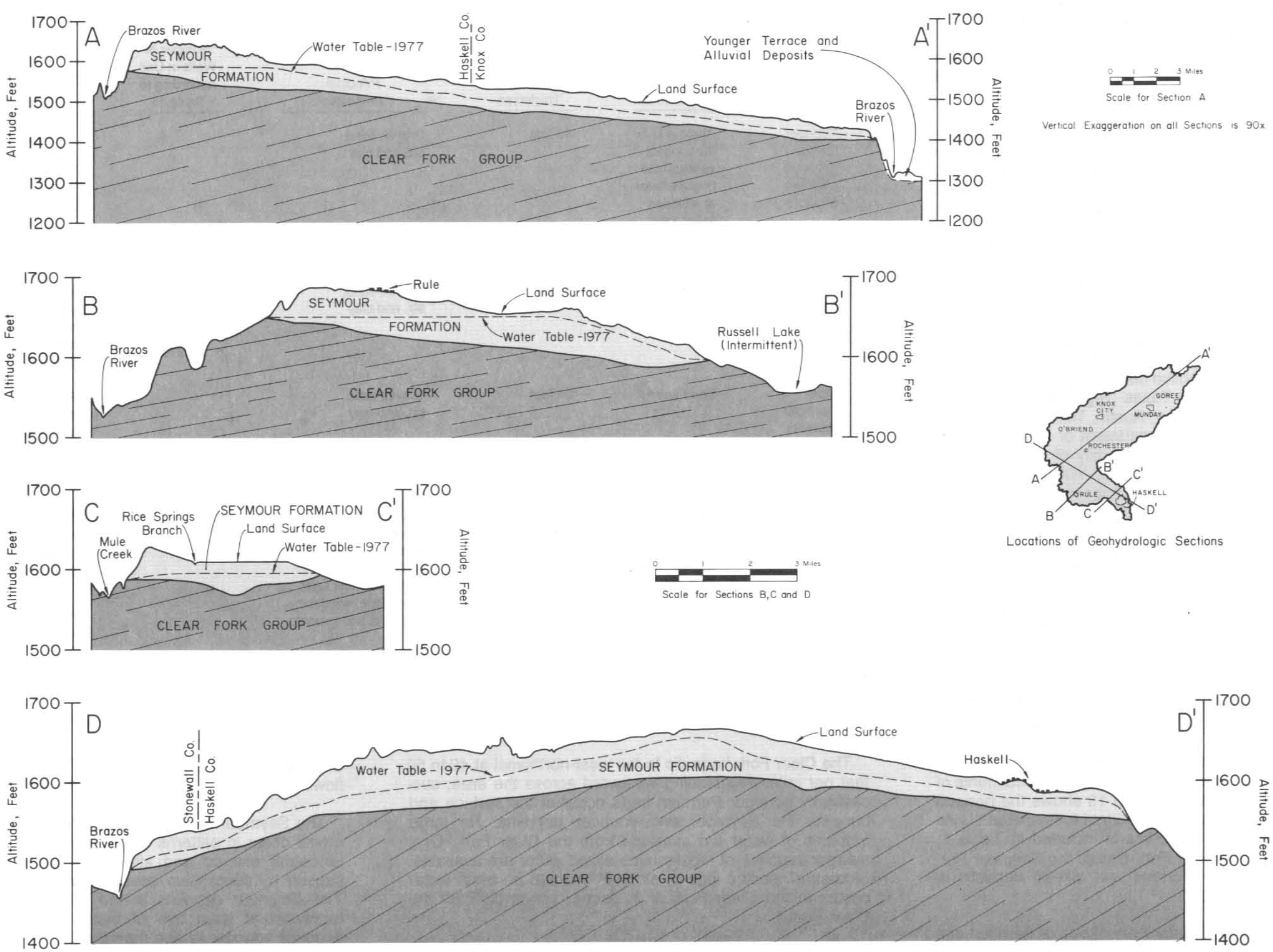

Figure 11. Geohydrologic Sections A-A′, B-B′, C-C′, and D-D′

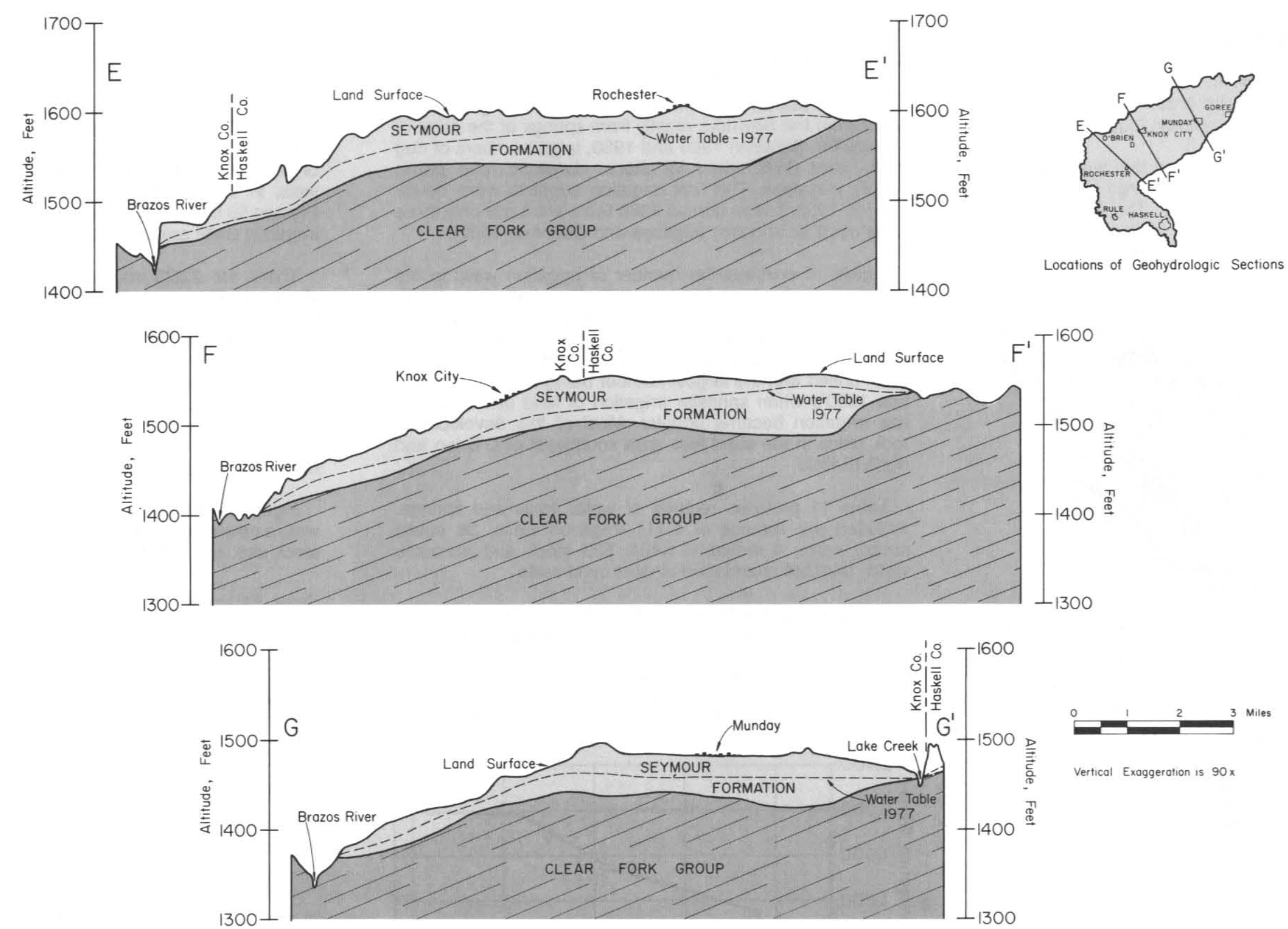

Figure 12. Geohydrologic Sections E-E′, F-F′, and G-G′

Seymour deposits and the Brazos River near the northern and western boundaries of the Seymour. One of the terrace deposits was termed the Lewis Creek Formation by Stricklin (1961). These younger deposits are at lower elevations than the Seymour at all localities where they were observed.

Both the Seymour and the younger terrace and alluvial deposits consist typically of a graded sequence having coarse materials at the base and increasingly finer materials toward the top. Recent windblown sand covers a large part of the Seymour in the sand hills area. These sands are mapped and shown with the Seymour on Figure 13.

The Seymour is by far the most important water-bearing unit in the area. It is the only source of large supplies and almost the only source of fresh water. The Seymour furnishes water to over 2,000 irrigation wells with yields as great as 1,300 gpm. The Seymour is responsible for the general availability of water over a large area.

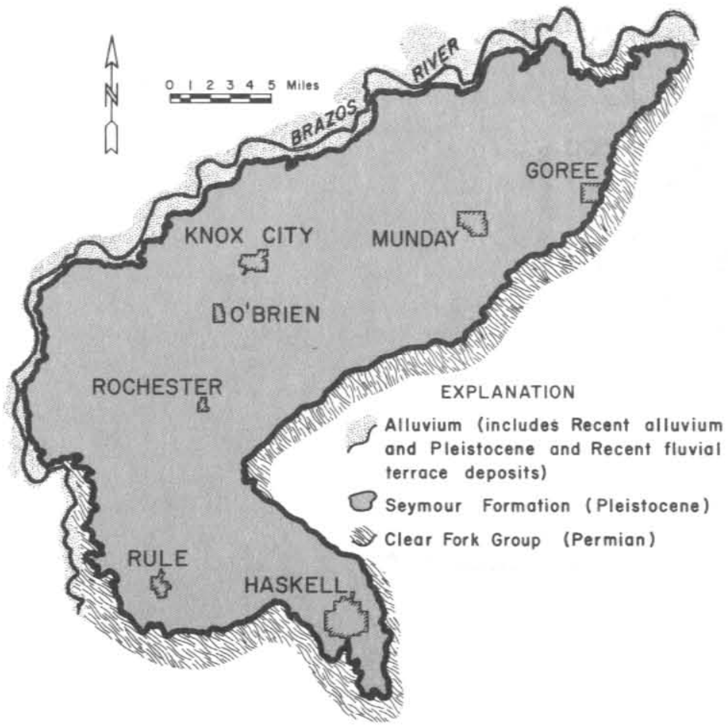

Figure 13. General Geologic Map

GROUND WATER IN THE SEYMOUR FORMATION

Extent of Aquifer

The lower water-saturated part of the Seymour Formation forms an important ground-water reservoir over an irregularly shaped area mostly in northwest Haskell and southern Knox Counties. It is the only available source of moderate to large irrigation supplies and a widely used source for domestic and stock supplies. The extent of the aquifer is shown on Figure 7. It comprises an area of about 430 square miles or 274,500 acres. Throughout this area, the Seymour is essentially a separate hydrologic unit.

Well Construction, Distribution, and Use

In early years, pioneers engaged in ranching obtained water from the Seymour mainly from springs at the edge of the aquifer. Between 1900 and 1930, large numbers of dug wells were constructed for stock, domestic, and public supply purposes. The first irrigation supplies were developed in 1938, but as late as 1950 there were still only three wells used for irrigation (Ogilbee and Osborne, 1962).

Figure 14 portrays the number of irrigation wells in the Seymour aquifer from 1952 to 1976. Over half of the irrigation wells were drilled during the drought of the 1950's. The number of irrigation wells increased from approximately 115 in 1952 to 1,100 in 1956. Since 1956, additional wells have been drilled with the largest number being drilled during the late 1960's when sprinkler irrigation of land unsuitable for row irrigation became popular. Most of this development took place in the sand hills area southwest of O'Brien and north of Rule.

Table 11 provides records of water wells and springs. Included are records of 1,111 irrigation wells, 38 public supply wells, 4 industrial wells, 533 stock and domestic wells, and 324 abandoned or destroyed wells.

There are approximately 3,000 Seymour water wells in the area. Table 11 lists records of over 1,900 wells tapping the Seymour aquifer. It also includes records of 4 alluvium wells, 75 Permian wells, and 20 wells believed to draw water from both the Seymour and the Permian. In conducting the field inventory to prepare Table 11, it was not practicable in all

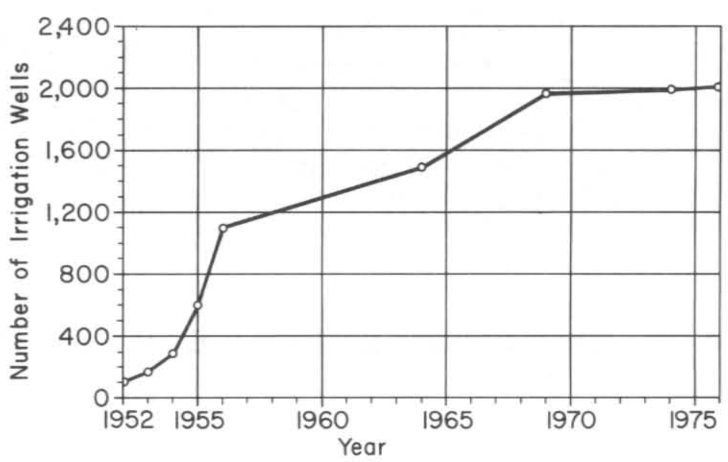

Figure 14. Number of Irrigation Wells

cases to update owners' names. Consequently, some names shown in Table 11 represent previous rather than current owners.

The stock and domestic wells are widely scattered over the Seymour aquifer. Irrigation wells tend to be located in those areas where ground-water conditions are more favorable for relatively high-yielding wells, namely those areas having larger saturated thicknesses and thicker, well-sorted sands and gravels.

Figure 16 shows the distribution of irrigation and municipal wells for the Seymour aquifer. The map also shows the type of power used for the irrigation wells. All of the irrigation wells in the Seymour are located on Figure 16 and on Figures 58 through 72. Records for approximately half of the irrigation wells are included in Table 11.

There are 2,023 irrigation wells and 38 municipal wells shown on Figure 16. Of the total irrigation wells, 1,665 are powered by electricity and 358 by butane or natural gas. The greatest density of irrigation wells tends to occur in a northeast-southwest belt approximately 6 miles wide, extending from southwest of Rochester to near the vicinity of Goree. The density of irrigation wells is not as great between Rule and Haskell and in the area shown on Figure 7 for the younger Seymour deposits. Generally, this is due to less favorable conditions for high-yielding wells in these areas.

Figure 15 shows the typical construction of an older dug well, a newer small-diameter drilled well for domestic or livestock use, and a larger-diameter drilled well for irrigation or

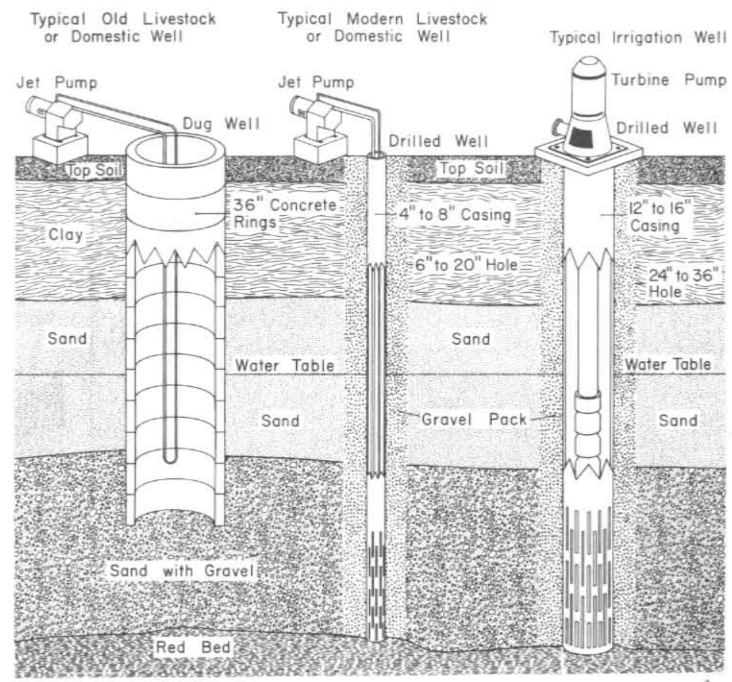

Figure 15. Construction of Wells

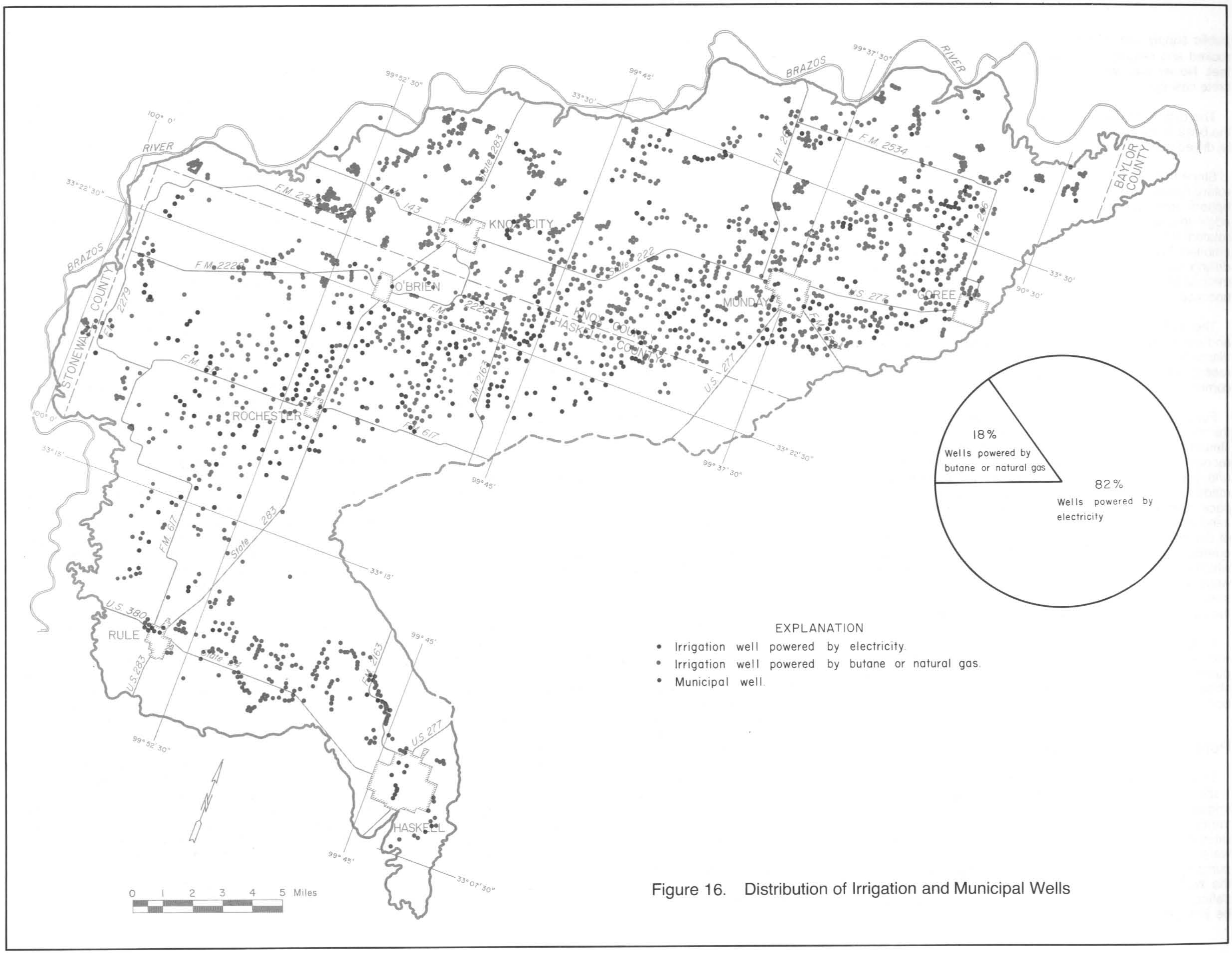

Figure 16. Distribution of Irrigation and Municipal Wells

public supply use. The earliest dug wells were bricked or rocked and ranged in diameter from 30 inches to over 20 feet. Newer dug wells are constructed using 36-inch concrete casings.

The depths of many of the dug wells are shallower than the base of the Seymour or the top of the red beds. Normally, drilled wells penetrate the entire thickness of the Seymour.

Since the 1950's, most of the wells have been drilled by rotary rigs equipped with 8 to 36-inch auger buckets. In the bottom of the bucket there is an entry slot above a cutting edge through which material enters the bucket as it is rotated. When the bucket is full, it is lifted to the surface and emptied. Typically, water and drilling mud are not used in the drilling operations unless the hole will not stand open. This method of shallow drilling has proven very successful in the unconsolidated materials.

The wells are cased to bottom with slotted steel casing and are gravel packed. Typically, casings are 4 to 8 inches in diameter for wells used for stock and domestic purposes. In recent years, plastic screen and casing have become more common.

For irrigation wells, steel casing 16 inches in diameter is the most common. In older irrigation wells, the casings were slotted from the water table to the bottom of the wells, but recently, only the bottom sections opposite the basal sand and gravel deposits have been slotted. No effort has been made to relate the width of the slots to the size of the gravel pack used, or the size of the gravel pack to the size of the sand in the Seymour. Most slots are 1/16-inch wide and most of the gravel ranges in diameter from ½ to 1 inch. Consequently, many of the wells pump large quantities of sand which results in worn, inefficient pumps. In some instances, wells are lost due to cave-ins. Also, it is common to see surface slumping in the vicinity of wells, allowing water from the surface to drain back underground outside the casing.

Most of the pumps for irrigation wells are turbine pumps with electric motors of 5 to 25 horsepower. Centrifugal pumps are common in areas where the water levels are shallowest. Jet pumps are the most common for stock and domestic wells.

Pumping Rates of Wells

There is a wide variation in pumping rates of Seymour wells and in well yields obtainable. Pumping rates for irrigation wells range from less than 50 gpm to a maximum measured rate of 1,300 gpm. Figure 17 shows the pumping rates measured for wells in the Seymour. The rates shown were measured in 1956 or 1975–1977 in connection with pumping tests or power tests. They are considered typical of the well yields available from Seymour wells, but do not define yields available in all areas. The largest yields tend to be in those areas having the larger saturated thicknesses and coarser, well-sorted sands and gravels. A large number of pumping rates are between 50 and 450 gpm. The average measured pumping rate is 270 gpm.

Geologic Character

Ground water in the Seymour is in unconsolidated sediments consisting principally of interfingering zones of fine to coarse-grained gravel, fine to coarse-grained sand, silt, and clay. The sediments were deposited by streams flowing generally eastward and mostly represent material eroded from the High Plains. The lowermost sediments are coarser, typically, and fill the valleys in the pre-Seymour or red bed surface. The lower zones consist typically of unconsolidated sands and gravels, although some cemented sandstone and conglomerate beds occur locally. The gravels are composed of rounded pebbles of quartz, chert, igneous rock, and some limestone. They range in size from less than ½ inch to approximately 4 inches in diameter. Occasionally, 1-foot blocks of Permian limestone and sandstone occur at the base of the formation. The basal gravel is not present consistently, and in some areas very little coarse water-bearing material is present. Also, the gravels are poorly sorted at some locations and mixed with clays and silts. Tables 28 and 29 give descriptive and sieve analyses data on the character of the Seymour.

The upper part of the Seymour is finer grained and consists of medium to fine-grained sands, silts, and clays. Frequently, the clays and silts are mixed with white or buff caliche nodules. Minor amounts of volcanic ash are present at some locations.

The thickness of the Seymour ranges from 0 to 94 feet. Throughout most of the area, its average thickness is greater than 40 feet.

Drillers' logs for 240 Seymour wells (Table 30) were plotted and analyzed statistically during this investigation for relative water-bearing characteristics of the materials described by the driller. This was done by listing all the descriptions used and by assigning each description to one of three categories of water-bearing materials: good, fair, or poor. For example, typical descriptions assigned to the good water-bearing category included: gravel, course sand, sand and small gravel, and clean coarse sand. This category included all descriptions containing the word "gravel" but none containing the word "clay." Descriptions assigned to the category of fair water-bearing materials included: fine sand, sand, dirty sand, sand and clay, and sand and sandstone. Descriptions included in the poor category of water-bearing materials included: clay, sandy clay, shale, top soil, rock, and soil and clay. For each 10-foot interval of each log, the footage of each of the three categories of water-bearing materials was noted. The data for all of the logs within each 7½-minute quadrangle were totaled, and the results are shown on Figure 18.

For each 7½-minute quadrangle and each 10-foot interval below land surface, Figure 18 shows the percentage of materials considered to be of good, fair, or poor character from a water-bearing standpoint. For example, in 1-degree quadrangle 21–27, the nine drillers' logs analyzed indicate that 90 percent of the material between the depths of 0 and 10 feet is in the poor category and 10 percent in the fair category. Similarly, between the depths of 20 and 30 feet, the nine logs indicate that 16 percent of the material is in the poor category, 45 percent in the fair category, and 39 percent in the good category.

The diagrams on Figure 18 show the extent to which the better water-bearing materials (gravels) occur in the lower part of the Seymour, and the extent to which the poorer water-bearing materials (clays and silts) occur in the upper part. Comparing areas, 7½-minute quadrangles 21–33, 21–41, and 21–51 have the least amount of poor water-bearing materials in the upper 10 feet. These quadrangles coincide approximately with areas where sandy materials are present at the surface. Those quadrangles which have the most clay in the upper part of the formation tend to be quadrangles 21–34, 21–35, and 21–36. These quadrangles, along with quadrangle 21–50, have little fair water-bearing material, whereas most of the other quadrangles show larger amounts of material in the fair category.

Base of Seymour Formation

The base of the Seymour represents the buried erosional surface on top of the Permian red beds. The relative position of the base is an important factor in the availability of large-capacity wells. Buried channels, where the depth to the base is deeper than normal, provide the possibility of obtaining large well yields due to an increased thickness and coarser character of water-bearing materials.

Figure 19 summarizes the available information on the depth to the base of the Seymour. The map is based on drillers' logs and on reported depths of wells. The depth to the base of the Seymour averages more than 50 feet over large areas extending generally from Rule to Rochester to Goree. It reaches a maximum of 94 feet in the vicinity of Rochester. Depths shallower than 40 feet occur typically in the vicinity of Haskell and along the northwestern part of the area where the younger Seymour deposits occur.

The altitude of the base of the Seymour is shown on Figure 20. The control points shown are based on drillers' logs penetrating the Seymour. In addition, the map is based on the altitudes of the total depths of a large number of wells. These depth data are considered reasonably reliable because most of the drilled depths of the irrigation wells and a large number of the stock and domestic wells reach the red beds. However, this is not always the case; consequently, in contouring the map some judgement was used as to which wells were most indicative of the altitude of the base of the Seymour.

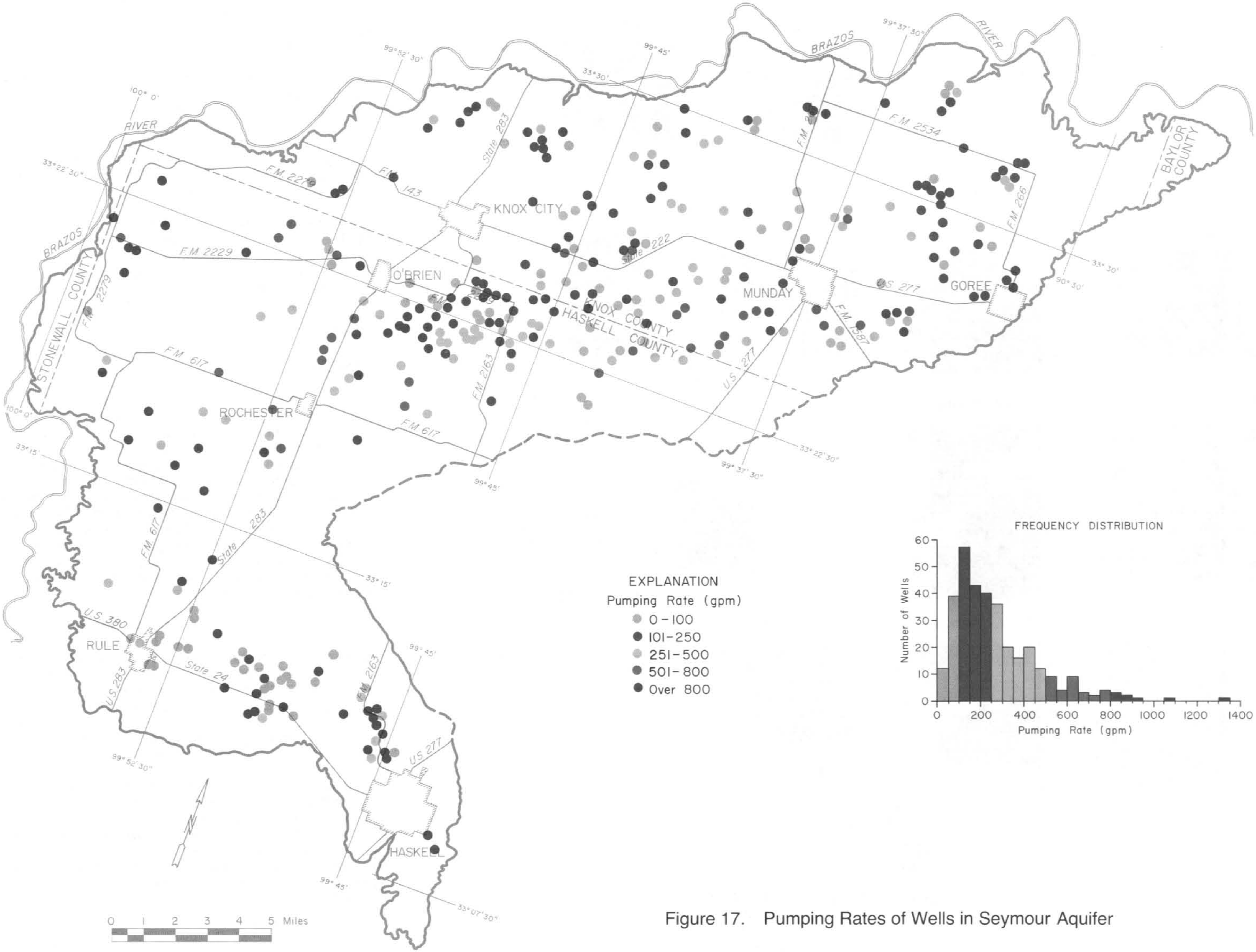

Figure 17. Pumping Rates of Wells in Seymour Aquifer

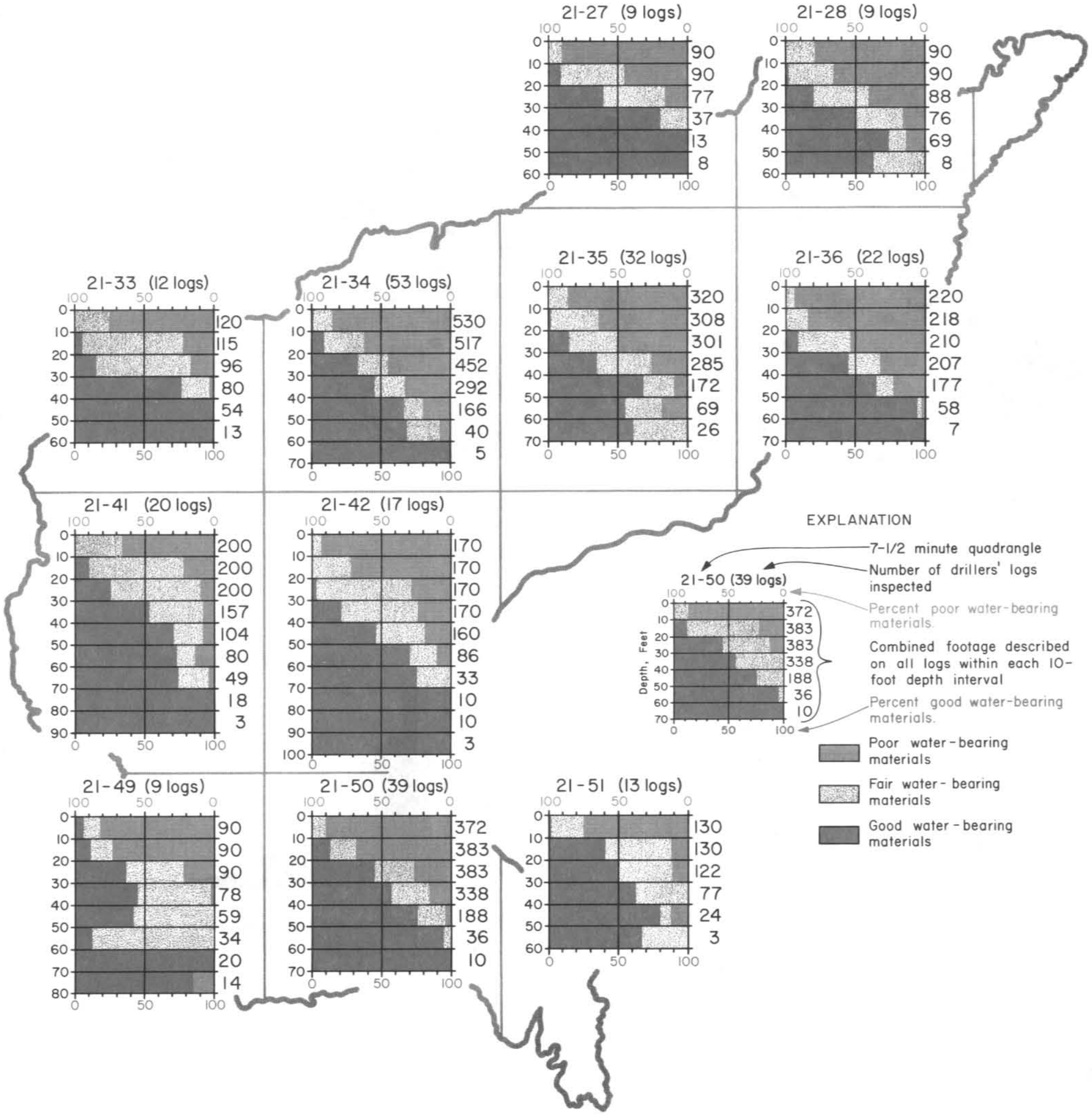

Figure 18. Characteristics of Seymour From Drillers' Logs

The base of the Seymour southwest of Rule is at an altitude of more than 1,640 feet above mean sea level. In general, the surface slopes to the east, northeast, and north away from this high point. The lowest elevation is found along the northernmost part of the area in quadrangle 21–28 where the altitude of the base of the Seymour is slightly below 1,360 feet above mean sea level.

The boundary between the older and the younger Seymour deposits is reflected on Figure 20 as a steepening of the base of the Seymour. The boundary is not well defined on Figure 20 due to the scarcity of wells along the boundary.

There are two major buried channels indicated by the map. The largest and most significant extends from near Rochester to approximately Goree. A smaller channel trends northwest-southeast through the Haskell area. It is likely that other, mostly smaller channels exist in the area, but the degree of accuracy and distribution of the well data makes mapping difficult.

Water Table

Figure 21 shows the depth to the water table for the Seymour aquifer based on measurements taken during January 1977. There is a wide variation in depth to water in most all of the individual 2½-minute quadrangles for which data are shown on Figure 21. The average depth to water is 23 feet. Measurements in individual wells range from about 4 feet to 55 feet. In general, the areas having the greater depths to water are west of Rochester, north of Rule, south of Knox City, and north of Goree. Those areas having the shallowest depths to water lie generally southeast and northeast of Rochester near the edges of the aquifer, at Haskell, and at numerous locations along the northern and western boundaries of the aquifer.

The altitude of the water table for the Seymour aquifer is shown on Figure 22. The map is based on approximately 450 water-level measurements made during January 1977. The highest water level was found just southeast of Rule at approximately 1,660 feet above mean sea level. The lowest level of approximately 1,370 feet above mean sea level was found along the northern border of the aquifer in quadrangle 21–28. The water table for January 1977 is shown also on the geohydrologic sections on Figures 11 and 12.

In general, the gradient of the water table is approximately equal to the gradient of the land surface and the top of the red beds. Water-level gradients range from approximately 5 feet per mile to 60 feet per mile and average about 7.6 feet per mile. The steepest gradients occur along the boundary between the older and younger Seymour deposits. These gradients indicate that the two parts of the Seymour are connected poorly.

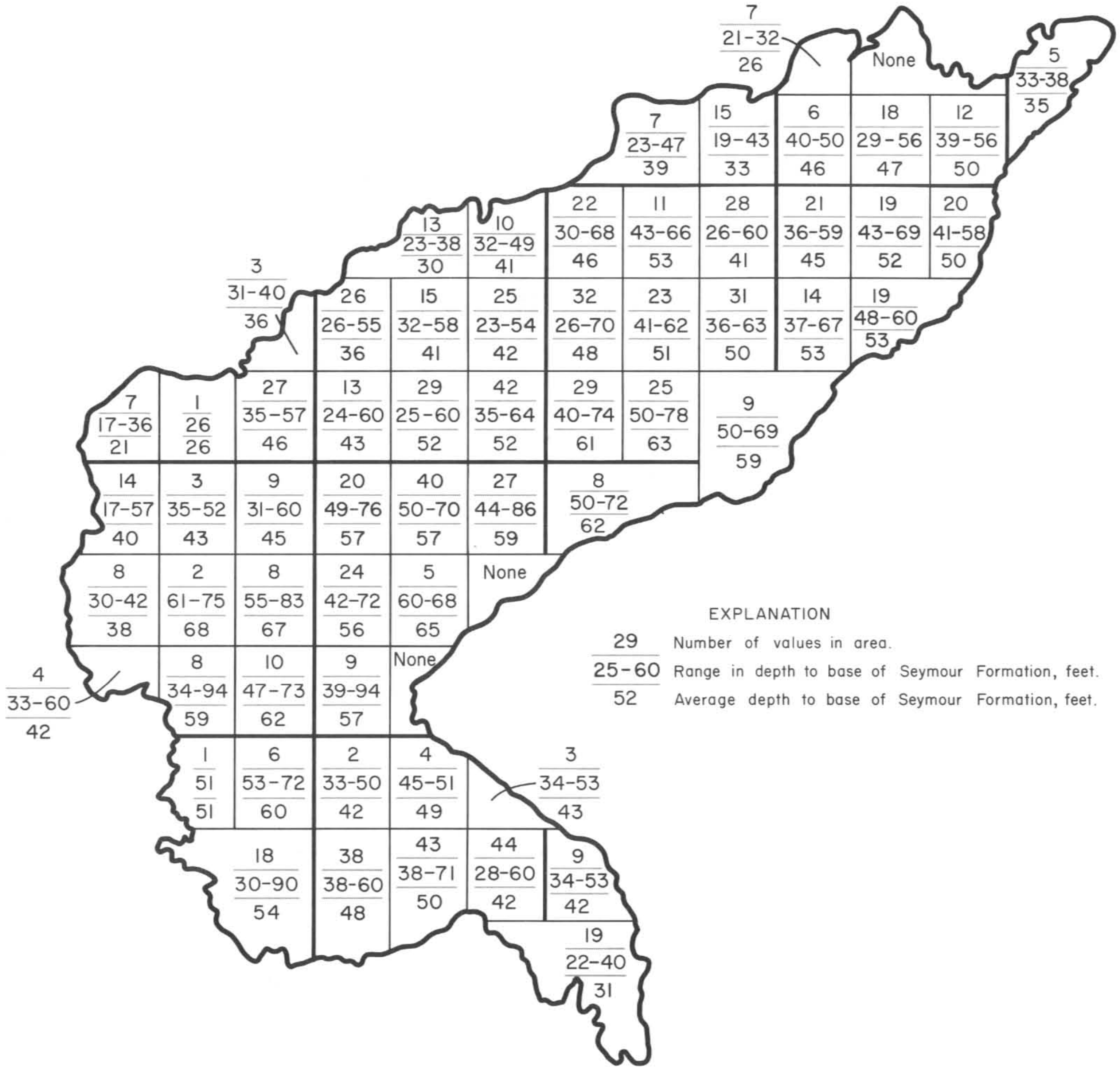

Figure 19. Depth to Base of Seymour Formation

Saturated Thickness

The saturated thickness of the Seymour is shown on Figure 23. The map is based on those wells having drillers' logs for which water-level measurements were made in January 1977 and a comparison of the altitude of the water table and the altitude of the base of the Seymour from Figures 20 and 22.

The saturated thickness ranges from less than 10 feet around the edge of the aquifer to more than 60 feet in a small area in northern Haskell County, northeast of Rochester. Large areas have saturated thicknesses between 20 and 40 feet.

For each 10-foot interval of saturated thickness, Table 2 shows the area and calculated volumes of water in storage in January 1977.

Hydraulic Properties

Results of pumping tests conducted to determine specific capacities of wells and the transmissivity of the Seymour are given in Table 3. Figure 24 shows the locations of the wells tested.

Specific Capacities of Wells

The specific capacity of a well indicates the amount of water which the well will produce with a given drawdown of water level within the well over a relatively short period of time. The units commonly used are gallons per minute per foot of drawdown (gpm/ft). The hydraulic characteristics of a formation and the construction efficiency of the well are the primary factors that determine the specific capacity of a well. A wide variance in specific capacities of Seymour wells indicates a wide variance in hydraulic character of the aquifer. Specific capacities range from less than 20 to 175 gpm/ft. The average for 24 tests is 57 gpm/ft.

Coefficients of Transmissivity, Permeability, and Storage

Table 3 lists the coefficients of transmissivity and permeability determined from pumping tests of Seymour wells. The coefficient of transmissivity is a measure of the amount of water that will move through an aquifer. It is expressed typically in gallons per day per foot (gpd/ft) of width of the aquifer. The coefficients of transmissivity for 24 wells tested range from 19,500 to over 300,000 gpd/ft. The average transmissivity is 100,000 gpd/ft. The wide range in values indicates a non-uniform aquifer which varies greatly in hydraulic character. This wide variance is typical of an aquifer with the geologic character of the Seymour.

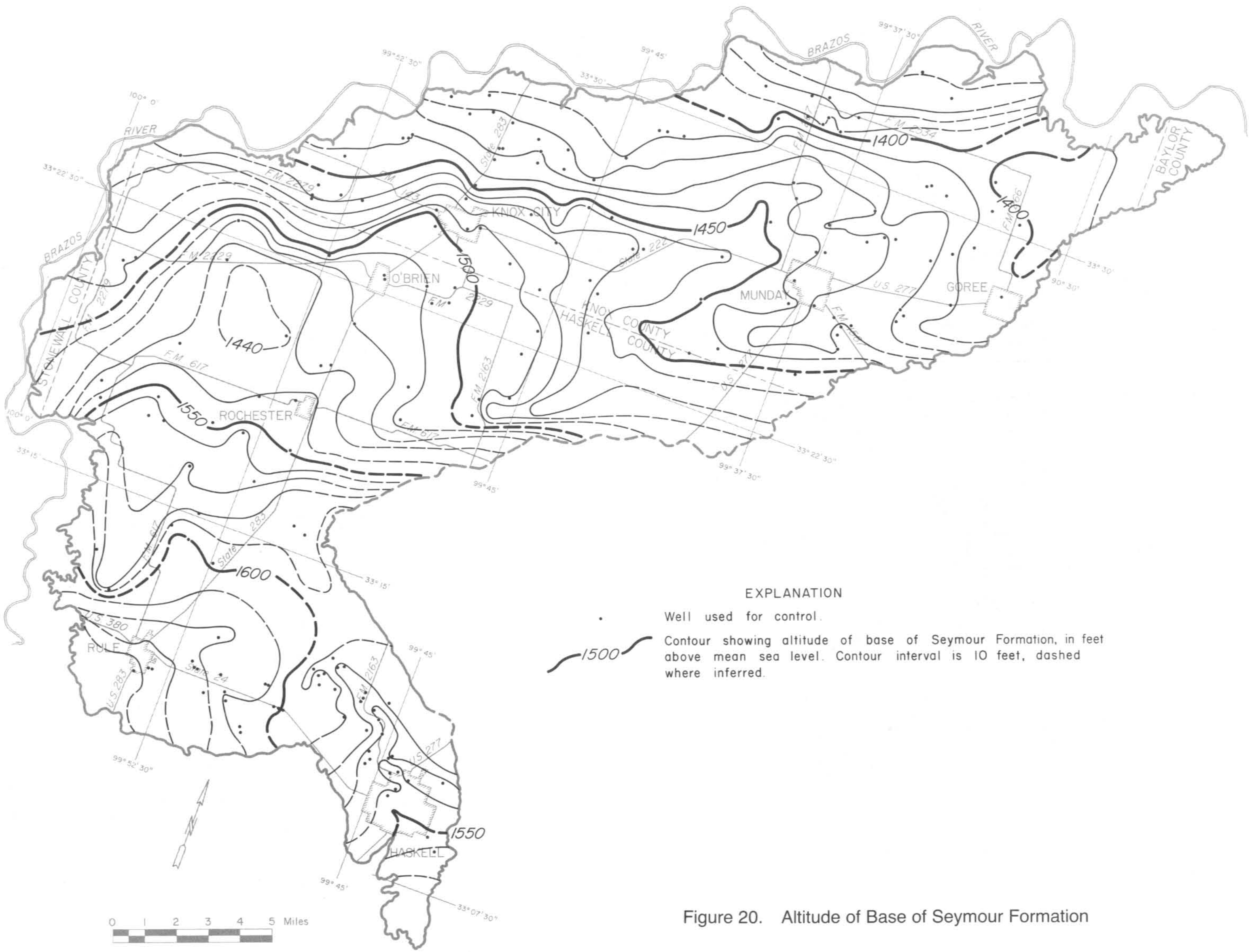

Figure 20. Altitude of Base of Seymour Formation

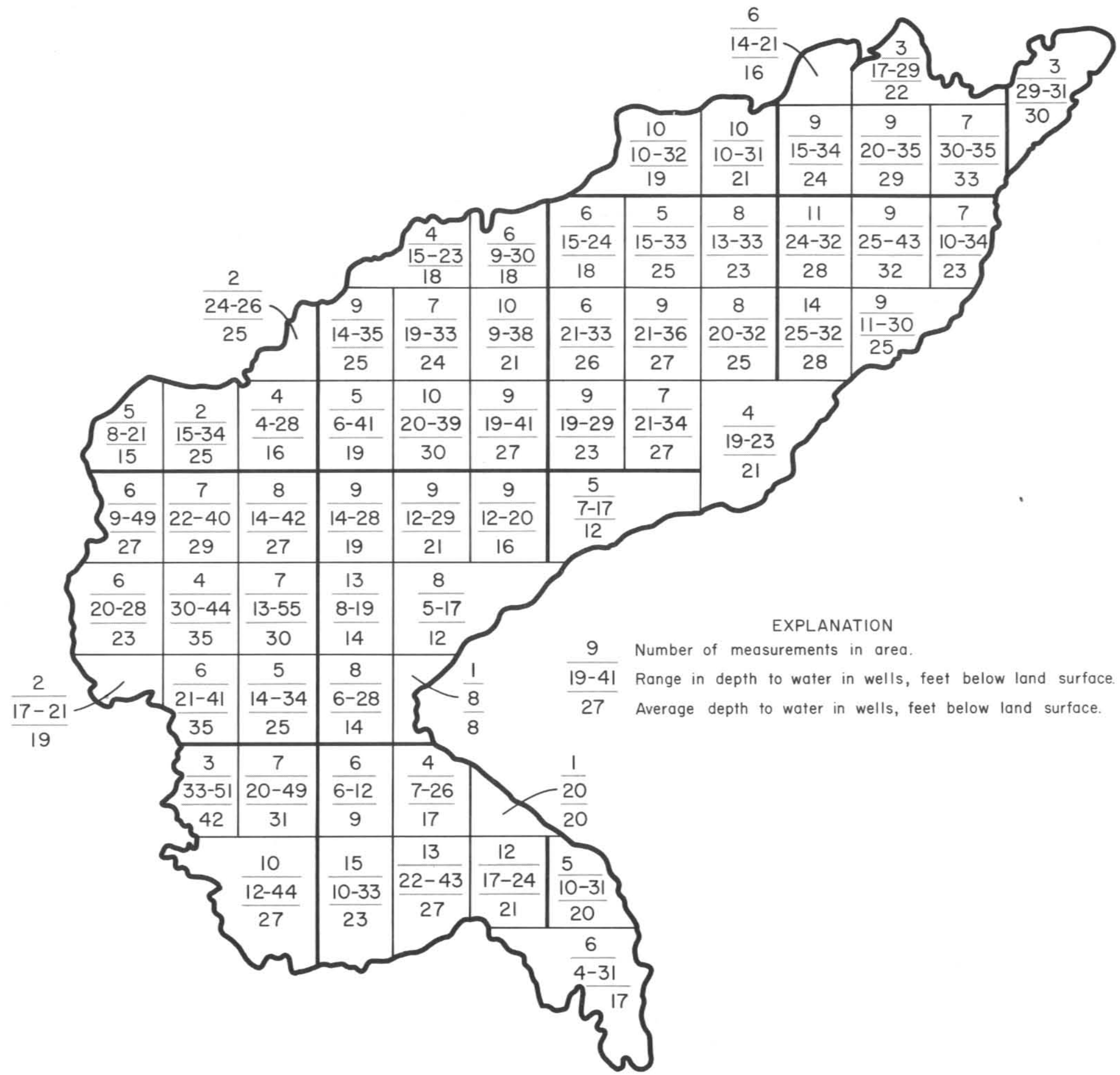

Figure 21. Depth to Water in Seymour Formation, January 1977

By using the coefficient of transmissivity and the thickness of the water-bearing materials at the pumped well, the field coefficient of permeability can be calculated. It is equal to the transmissivity divided by the thickness of the aquifer. It is expressed typically in gallons per day per square foot (gpd/ft^2). The average permeability of the zones tested in 24 wells is 4,200 gpd/ft^2. The range in permeability for individual wells is from 900 to 17,800 gpd/ft^2.

The coefficient of storage is a measure of the amount of water which is given up from storage in an aquifer when the water level is lowered. It is dimensionless and is equivalent to the number of cubic feet of water released in each square-foot column of the aquifer when the later level is lowered one foot. In an unconfined aquifer under water-table conditions such as the Seymour, the coefficient of storage is equal to the specific yield. It is estimated that the coefficient of storage for the Seymour ranges from less than 10 percent to more than 20 percent and averages approximately 15 percent.

Interference Between Wells and Water-Level Drawdown

When a Seymour well is pumped, it creates drawdown effects in nearby wells. Figure 25 shows the typical drawdown due to pumping 300 gallons per minute from a well in an infinite aquifer having hydraulic characteristics similar to those of the Seymour. The maximum water-level drawdown occurs at the pumping well. The drawdown becomes progressively less at increasing distances from the well. The drawdowns shown on Figure 25 are proportional to the pumping rate shown; accordingly, the drawdown due to pumping at any rate can be estimated using the graph.

When wells are spaced close together, the interference between pumping wells can result in significant decreases in yields for the individual wells. These decreases are due to the interference effects diminishing the amount of available drawdown and causing larger pumping lifts. Figure 26 shows the interference between two pumping wells. The wells are spaced 200 feet apart, and the drawdown curves shown represent pumping for 90 days at 300 gpm. Normally, large-capacity irrigation wells in the Seymour should be spaced several hundred feet apart or more.

Recharge

Figure 27 schematically shows the hydrologic cycle as related to the Seymour, including general recharge and discharge relationships. Direct infiltration of precipitation at the land surface is the method by which nearly all recharge to the Seymour occurs. Surface streams adjoining the Seymour, including the Brazos River and Lake Creek, are at elevations lower than the water levels in the Seymour

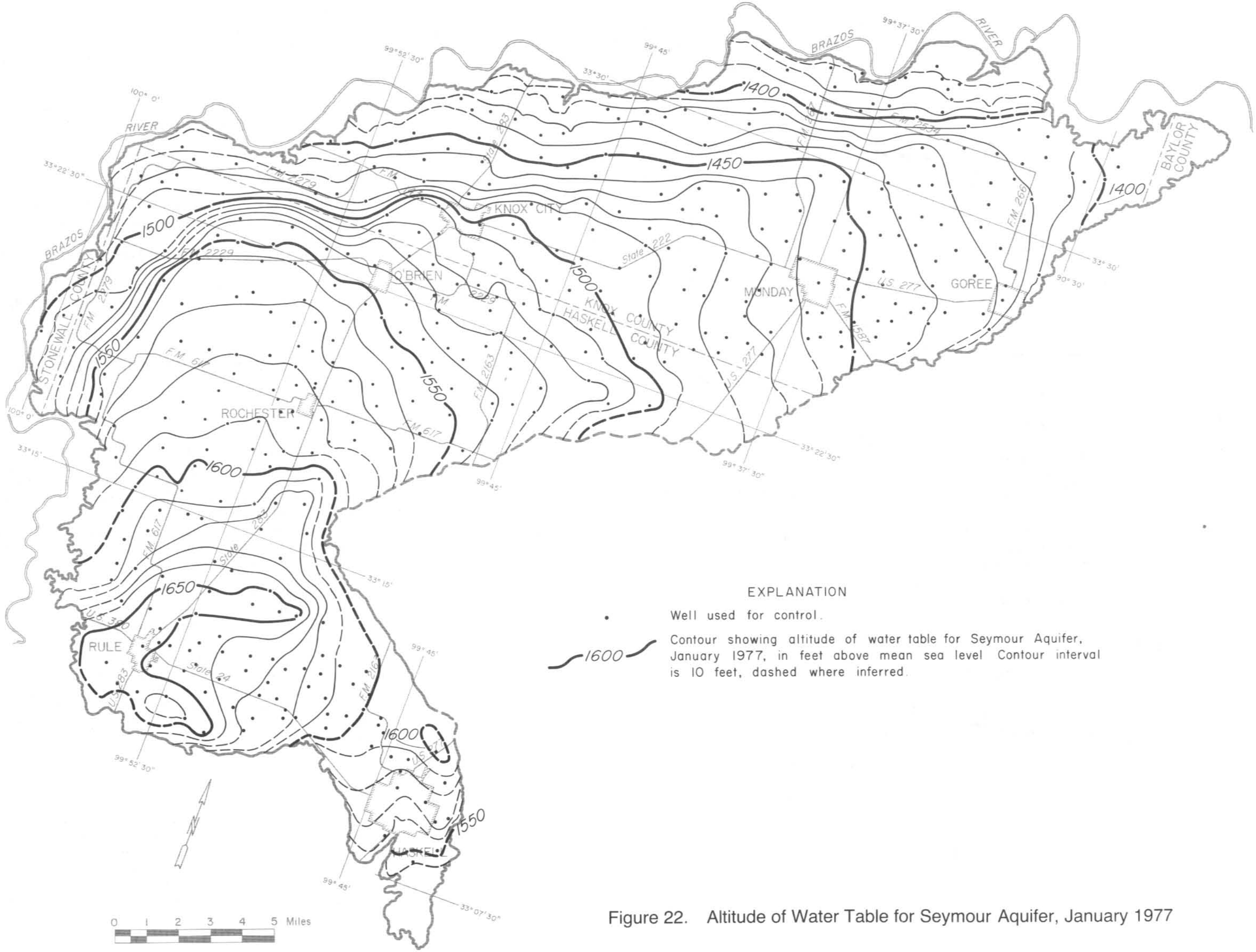

Figure 22. Altitude of Water Table for Seymour Aquifer, January 1977

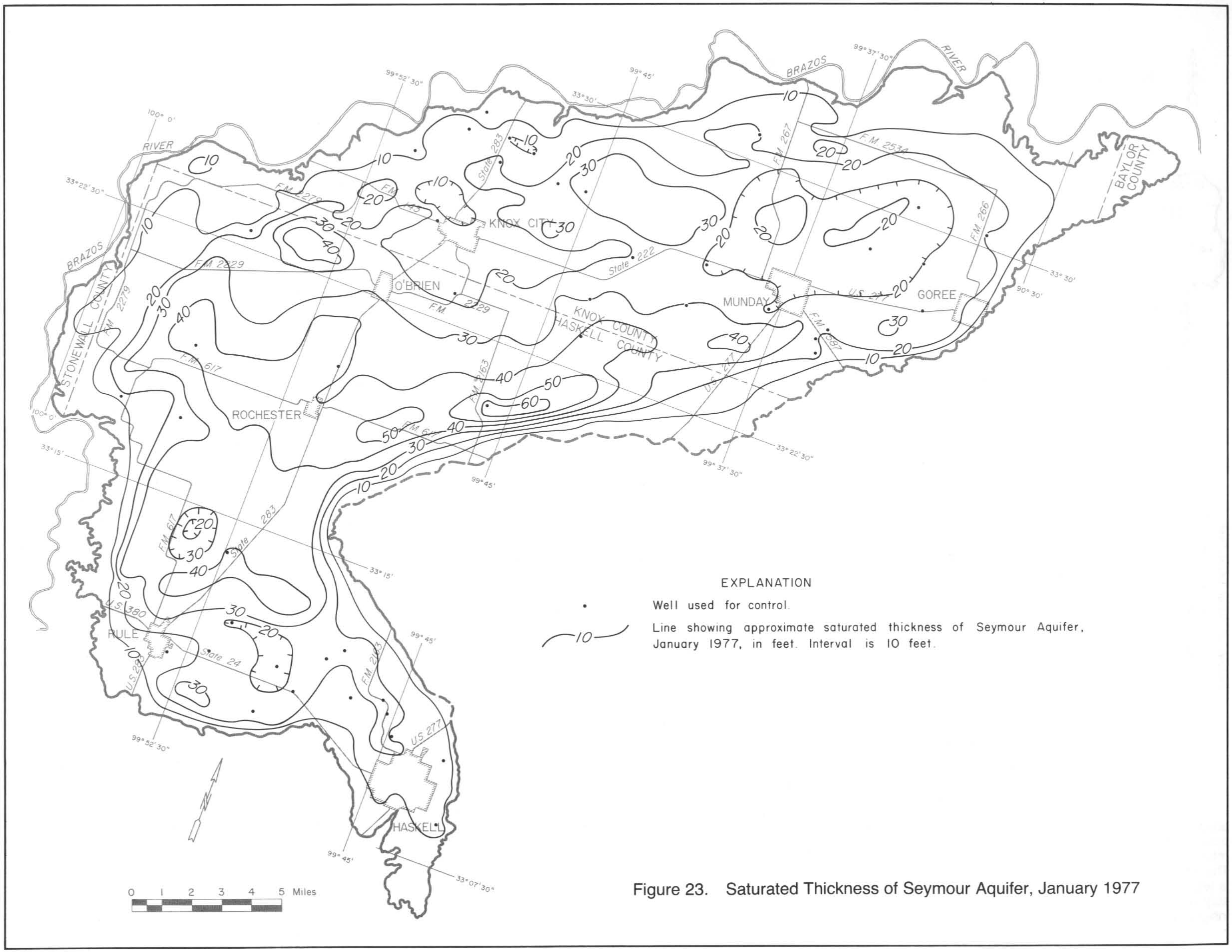

Figure 23. Saturated Thickness of Seymour Aquifer, January 1977

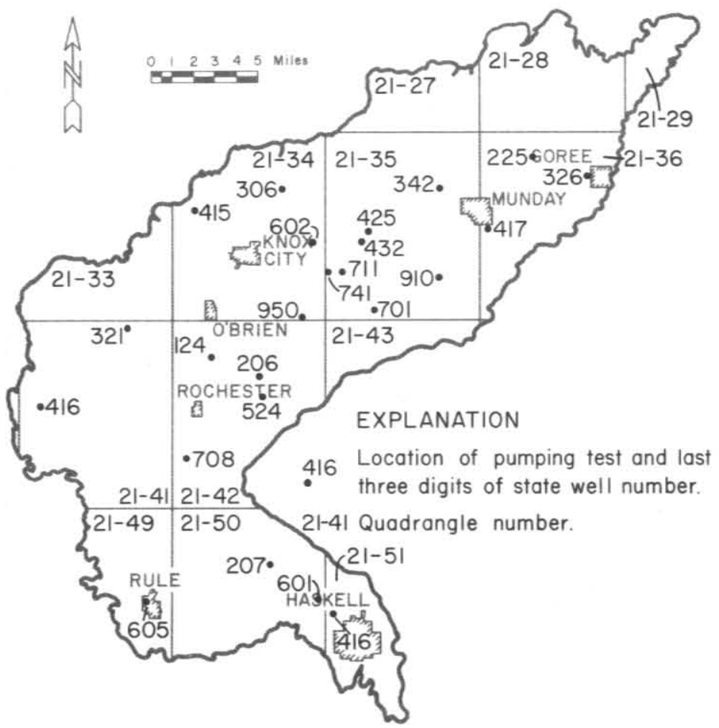

Figure 24. Locations of Pumping Tests

Table 2. Estimated Water in Storage, 1977

Mapped Saturated Thickness Interval (feet)	Area (acres)	Volume of Water In Storage[1] (acre-feet)	Drainable Volume of Water In Storage[2] (acre-feet)
0–10	52,398	79,000	39,000
10–20	75,023	338,000	169,000
20–30	70,118	526,000	263,000
30–40	51,173	537,000	269,000
40–50	22,351	302,000	151,000
50–60	2,948	49,000	24,000
60–70	523	10,000	5,000
Total	274,534	1,841,000	920,000

[1] Based on a porosity of 30 percent. This is the approximate amount of water the aquifer contains.

[2] Based on a storage coefficient of 15 percent. This is the approximate amount of water that would drain from the aquifer by gravity drainage, if the entire saturated thickness could be drained.

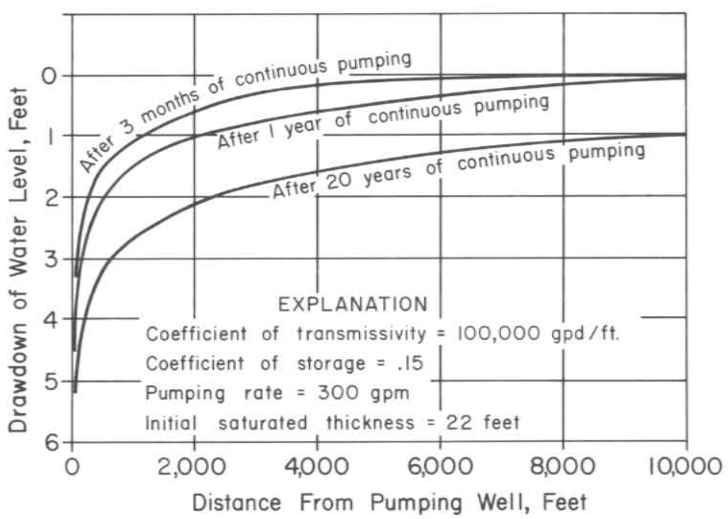

Figure 25. Drawdown Due to Pumping 300 Gallons Per Minute

aquifer and cannot contribute to the Seymour. Some water pumped for irrigation and municipal use infiltrates and returns to the aquifer, but these amounts are relatively small. The only other possible source of recharge to the Seymour is leakage from underlying Permian formations. This probably occurs in some areas, but amounts are very small and insignificant.

Recharge from precipitation is not uniform over the study area. Considerably more recharge occurs in the sand hills area, and in other areas where the land surface consists of sandy materials, than in those areas where clay soils predominate. Three indicators of significant recharge areas are sandy soils, large water-level rises during past wet periods, and better water quality.

Figure 28 shows the principal areas where sandy soils occur and most of the infiltration to the Seymour takes place. The areas are some distance from areas of natural discharge from the Seymour. Consequently, there is no large amount of rejected recharge from the aquifer. Most of the recharge that occurs goes into storage in the aquifer and results in water-level rises unless pumped out.

Significant water-level rises occur in the main recharge areas of the Seymour due to precipitation. The hydrograph for well LP 21-42-409 depicted in Figure 29, shows water-level rises as a result of the early spring and summer rains which occurred in 1975 and 1977. Ogilbee (1962) reports that water levels near Rochester rose over 2 feet from February to May 1957 in response to spring rains of about 11 inches, and that during the same time period, water levels in other wells in the Rochester-O'Brien area rose from 1½ feet to 2½ feet. These rises indicate that over 20 percent of the precipitation reached the Seymour as recharge.

Estimates of the amount of recharge based on the historical pumpage and water levels in the aquifer for the past 20 years indicate that total infiltration from precipitation and return flow from irrigation is 2.2 inches per year plus an amount equivalent to the average annual natural discharge from the aquifer. Most of this infiltration is from precipitation. Return flow is only a small part of the infiltration due principally to the relatively low amounts of irrigation water applied. Moreover, if reasonably large quantities of return flow were occurring, there would have been significant water quality changes, and such changes have not been experienced in the area.

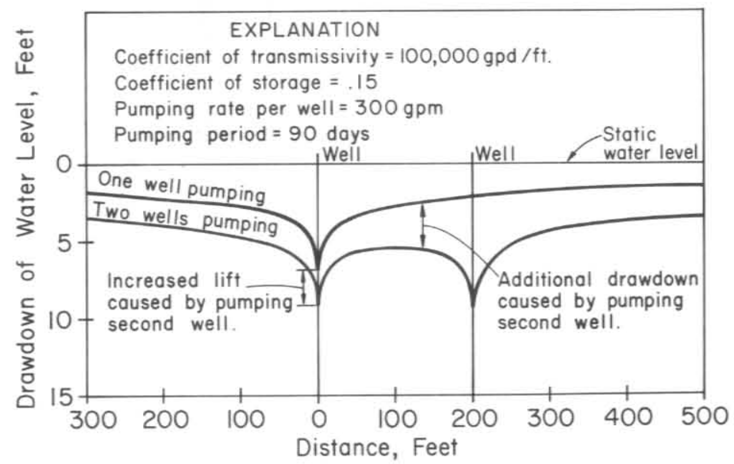

Figure 26. Interference Between Two Pumping Wells

Table 3. Results of Pumping Tests

Well Number	Pumping Rate (gpm)	Year of Test	One-Hour Specific Capacity (gpm/ft)	Saturated Thickness (feet)	Coefficient of Transmissivity (gpd/ft)	Field Coefficient of Permeability (gpd/ft²)
HASKELL COUNTY						
21-34-950	357	1957	113.7	29	75,000	2,600
21-35-701	422	1976	73.8	42	130,000	3,100
21-41-321	215	1976	36.0	14	34,000	2,400
21-41-416	95	1976	29.3	17	130,000	7,600
21-42-124	136	1976	54.8	27	33,000	1,200
21-42-206	590	1957	61.5	30	220,000	7,300
21-42-524	769	1976	72.7	53	240,000	4,500
21-42-708	257	1976	21.5	39	45,000	1,200
21-49-605	429	1976	105.0	18	320,000	17,800
21-50-207	95	1957	31.6	9	32,000	3,600
21-50-601	255	1957	56.8	16	135,000	8,400
21-51-416	112	1957	77.2	6	90,000	15,000
KNOX COUNTY						
21-34-306	146	1956	28.9	14	107,000	7,600
21-34-415	181	1956	85.8	13	177,000	13,600
21-34-622	335	1976	39.3	22	88,000	4,000
21-35-342	63	1976	20.0	11	19,500	1,800
21-35-425	255	1957	29.2	25	23,000	900
21-35-432	543	1957	95.6	26	83,000	3,200
21-35-711	917	1956	175.0	27	97,000	3,600
21-35-741	355	1956	19.2	35	50,000	1,400
21-35-910	356	1956	66.3	36	60,000	1,700
21-36-225	258	1976	16.7	19	98,000	5,100
21-36-326	191	1976	19.1	20	25,000	1,200
21-36-417	540	1957	40.9	39	79,000	2,000
Average:	328		57	24	100,000	4,200

Natural Discharge

Natural discharge from the Seymour occurs through seeps and springs, evapotranspiration by plants, evaporation from the water table, and leakage to the Permian. Seeps and springs occur along the edges of the aquifer. The more important springs are mapped on Figure 30. Spring flows range from less than 1 gallon per minute to an aggregate of a few hundred gallons per minute for springs along Wild Horse Creek, the largest group of springs in the area. Seeps and springs along Rice Springs Branch, China Branch, and Union Creek are small, and most natural discharge in these areas is by evapotranspiration. Most of the other springs flow only a few gallons per minute, but a few flow 20 to 30 gallons per minute. Many seep areas occur along the edge of the formation, particularly in the small drainageways and along the bluffs overlooking the Brazos River on the northern and western boundaries of the aquifer.

It is estimated that the total ground-water discharge by evapotranspiration is a large part of the total natural discharge from the aquifer and is considerably larger than that from springs and seeps. The main areas of evapotranspiration occur in many places along the edge of the Seymour and along the principal creeks. They are mapped on Figure 30. The areas are marked by dense plant growth, mainly native grasses, willows, and mesquites. In addition, there are many small scattered areas away from the edge of the Seymour which are covered by dense growths of mesquite. These areas are also mapped on Figure 30, and represent former pasture areas, primarily. The depth to water under these areas is not deep enough to preclude mesquites from developing root systems to sufficient depths to draw from the water table. Some evapotranspiration probably occurs in these areas, but the amount is unknown.

Direct evaporation from the water table occurs only in small amounts and in limited areas due to the depth of the water table. In only a few localities is the depth to water less than 10 feet, and no areas are known to exist where the water table is less than about 4 feet. For depths to water ranging from 4 to 8 feet, it has been estimated by White (1932) that direct evaporation is on the order of 2 to 5 percent of pan evaporation. This is equivalent to 0.12 to 0.3 feet per year.

Leakage from the Seymour to the adjacent underlying Permian rocks is very small due to the geologic character of the Permian, and the amount is not believed to be significant quantitatively.

Direction and Rate of Ground-Water Movement

The general direction of movement of water in the Seymour aquifer is shown on Figure 31. The map approximates the natural direction of flow, unaffected by pumping from wells. Basically, the movement of the ground water is from higher to lower elevations and from recharge areas to discharge areas. The flow is outward from the highest points on the water table along the ground-water divide near and northeast of Rule. One segment of the flow is from this divide to the southeast toward Haskell. North of the Rule ground-water divide, the flow is toward the north, northwest, or northeast. The direction of flow tends to be perpendicular to the water-table contours shown on Figure 22.

Based on the contours of the water table and the permeabilities for the formation indicated by pumping tests, it is estimated that the natural rate of movement of water in the Seymour, where unaffected by pumping, ranges locally from approximately 200 to 5,000 feet per year. It is estimated that over several miles, the average rate of movement is typically between 800 and 1,200 feet per year.

Pumpage

Before large withdrawals for irrigation began in the 1950's, the water from the Seymour was used primarily for municipal, domestic, and livestock purposes. These withdrawals have been estimated for 10-year intervals on the basis of population:

Year	Pumpage (acre-feet)
1900	200
1910	400
1920	400
1930	900
1940	1,200

Table 4 shows the estimated pumpage for irrigation and public supply for 1950–1976. During this period, it is estimated that pumpage by industrial, livestock, and private wells in urban areas was less than 1,000 acre-feet per year.

The irrigation pumpage was estimated based on the amount of electricity used for irrigation each year. This information was obtained from three electric utility companies which serve the area, B-K Electric Cooperative, West Texas Utilities, and Stamford Electric Cooperative. Tests were conducted on 45 wells to determine the amount of water that wells pumped per unit of power consumed. These tests are referred to as power tests, and the results are shown in Table 5. Based on the power tests, it is estimated that a sprinkler system well averages approximately 970 gallons per kilowatt hour used, while an open discharge well averages approximately 2,330 gallons per kilowatt hour used. These values are similar to those obtained in adjacent areas of the Seymour (Price, 1978 and Preston, 1978). Historical use of sprinklers was studied in order that the amount of pumpage by sprinkler wells and open discharge wells could be estimated. The irrigation pumpage by wells powered by butane and natural gas was estimated based on the number of wells. Pumpage for municipal usage was obtained from individual towns or from records of the Texas Department of Water Resources. As shown in Table 4, the municipal use is small and usually less than 5 percent of the irrigation pumpage. There is no industrial pumpage at present. Very small amounts were used in the past for water-flooding purposes.

The amounts of annual pumpage for irrigation vary greatly. These variations are due primarily to large differences in the timing and amounts of precipitation, but are due also to type of crop, cost of labor and power, and other factors. Figure 29 shows the variation in monthly precipitation and amounts of electricity sold by B-K Electric Cooperative for irrigation during 1975, 1976, and 1977.

Table 4. Estimated Pumpage of Ground Water From Seymour Aquifer, 1950–1976

Year	Irrigation (acre-feet)	Public Supply (acre-feet)	Total (acre-feet)
1950	100	1,200	1,300
1951	900	1,200	2,100
1952	6,700	1,200	7,900
1953	9,900	1,200	11,100
1954	16,800	1,200	18,000
1955	34,800	1,200	36,000
1956	63,800	1,200	65,000
1957	46,800	1,300	48,100
1958	34,500	1,800	36,300
1959	17,900	1,600	19,500
1960	54,600	1,800	56,400
1961	36,200	1,600	37,800
1962	60,200	1,900	62,100
1963	56,800	1,800	58,600
1964	64,400	1,500	65,900
1965	53,000	2,100	55,100
1966	51,100	2,000	53,100
1967	51,600	1,900	53,500
1968	26,500	1,700	28,200
1969	32,000	1,700	33,700
1970	41,900	1,900	43,800
1971	51,200	1,700	52,900
1972	34,800	1,500	36,300
1973	24,000	1,600	25,600
1974	63,600	1,600	65,200
1975	25,100	1,600	26,700
1976	39,100	1,700	40,800

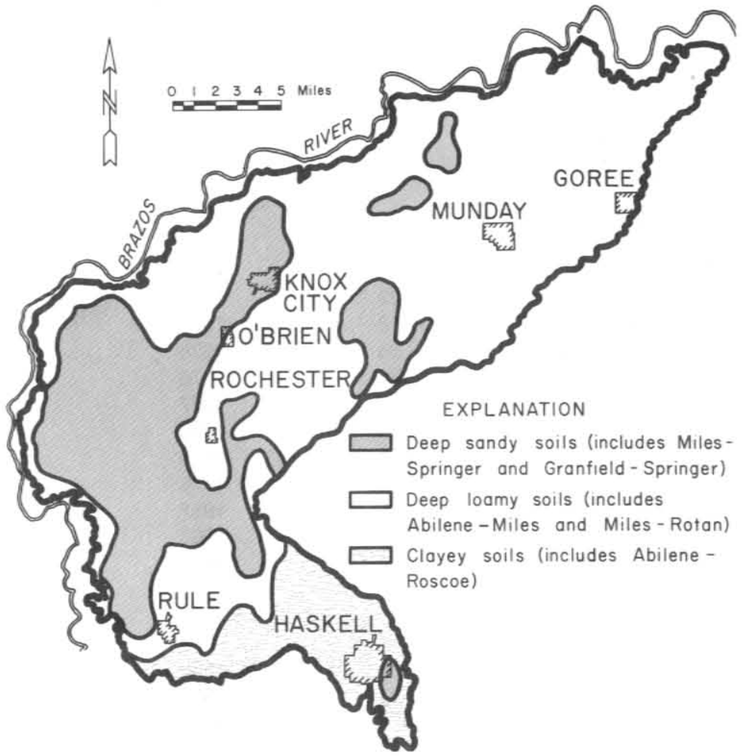

Figure 28. General Soil Map

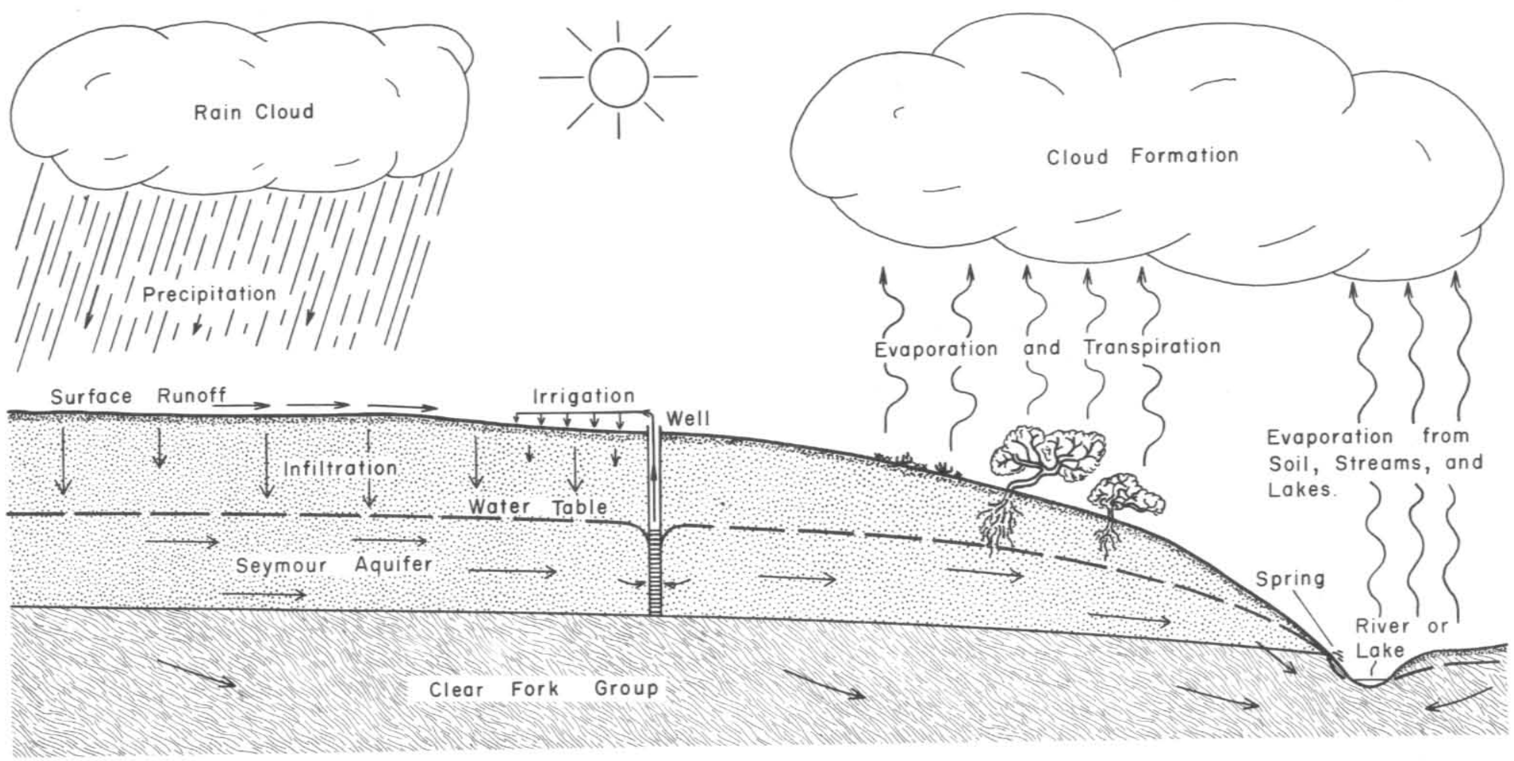

Figure 27. Schematic Diagram of Hydrologic Cycle

Fluctuations of Water Levels

Early water levels in the Seymour were substantially lower than current levels. Gordon (1913) based on work done in 1906 and 1907, reports:

> In places in the upland area also the beds are destitute of water, many wells extending through the gravels into the Permian beds called "Birdseye" by the drillers. The localization of the water in the gravels may be due to collection in basins in the unevenly eroded surface of Permian.

In 1934, Bandy made a two-day investigation consisting largely of interviews with local residents and reported in part as follows:

> Mr. Hudspeth, manager of the City Water Works of Rochester connected with the Water plant for seven years, stated that the water level [in] 1926 in the city well (sheet water in fine gravel) stood at 45 feet below the ground level. At this date it stands at 35 feet, 4 feet of this rise having occurred during the last two years. Pumps and motors had to be moved on this account. Mr. Hudspeth was raised 5 miles west of Rochester. Twenty five years ago the water on his home place was 70 to 75 feet below the surface, the water was hard and gip so much that water was hauled for domestic uses. Now this same well has water standing 45 feet from the ground level and the water is soft and fresh. Laundry work is done without breaking the water. This is a rise of 20 to 25 feet in twenty five years.

A. M. Allen, a resident of the vicinity for 33 years and a well digger in his youth states that he dug a well on his father's place in 1906. The well was located in a canyon near the Brazos River and a well was made at 16 feet. The water level gradually rose until 1918 when it began to run over the top of the well which it still does. Please note that 1917 and 1918 were the driest years of all history of the county and this drouth affected all west Texas. A well dug on the B. E. Carr place 8 miles west of Rochester was dug to a depth of 78 feet where water was found that rose to a depth of 4 feet. The water was very hard. Now the water stands 13 feet from the top and is very soft and fresh. He dug a well in a canyon to a depth of 44 feet near Jud and obtained water to a depth of less than 10 feet in the well. Water is now running over the top of the well.

J. H. Wolf, a resident since 1906 stated that one well on his place one mile west of Rochester stood 75 feet below the top and the water was gip. Now the same well is soft and fresh, water standing at 47 feet from the top. Another well was dug 108 feet finding gip water, this well now has an abundance of soft water at 45 feet. Numerous others were interviewed and their statements all tended to show the same thing: that the rise of ground water in this area is no myth, but a fact, that the rise has been about a foot per year with some little acceleration during the last few years, and the water has changed from hard, gip and salt water to soft, fresh water.

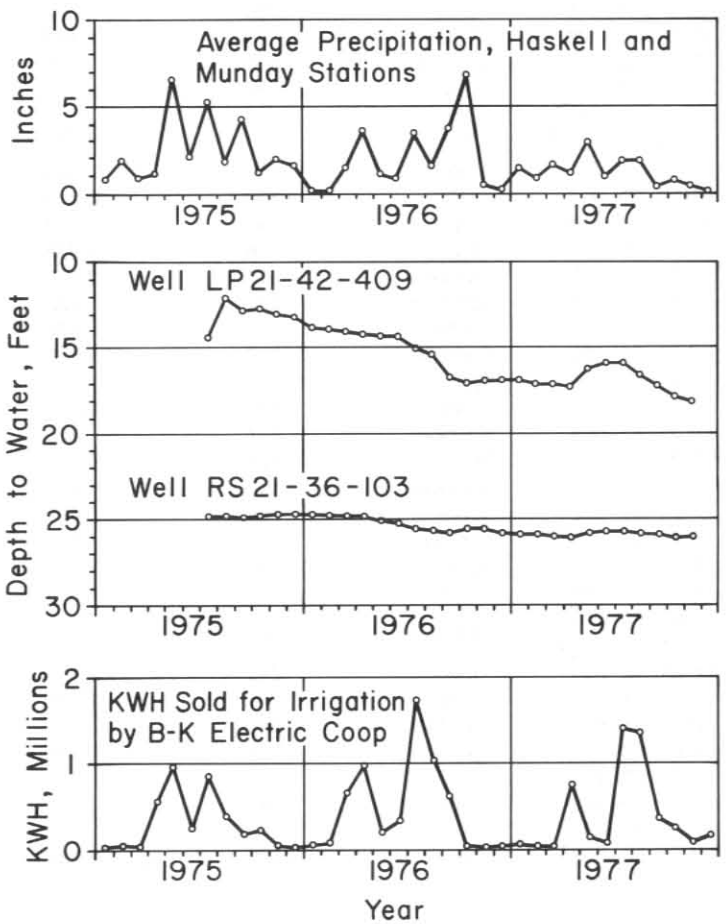

Figure 29. Precipitation, Water Levels, and Electricity Used for Irrigation, 1975–1977

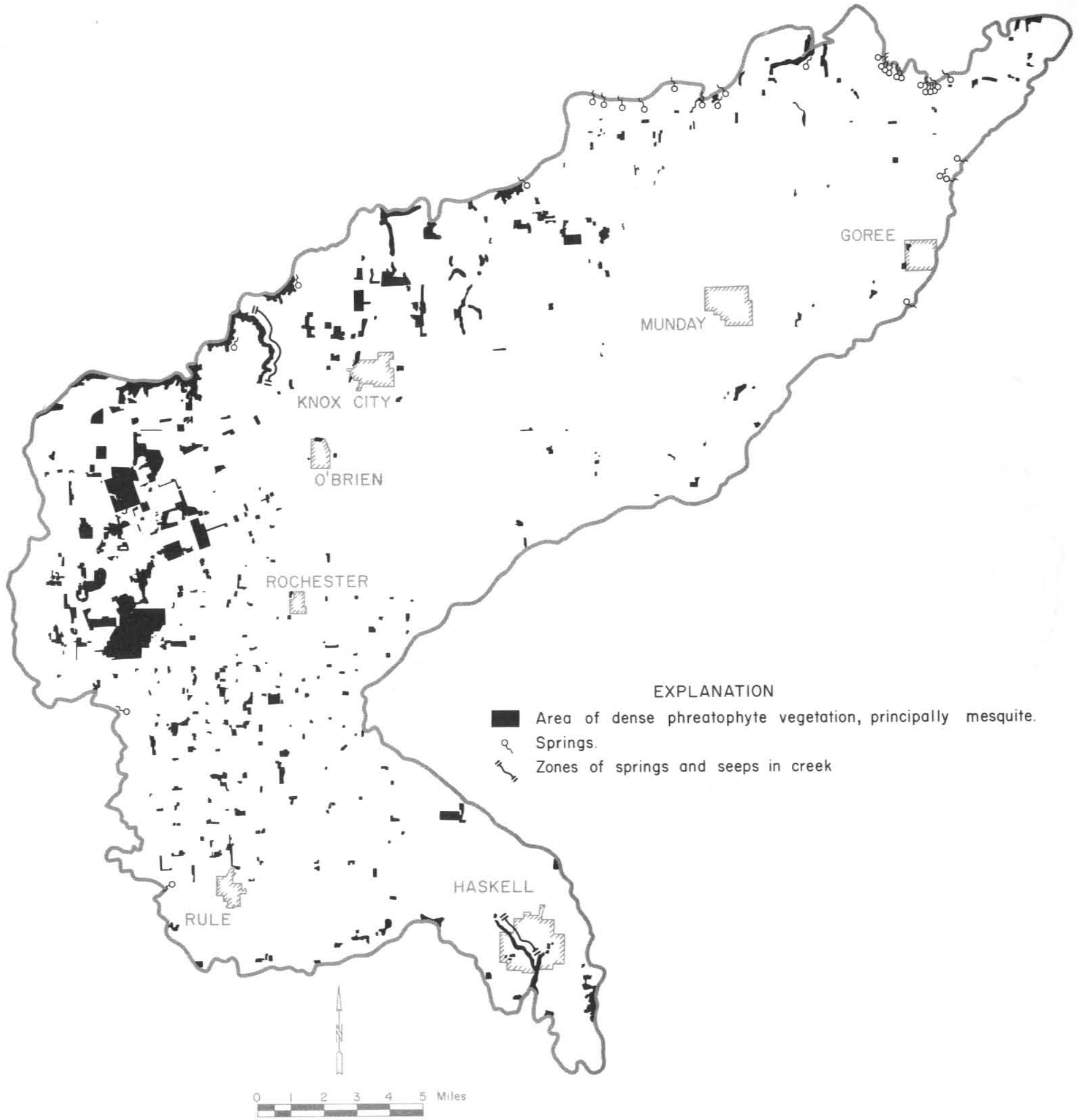

Figure 30. Areas of Natural Discharge From Seymour Aquifer

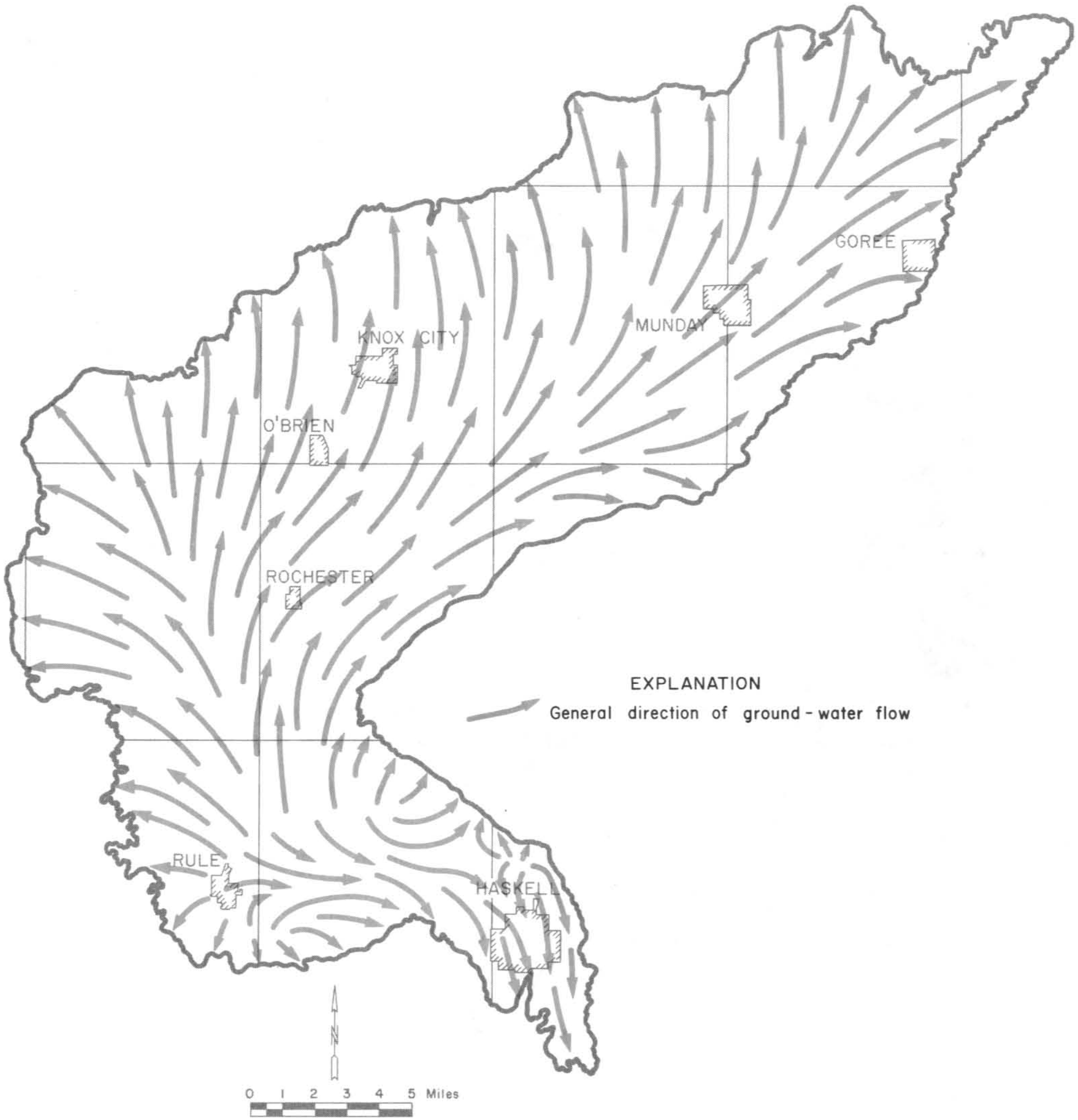

Figure 31. Direction of Ground-Water Flow in Seymour Aquifer

Table 5. Results of Power Tests

Well Number	Type of Discharge*	Pumping Rate (gpm)	Gallons Per Unit of Power (gal/kwh)
RS 21-27-804 RS 21-27-806	Open	289	2,173
RS 21-28-723	Open	102	1,545
RS 21-28-834	Open	273	2,647
RS 21-33-939	Open	609	1,934
RS 21-34-211	Open	80	988
RS 21-34-322	Sprinkler	152	1,707
RS 21-34-443 RS 21-34-444	Sprinkler	175	531
RS 21-34-533	Sprinkler	155	931
RS 21-34-622	Open	335	1,801
RS 21-34-920	Open	98	1,690
RS 21-34-929	Open	128	2,331
RS 21-35-130	Open	382	3,937
RS 21-35-318	Open	330	2,377
RS 21-35-342	Open	63	1,280
RS 21-35-547	Open	58	308
RS 21-35-548	Open	120	2,352
RS 21-35-720	Open	125	1,113
LP 21-35-734	Sprinkler	330	955
RS 21-36-201	Open	276	2,642
RS 21-36-217 RS 21-36-231	Open	385	2,094
RS 21-36-225	Open	258	3,690
RS 21-36-417	Open	360	2,254
RS 21-36-434	Open	30	1,323
RS 21-36-524	Open	178	2,918
LP 21-41-107	Open	514	3,274
LP 21-41-321	Sprinkler	215	622
LP 21-41-328	Sprinkler	258	629
LP 21-41-401	Sprinkler	256	1,113
LP 21-41-416	Sprinkler	95	657
LP 21-41-608	Open	710	2,360
LP 21-41-625	Sprinkler	347	895
LP 21-41-910	Sprinkler	196	652
LP 21-41-916	Sprinkler	134	672
LP 21-41-922	Sprinkler	104	452
LP 21-42-229	Sprinkler	222	1,116
LP 21-42-245	Sprinkler	185	814
LP 21-42-250	Open	370	3,519
LP 21-42-313 LP 21-42-336	Open	387	3,521
LP 21-42-334	Open	242	3,142
LP 21-42-425	Sprinkler	280	1,328
LP 21-42-516	Sprinkler	242	938
LP 21-42-524	Sprinkler	769	3,387
LP 21-42-710	Sprinkler	167	428
LP 21-50-559	Sprinkler	67	593
LP 21-50-652 LP 21-50-653 LP 21-50-654	Open	429	3,351

*Open refers to row irrigation.

As a follow-up to the two-day investigation, Bandy and others inventoried wells in northwestern Haskell County about a month later. Their original notes contain numerous reports of early water levels together with water-level measurements taken in 1934. The exact location of the wells could not be determined during the present investigation, but the records indicate generally the water-level rises occurring in the vicinity of O'Brien and Rochester prior to 1934.

Figure 32 summarizes the data reported by Bandy's survey. The records indicate large water-level rises prior to the mid-1930's. Mainly, the cultivation of the land caused the rising water levels. Prior to cultivation, the area was covered with tall, thick native grasses. Cultivation increased the recharge to the Seymour by decreasing the amount of water lost formerly by evapotranspiration, especially during the growing season of April through October when a large part of the precipitation occurs. Other factors which contributed to the increase in recharge were row-cropping which leaves a large percentage of the sandy soils exposed and contour farming. In more recent times, additional contributing factors have included terracing which has been a common practice in the area since the 1940's, land leveling, and deep plowing. All of these activities, in conjunction with the presence of sandy soils, have increased infiltration to the ground-water reservoir.

Available records indicate that water levels in the Seymour continued to rise during the 1940's, but only slightly. Since the 1950's, water levels have fluctuated in response to pumpage and precipitation cycles.

Average water levels for all Seymour observation wells are summarized for Haskell and Knox Counties on Figure 33. The graphs indicate that beginning in the early 1950's, water levels declined substantially due to drought conditions and the increase in irrigation withdrawals. The average water level in Knox County has changed little during the last 10 years. Water levels in Haskell County have risen substantially over the same time period. The average rise has been approximately 7 feet.

Tables 12 and 13 give past water-level measurements in observation wells. Hydrographs for individual observation wells at representative locations in the Seymour aquifer are shown on Figures 34 and 35. The hydrographs indicate the water-level fluctuations which have occurred in each area. Water levels in the Goree, Munday, and Haskell areas have changed little over the past 5 years. The largest water-level rises in the past decade have been in the Rochester, Rule, and O'Brien areas. The past 5- to 10-year period has been a period of above average precipitation and slightly lower than average ground-water pumpage.

Figure 36 shows the change in water levels from the winter of 1956–1957 to the winter of 1976–1977. Over this 20-year period, a net water-level decline occurred in most wells located to the northeast of a line approximately mid-

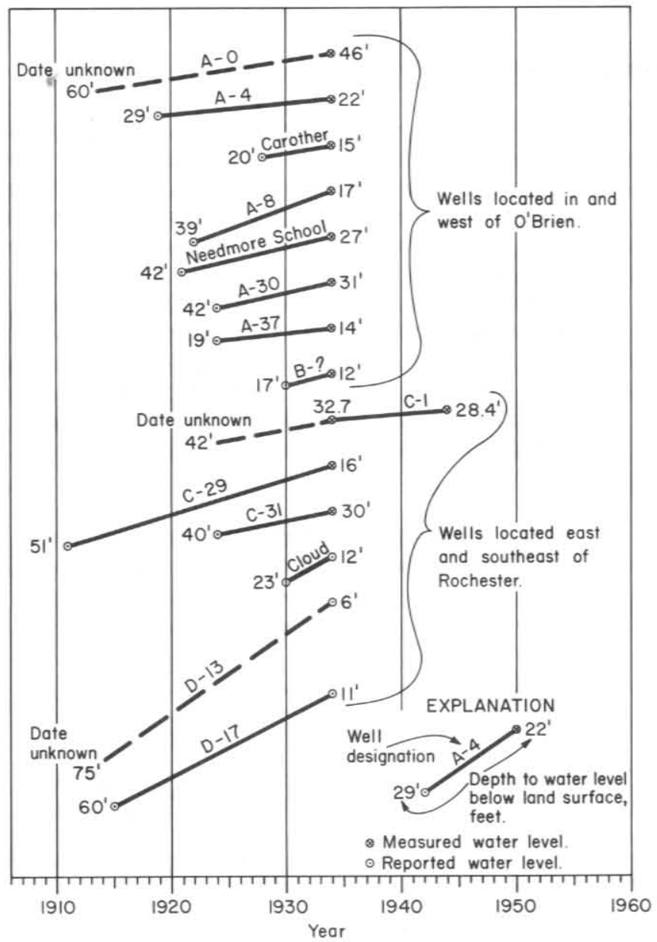

Figure 32. Reported Water-Level Rises in Seymour Aquifer

way between Knox City and Munday. Generally, substantial water-level rises have occurred in those wells located to the southwest of this line. Net water-level declines have averaged approximately 4 feet in the Munday and Goree area over the past 20 years. Water-level rises have averaged 4 to 10 feet over the same period in various areas between Knox City and Haskell.

Areas marked by water-level rises outnumber areas where water-level declines have occurred, and a significant amount of water has been added to storage in the aquifer. It is estimated that the volume of water in storage increased by about 113,000 acre-feet from 1956 to 1976.

Availability of Water

For the 20-year period 1957–1976 inclusive, pumpage from the Seymour totaled approximately 902,000 acre-feet, plus an additional small amount by domestic and livestock wells. Water levels during the same period rose in the southwestern part of the aquifer and declined in the northeastern part. On balance, it is estimated that storage increased in the aquifer by about 113,000 acre-feet. Thus, about 1,015,000 acre-feet was available for pumping over the 20-year period without a change in storage in the aquifer. This amount is equivalent to slightly more than 50,000 acre-feet per year.

Precipitation was above average at Munday and Haskell for the period 1957–1976 and accordingly, recharge to the Seymour was also above average. The precipitation averaged about 26.3 inches for the period, in comparison to a long-term average of 24.5 inches. Proportionally, it is estimated that an average of about 47,000 acre-feet per year is available for pumping from the Seymour under average precipitation conditions.

Quality of Water

All ground water contains dissolved minerals. The concentration and type of constituents present depend on the source of the water and the details of the surface and subsurface environments through which the water has traveled. The chemistry of ground water can be complex.

Essentially, all fresh ground water originates as precipitation which is relatively free of dissolved minerals. When precipitation strikes the ground, it comes in contact with many different soluble materials. The types of soluble materials at the land surface and in the subsurface control the amount of mineral matter incorporated by the water. Time and temperature are important also in determining which minerals are dissolved by water. In addition, the activities of man, particularly waste disposal, can have important effects on ground-water quality.

Dissolved minerals in water may be beneficial, undesirable, or even harmful. For this reason, it is important to know the kinds and amounts of dissolved minerals present in a ground-water supply, and how they effect the water's use.

1975–1977 Sampling Program

To define the existing chemical content of water from the Seymour aquifer, over 1,100 water samples were collected from wells and springs during 1975–1977; most were collected in 1976. Samples were obtained from all municipal wells, from approximately one-third of the existing irrigation wells, and from 247 domestic and stock wells. In selecting wells for sampling, consideration was given to obtaining a representative areal distribution. Also, efforts were made to resample, if possible, all wells which had been sampled previously in order to detect changes in chemical quality. The results are included in Tables 14, 15, and 16.

About 200 samples were obtained for special constituents or from special sources. The results of these analyses are given in Tables 17 through 27.

Laboratories

The laboratory of the Texas Department of Health performed all chemical analyses in accordance with Environmental Protection Agency standards (U.S. Environmental Protection Agency, 1974). Relatively complete chemical analyses were made on approximately 70 percent of the samples. The constituents determined included silica, calcium, magnesium, sodium, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids (calculated), total hardness, specific conductance, and pH. Partial chemical analyses were made on about 20 percent of the samples. Typically, these analyses included specific conductance, chloride, sulfate, nitrate, and fluoride determinations. Determinations of special constituents including pesticides, oil and grease, nitrite, nitrogen cycle, boron, iron, and potassium were made also by the Texas Department of Health's laboratory in Austin. Forty-one samples were submitted to the Bureau of Economic Geology of the University of Texas for nitrogen isotope determination. Techniques described by Kreitler (1975) were used.

Sample Collection, Preservation, and Methodology

Irrigation wells and public supply wells were sampled as close to the pump discharge manifold as possible. The wells were sampled a few minutes after commencement of pumping or soon after arrival if the wells were pumping already. Usually, domestic and stock wells were sampled from pressure tanks. Typically, specific conductance was measured in the field repeatedly during pumping and prior to sampling to determine if water quality variations occurred with pumping time and to preclude sampling until uniform quality was obtained from the well. Only on rare occasions was there any difference between specific conductance measurements taken seconds after commencing pumping and those taken later.

Early in the investigation, duplicate samples were obtained from 27 wells distributed over the project area. One set of samples was refrigerated and delivered to the laboratory. The other set was not cooled. Results of complete analyses on both sets indicated no significant difference in the results of the two sets of samples. Because of these findings and recommendations from the laboratory, all later samples for complete or partial chemical analyses were collected, kept at room temperature, and delivered to the laboratory weekly. Sampling and preservation techniques used for all samples are summarized in Table 6.

Special sampling was done to assist in interpreting the results of past analyses and to learn of natural variations in the formation. Samples were bailed from selected wells from near the total depth of the well and from just below the static water level using a Kemmerer bailer. The results of these analyses are given in Table 19. The bailed samples indicate little stratification of the water in the formation, except in those wells affected by oil field brines.

For several wells, a series of consecutive samples was obtained on start-up directly from open discharge. As shown in Table 20, the results of the consecutive samples show no significant variation in water quality after the first 10 to 20 seconds of pumping.

Previous Sampling Programs (1907–1974)

As a part of the current study, a careful search was made for past chemical analyses of Seymour water. The files of the Texas Department of Water Resources (and predecessor agencies), the U.S. Geological Survey, the Texas Railroad Commission, and the Texas State Department of Health yielded the most analyses. Accurate well locations for over 1,100 previous chemical analyses were determined in the field. These analyses are included in Tables 14, 15, and 16.

Figure 37 shows the distribution through time of the available chemical analyses on water samples collected since 1907. The earliest years for which more than a few chemical analyses are available are 1936, 1944, and 1956. Only two analyses are available before 1936, and only a few are available in any of the years from 1937 to 1944 or from 1945 to 1956. Between 1960 and 1972, a large number of analyses were made by the Texas Railroad Commission, and most consisted of chloride determinations only.

Approximately 180 of the past analyses were made by the U.S. Geological Survey, over 100 by the Texas Department of Health, approximately 700 by the Texas Railroad Commission, and approximately 160 by various private laboratories and Texas A&M University.

The methods of analysis used by the Texas Department of Health and the U.S. Geological Survey are considered approximately equal in precision and satisfactory for most purposes. The precision of the analyses and the techniques

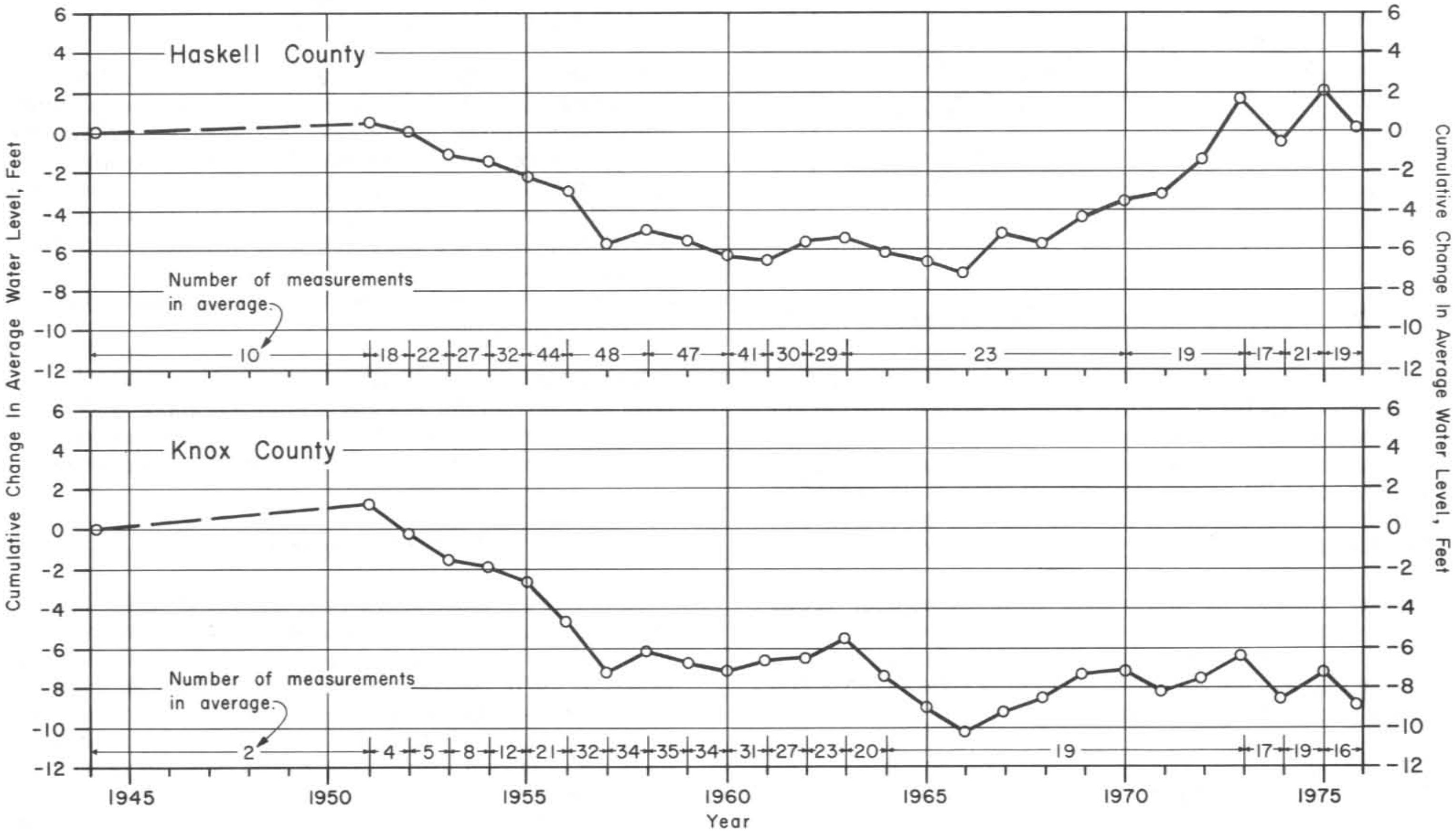

Figure 33. Cumulative Change in Average Water Levels, 1944–1976

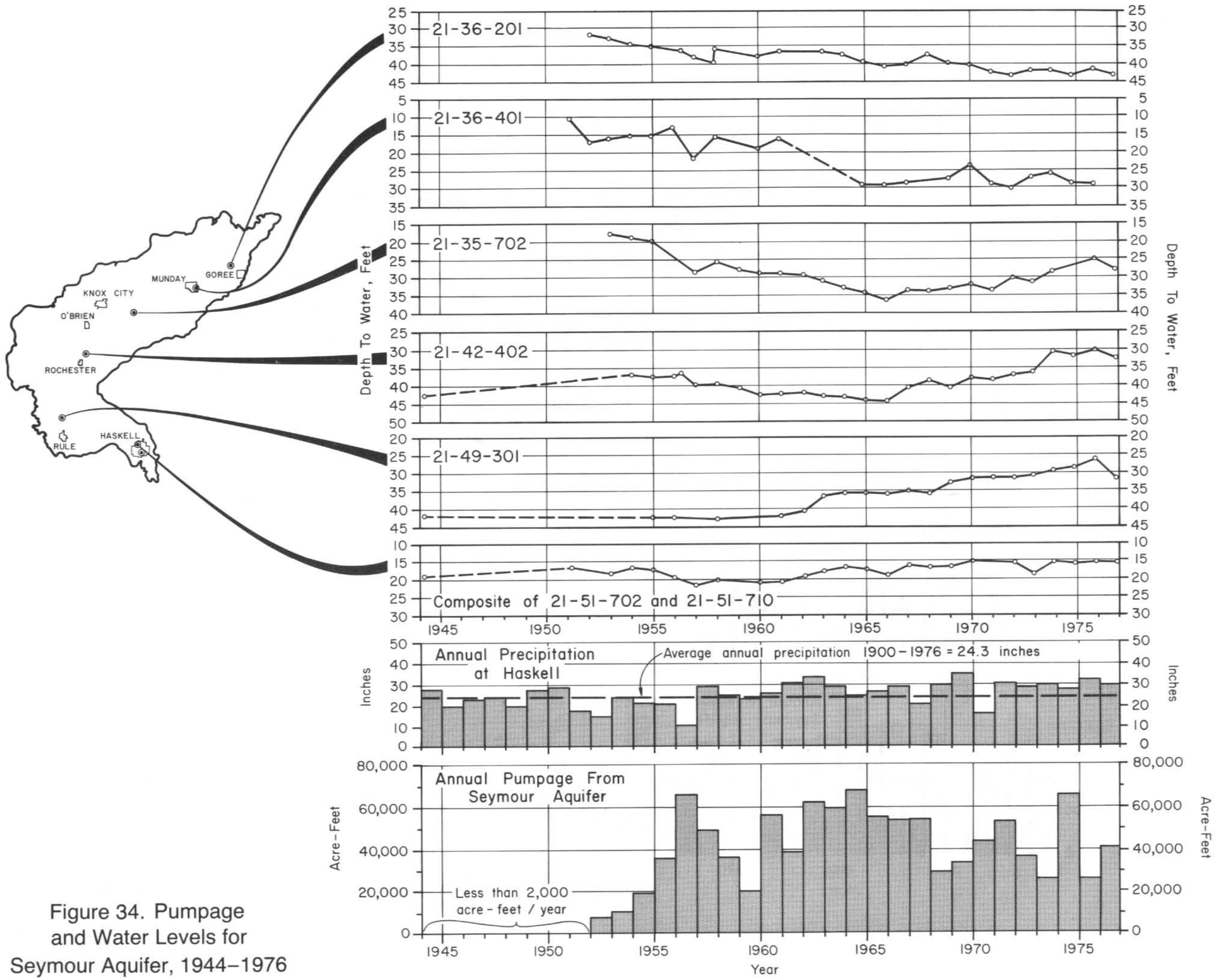

Figure 34. Pumpage and Water Levels for Seymour Aquifer, 1944–1976

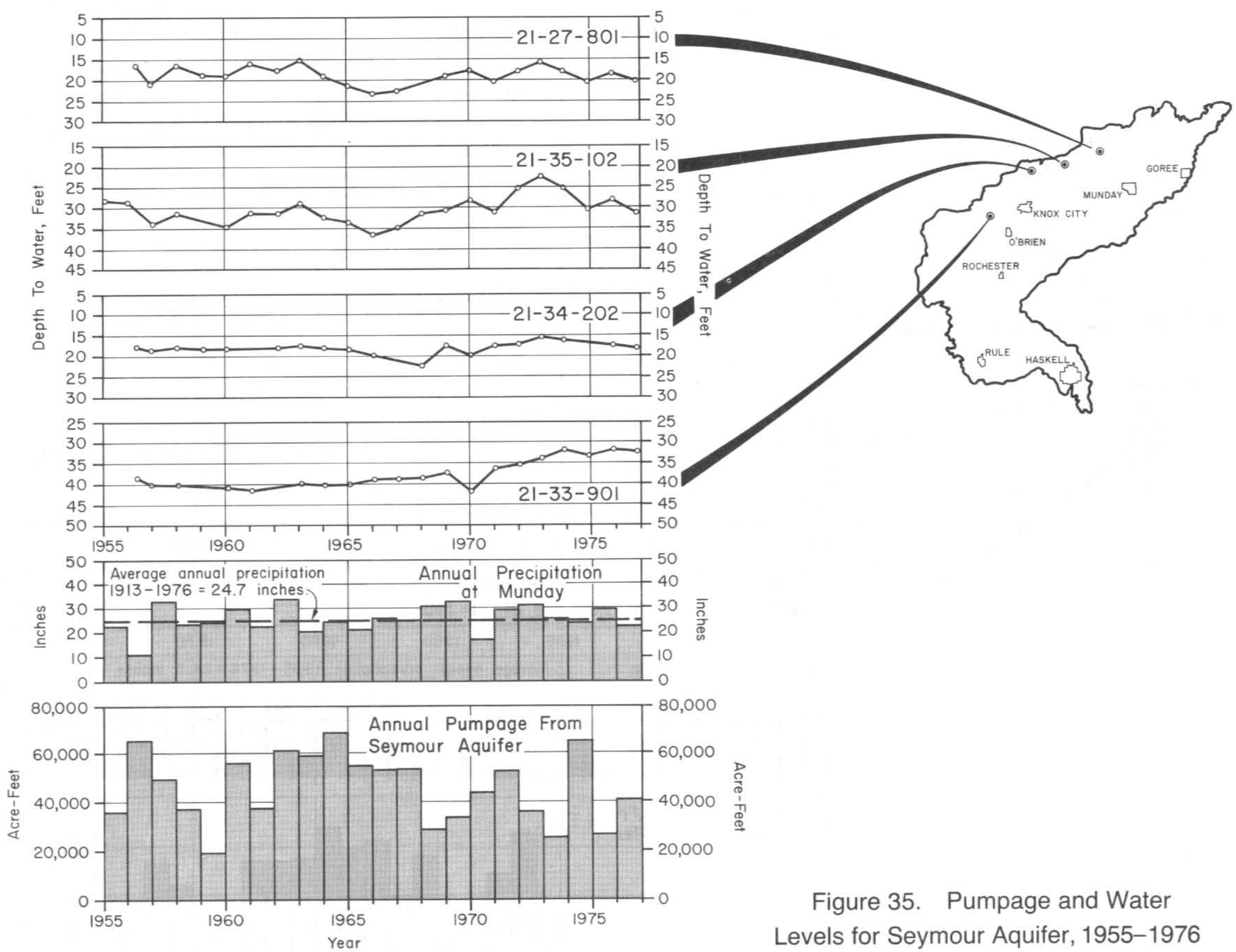

Figure 35. Pumpage and Water Levels for Seymour Aquifer, 1955–1976

Figure 36. Change in Water Levels, 1956–1976

used by the private laboratories and Texas A&M were not investigated. The chloride analyses by Texas Railroad Commission personnel were made using techniques that are not as precise as the techniques used for those samples analyzed by laboratories of the Texas Department of Health or the U.S. Geological Survey. The Railroad Commission analyses were made normally to detect large differences in chloride concentration or particularly high values. They are satisfactory for these purposes, but not for detailed comparisons with other chloride analyses. From a review of the methods used by Railroad Commission personnel and from studying the analyses, it appears that the results are accurate generally within approximately 50 milligrams per liter (mg/l) for chloride concentrations up to approximately 1,000 mg/l.

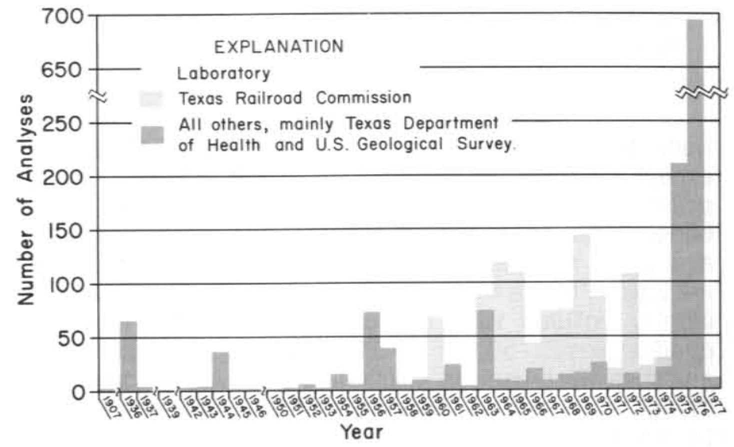

Figure 37. Available Chemical Analyses

Chemical Content of Water

The water in the Seymour Formation is characterized by a wide variability in quality. Large differences in chemical quality occur in adjacent wells. Also, there is a large difference between those areas having the best quality and those having the worst quality. The variance in water quality is due to the wide range in geologic and hydrologic conditions in the Seymour.

The sources, significance, and representative values of selected chemical constituents and properties of Seymour water are summarized in Table 7. Tables 14, 15, and 16 give the results of all complete and partial analyses on wells and springs. A series of water quality maps (Figures 38, 39, 40, 43, 44, and 45) summarize the dissolved solids, chloride, sulfate, nitrate, fluoride, silica, bicarbonate, calcium, magnesium, and sodium content of water from wells tapping the Seymour. The maps are based on the analyses of samples collected during 1975– 1977. The maps include averages of the data by small areas. The averages are calculated for individual 2½-minute quadrangles or for combinations of 2½-minute quadrangles. The averages include all the ana-

Table 6. Water Sampling and Preservation

Type Sample	Method Sampled	Sample Container	Fixing Agent	Cooled To 4°C
Complete water analyses	Pumped	1-liter plastic	None	No
Partial water analyses	Pumped	1-liter plastic	None	No
Nitrogen cycle	Pumped	1-liter glass	H_2SO_4	Yes
Nitrogen isotope	Pumped	1-liter glass	None	Yes
Bailed	Kemmerer bailer	1-liter plastic	None	No
Pesticides	Pumped	1-liter glass w/Teflon lid	None	No
Oil and grease	Pumped	1-liter glass	H_2SO_4	Yes
Oil field brine	Storage tank valve	1-liter plastic	None	No
Consecutive from pumping wells	Pumped	1-liter glass	None	No
Formation extracts	Filtered	1-liter plastic	None	No
Creeks	Grab	1-liter plastic	None	No
Sewage effluent:				
a) Nitrogen cycle	Grab	1-liter glass	H_2SO_4	Yes
b) Complete water analysis	Grab	1-liter plastic	None	No

lyses available on samples obtained during 1975–1977, except for those analyses showing the effects of nitrate pollution from septic tanks or chloride pollution from oil field brine. These analyses, if recognizable, were omitted in averaging, so that the averages would better approximate the typical, native mineral content of the Seymour water. To identify polluted wells is not difficult except in parts of quadrangles 21–50 and 21–51. In these quadrangles, all the analyses were used in calculating the average data, even though some of the analyses probably indicated pollution from oil field brine.

The following sections of the report summarize the occurrence and concentrations of the principal constituents in Seymour water. The water quality maps portray the data in a graphic manner. For the exact results of individual analyses or for detailed studies of local areas, see Tables 14, 15, and 16.

Dissolved Solids Content

Figure 38 summarizes the dissolved solids content of the Seymour water based on the 1975–1977 analyses. The dissolved solids content was not determined in the laboratory. It represents a calculated sum based on complete analysis of each water sample. For those samples having only partial analyses, the dissolved solids content, as shown on Figure 38, was estimated based on correlation of specific conductance with the calculated dissolved solids content of complete analyses.

The dissolved solids content of water from individual wells ranges from a low of 300 mg/l to over 3,000 mg/l. Most values are between 400 and 1,000 mg/l. Areas having the lowest dissolved solids content are principally in the western part of the area. They coincide with the significant recharge areas having sandy soils as indicated on the soil map (Figure 28).

Areas where the Seymour water contains higher dissolved solids content are in the vicinity of Munday, in an area extending northwest from Haskell, and in a small area west of Knox City. Numerous values are between 1,500 and 3,000 mg/l. Other scattered localities exist where the dissolved solids content is in excess of 1,500 mg/l. They are mostly outside the area of more significant recharge. Some of the localities having higher mineralization are affected by pollution from oil field brine, but most represent natural occurrences of more mineralized water.

Chloride Content

The chloride content of water from the Seymour aquifer varies within wide limits. Figure 39 summarizes the available analyses for samples collected during 1975–1977. The chloride content of water from individual wells ranges from less than 10 mg/l, for a few wells north of Rule, to over 750 mg/l. For approximately 75 percent of the wells sampled, the chloride content is less than 250 mg/l. The lowest chloride values are in the same areas having the lowest dissolved solids values. The highest values are in the vicinity of Haskell, in several areas in the general vicinity of Munday, and at a few scattered localities. Some of the higher chloride values represent natural mineralization in the Seymour or possibly the effect of Permian inflow. Others represent pollution from oil field brine or septic tanks.

Sulfate Content

Sulfate content for individual wells ranges from less than 20 mg/l to over 1,000 mg/l (Figure 40). About 75 percent of the analyses indicate water containing less than 250 mg/l. The regional sulfate distribution is similar to that of dissolved solids and chloride. Some of the wells, exhibiting water with sulfate contents in excess of 500 mg/l, are believed to draw from both the Seymour and underlying Permian deposits or to be in areas where the Permian may be leaking into the Seymour aquifer.

Chloride/Sulfate Ratio

Figure 41 shows the average ratio of chloride to sulfate content by area. The average ratio is near 1 for large areas of the Seymour, even though average chloride and sulfate concentrations vary widely from areas of lower to areas of higher mineralized water. The average chloride/sulfate ratio tends to be significantly less than 1 in recharge areas where overall mineralization is low and also in areas where Permian formations are believed to contribute to the Seymour. The average chloride/sulfate ratio is considerably greater than 1 only in quadrangles 21–50 and 21–51.

The chloride/sulfate ratio is a useful indicator of pollution from oil field brines because oil field brines have very high chloride content relative to sulfate content. Consequently, the mixture of even small quantities of oil field brine with natural water results in a significant increase in the chloride/sulfate ratio. For individual wells and springs showing effects of pollution from oil field brines, the chloride/sulfate ratio ranges from about 1.3 to over 35; values of 2 to 10 are common.

The chloride/sulfate ratio is also an indicator of the influence of Permian water. Chloride/sulfate ratios are low for Permian waters which are high in sulfate content. Mixture of such waters with Seymour water results in low chloride/sulfate ratios. Individual wells believed to be drawing from both the Permian and Seymour typically have chloride/sulfate ratios of less than 0.3 and higher chloride and sulfate content than normal for a local area.

Nitrate Content

Nitrogen occurs in most natural waters predominantly as nitrate. Sometimes nitrogen is present in water in other forms including ammonia, nitrite, and organic nitrogen. To check Seymour waters for the occurrence of nitrogen in forms other than nitrate, 20 samples were collected for nitrogen cycle analyses. The results, shown in Table 24, indicate that the nitrogen present is in the form of nitrate except in some wells which exhibit small amounts of nitrite.

Nitrate and nitrite analyses were performed on most all of the water samples collected during 1975–1977. Of 898 analyses, 744, or 83 percent, had nitrite contents of 0.06 mg/l or less. The results of the analyses showing more than 0.06 mg/l nitrite are listed in Table 25 together with nitrate results. Some nitrite values are as high as 15 mg/l, but most are less than 1 mg/l. All wells showing values of more than 1 mg/l are irrigation wells or domestic or stock wells of large diameter. No values larger than 0.06 mg/l were reported for any of the public supply wells.

Table 7. Representative Values, Sources, and Significance of Selected Chemical Constituents and Properties of Seymour Water

Constituent or Property	Representative Value	Source or Cause	Significance
Silica	18–35 mg/l	Dissolved from most all rocks and soils, commonly less than 30 mg/l.	Forms hard scale in pipes and boilers. Carries over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.
Iron	Typically < 0.2 mg/l	Dissolved from most all rocks and soils. May be derived also from iron pipes, pumps, and other equipment.	On exposure to air, oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stains laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Texas Department of Health (1977) drinking water standards recommend that iron not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.
Calcium and Magnesium	50–220 mg/l 10–110 mg/l	Dissolved from most all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; prevent formation of soap lather (see Hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.
Sodium and Potassium	40–350 mg/l 3–10 mg/l	Dissolved from most all rocks and soils. Found also in oil field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. High sodium content may limit the use of water for irrigation.
Bicarbonate	300–450 mg/l	Caused by action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Produces alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, causes carbonate hardness.
Sulfate	35–500 mg/l	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Present in some industrial wastes.	In water containing calcium, forms hard scale in steam boilers. In large amounts in combination with other ions, gives bitter taste to water. Texas Department of Health (1977) drinking water standards recommend that the sulfate content not exceed 300 mg/l.
Chloride	20–675 mg/l	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. Texas Department of Health (1977) drinking water standards recommend that chloride content not exceed 300 mg/l.
Fluoride	0.3-2.4 mg/l	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	In drinking water, reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, may cause mottling of the teeth depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950). Texas Department of Health (1977) drinking water standards set a maximum limit of 1.6 mg/l for Haskell and Knox Counties.
Nitrate	20–120 mg/l	Derived from soil, fertilizers, sewage, and decaying organic matter.	Concentration much greater than the local average may suggest pollution. Texas Department of Health (1977) drinking water standards set a maximum limit of 45 mg/l. Waters of high nitrate content have caused methemoglobinemia (a sometimes fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950). Encourages growth of algae and other organisms which produce undesirable tastes and odors.
Boron	Typically < 1.0 mg/l	A minor constituent of rocks and of natural waters.	Excessive amount will make water unsuitable for irrigation. Wilcox (1955) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruits and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.
Dissolved Solids	440–2,000 mg/l	Chiefly mineral constituents dissolved from rocks and soils.	Texas Department of Health (1977) drinking water standards recommend that dissolved solids not exceed 1,000 mg/l.
Total Hardness as $CaCO_3$	250–800 mg/l	In most waters, nearly all the hardness is due to calcium and magnesium.	Consumes soap before a lather can form. Causes soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.

Table 7. Representative Values, Sources, and Significance of Selected Chemical Constituents and Properties of Seymour Water—Continued

Constituent or Property	Representative Value	Source of Cause	Significance
Specific Conductance	700–2,900 mmhos/cm at 25°C (mmhos/cm)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.
pH (hydrogen ion concentration)	7.1–8.0	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. Generally, corrosiveness of water increases with decreasing pH. However, excessively alkaline waters may also attack metals.
Percent Sodium	30–60 percent	Sodium in water.	A ratio (using equivalents per million) of the sodium ions to the total sodium, calcium, and magnesium ions. A sodium percentage exceeding 50 percent is a possible indication of a sodium hazard. Continued irrigation with this type of water may impair the tilth and permeability of the soil.
SAR (sodium adsorption ratio)	Typically < 10	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954). Defined by the following equation: $SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$ where Na^{+}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (meq/l) of the respective ions. Used in conjunction with specific conductance to evaluate waters for irrigation purposes.
RSC (residual sodium carbonate)	Typically < 1.25 meq/1	Sodium and carbonate or bicarbonate in water.	As calcium and magnesium precipitate as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950). [Defined by the following equation: $RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{++} + Mg^{++})$ where CO_3^{--}, HCO_3^{-}, Ca^{++}, and Mg^{++} represent the concentrations in milliequivalents per liter (meq/l) of the respective ions.] Used to evaluate waters for irrigation purposes.

Note: Explanations modified from Klemt, et al (1976)

The measurable nitrite values are believed to result from organic matter in the wells creating an environment conducive to the reduction of nitrate in and near the well bore to nitrite. Very low nitrite values are indicated for wells protected from surface contamination and runoff.

Figure 43 summarizes the nitrate content based on the 1975–1977 analyses. The nitrate content for individual wells ranges from 8 mg/l to 935 mg/l. Most values are between 30 and 90 mg/l. The average nitrate content for 2½-minute quadrangles is between 40 and 70 mg/l, generally. The highest nitrate values, which occur mostly in parts of quadrangles 21-50 and 21-51, average between 111 and 154 mg/l.

There are 23 widely-scattered domestic and stock wells which show nitrate contents in excess of 150 mg/l. These wells represent approximately 9 percent of the domestic and stock wells sampled during this investigation. Of the 23 wells, nine wells have nitrate contents between 150 and 200 mg/l, eight between 200 and 300 mg/l, five between 300 and 400 mg/l, and one has 935 mg/l. It is believed that all are affected by septic tank, barnyard, or similar wastes.

Only a few irrigation wells in the Haskell area in quadrangles 21-50 and 21-51 show nitrate contents in excess of 150 mg/l. The highest nitrate contents for irrigation wells, outside of the Haskell area, range from approximately 90 mg/l to 130 mg/l.

Nitrate values for wells furnishing municipal needs have the following ranges:

	Number of Wells	Range in Nitrate Content (mg/l)
Aspermont	3	56-57
Benjamin	2	41-51
Goree	3	40-53
Haskell	11	71-148
Knox City	3	75-78
Munday	4	50-60
O'Brien	1	118
Rochester	1	63
Rule	4	40-73
Weinert	2	50-52

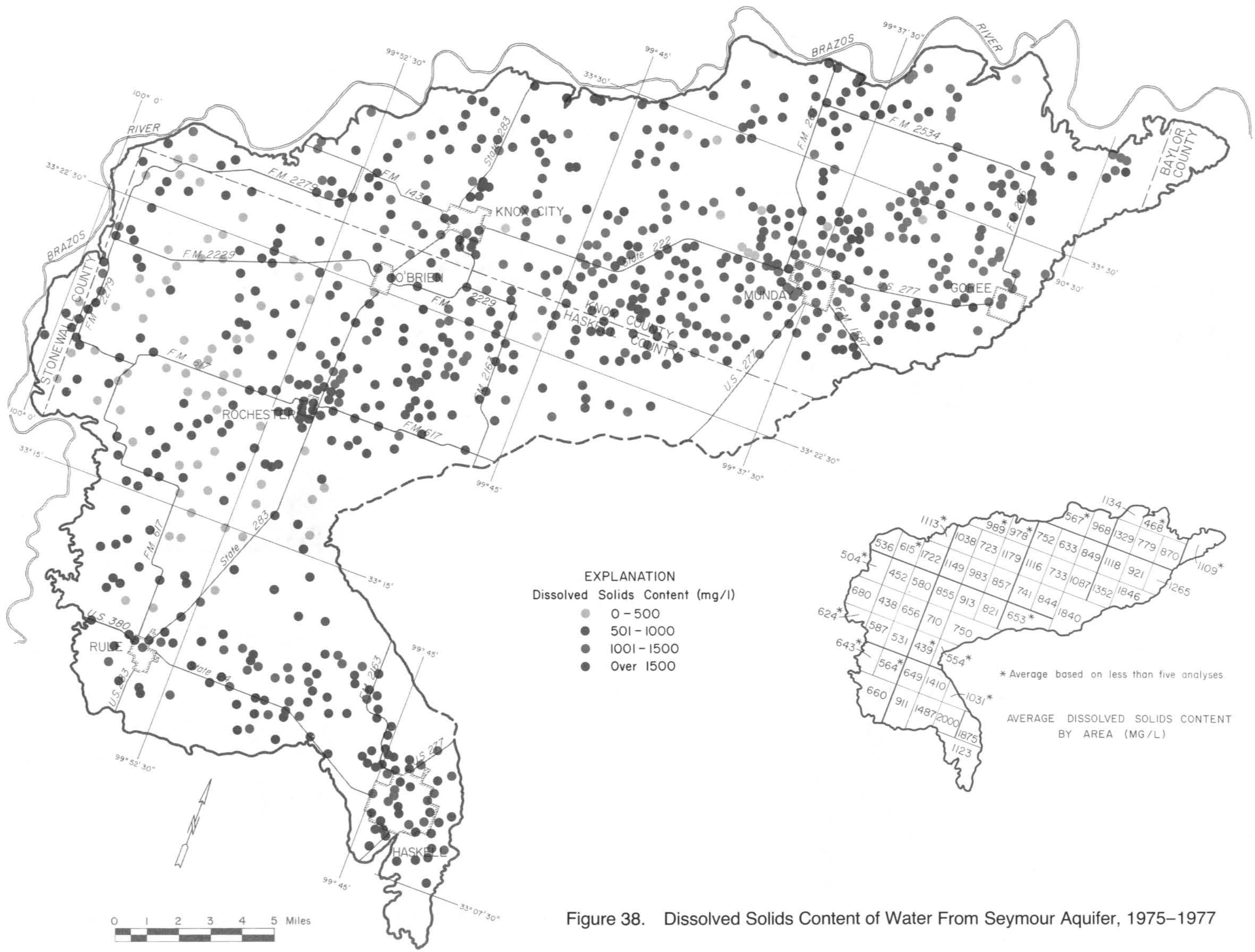

Figure 38. Dissolved Solids Content of Water From Seymour Aquifer, 1975–1977

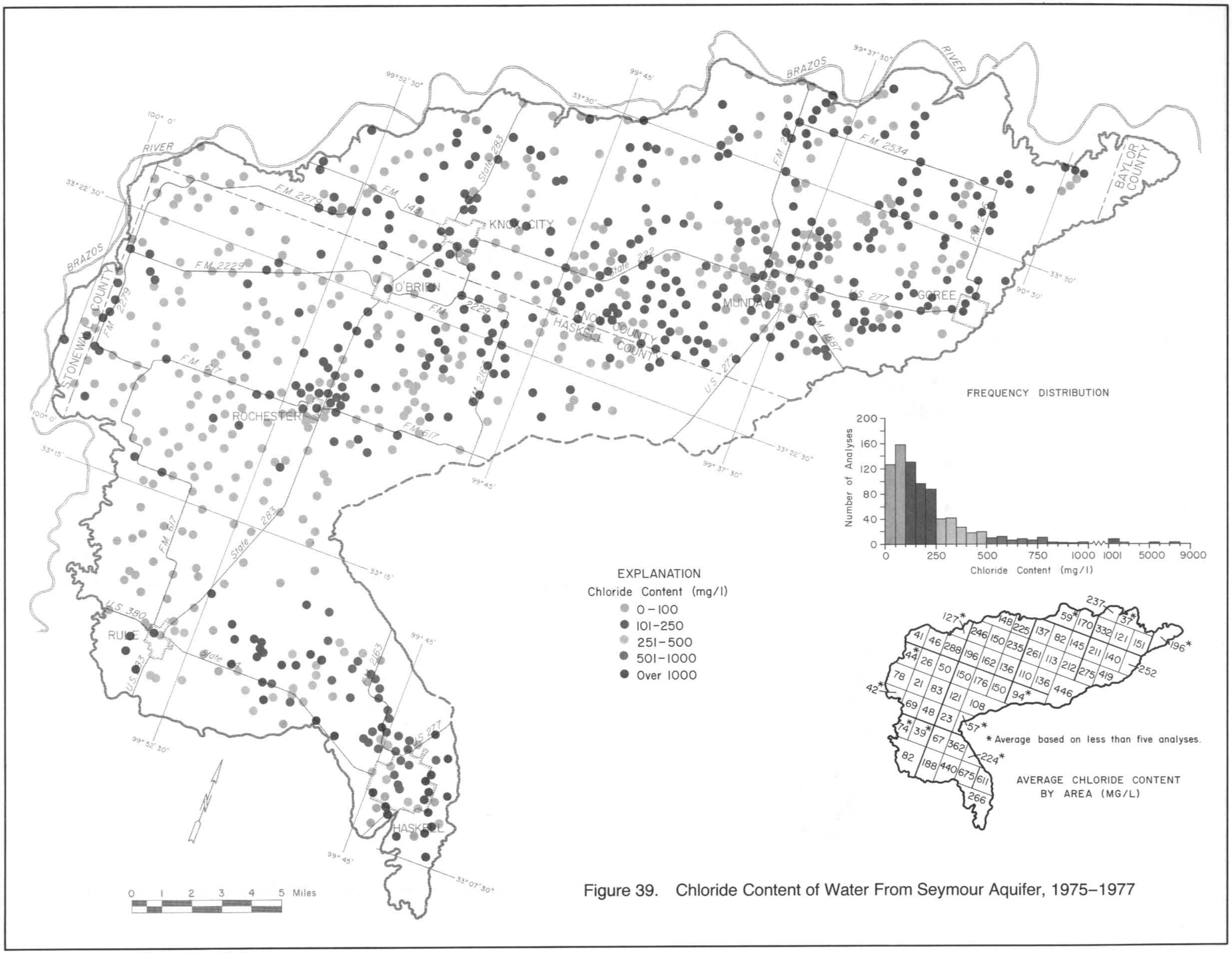

Figure 39. Chloride Content of Water From Seymour Aquifer, 1975–1977

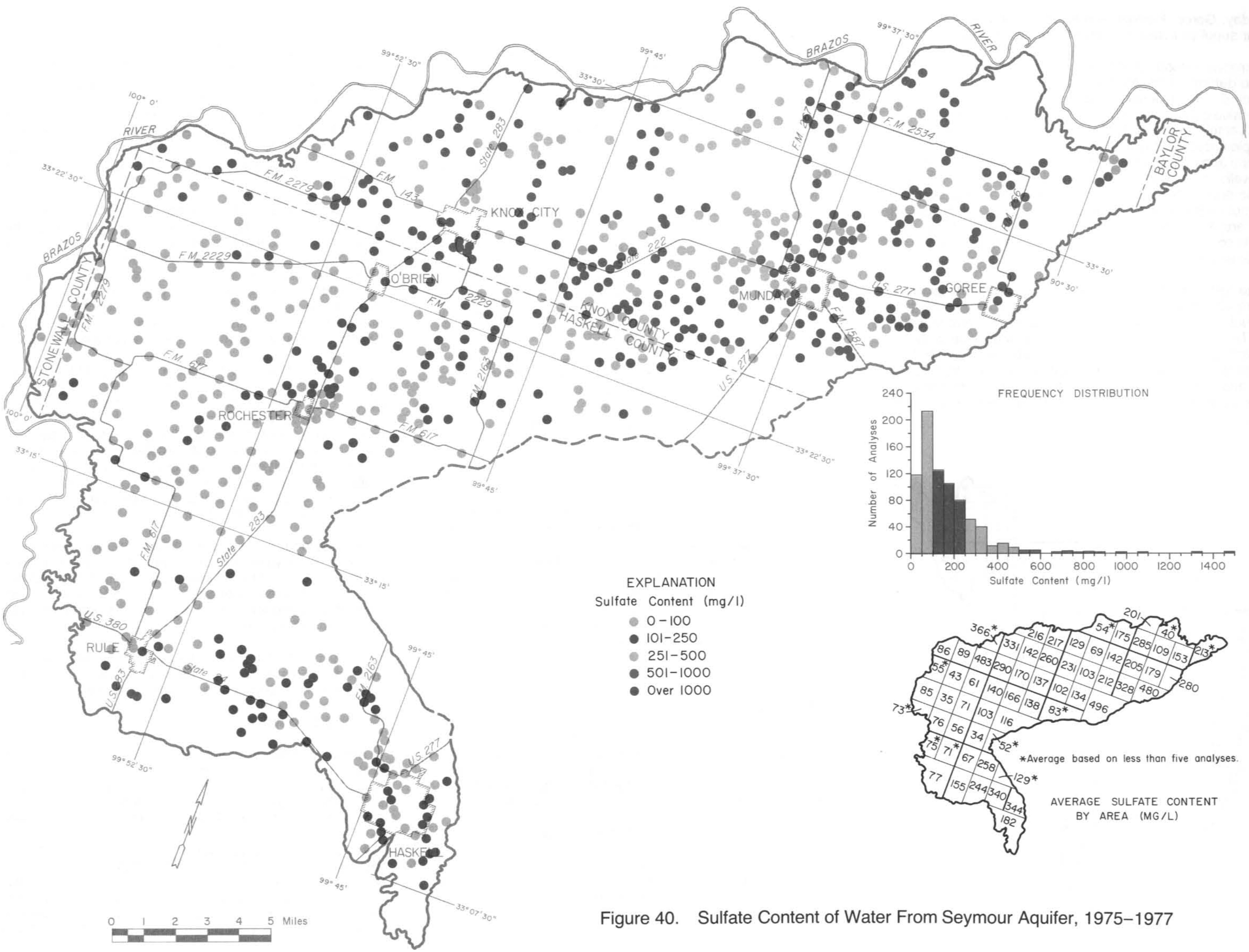

Figure 40. Sulfate Content of Water From Seymour Aquifer, 1975–1977

Munday, Goree, Haskell, and Knox City will have alternate water supplies available from Millers Creek Reservoir.

Nitrogen isotope values have been used by various workers to determine the source of nitrate in natural water (Kohl and others, 1971; Jones, 1973; and Kreitler, 1975 and 1978). The value determined is del N15 which is a ratio of N15/N14 of a sample to the N15/N14 of a standard. Ground-water samples from 37 Seymour wells were subjected to nitrogen isotope analysis. Samples were obtained from 6 public supply wells, 16 irrigation wells, and 15 domestic wells. The public supply and irrigation wells were scattered over the Seymour aquifer and contained nitrate contents typical for their areas. All domestic and stock wells sampled had high nitrate contents, indicating pollution from domestic or animal waste sources.

The results of the nitrogen isotope analyses are given in Figure 42 and in Table 18. The del N15 values for irrigation and public supply wells range from 2.6 to 11.4 and average 7.6. These values are within the range indicative of water containing nitrate derived from cultivated soils. The del N15 values for the 15 domestic and stock wells range from 7.3 to 17.6 and average 10.9. This is within the range indicative of water containing nitrate derived from domestic and animal wastes.

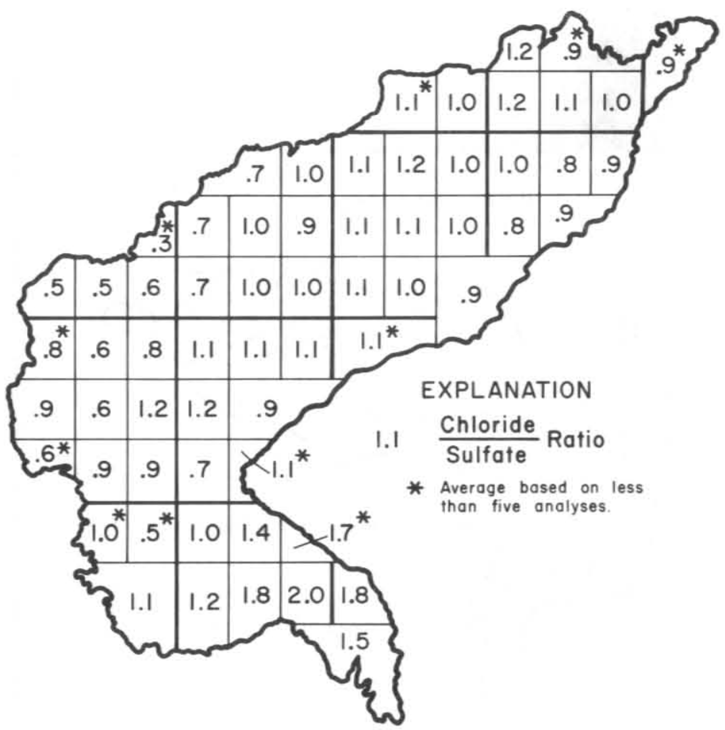

Figure 41. Average Chloride/Sulfate Ratio by Area

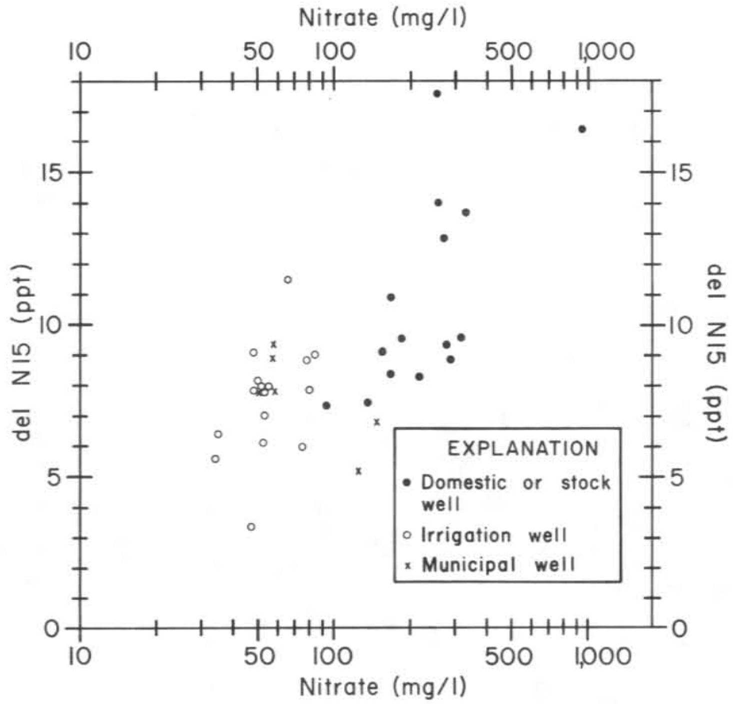

Figure 42. Nitrate vs. del N15 Analyses

Fluoride Content

Figure 44 summarizes the fluoride content of the Seymour water based on the 1975–1977 analyses. The fluoride content for individual wells ranges from 0.2 to more than 3.5 mg/l. Most values are between approximately 0.4 and 2.0 mg/l. Approximately 70 percent of the analyses indicate water containing less than 1.6 mg/l. The lowest values are typically in the Rule-Rochester area. Generally, the higher values are at scattered locations or in quadrangles near the edge of the aquifer including 21-29-4, 21-34-3, 21-34-6, 21-36-3, and 21-51-7.

Other Constituents

The average silica, bicarbonate, calcium, magnesium, and sodium contents of Seymour water are shown on Figure 45. The silica and bicarbonate values vary within reasonably narrow limits. The other constituents vary considerably, but lower values are typically in and near recharge areas.

Suitability of Water for Use

Standards for the chemical suitability of water depend on the proposed use of the water. Irrigation, public supply, and domestic purposes are the most important for the Seymour.

Irrigation

The chemical quality of water is an important factor to be considered in evaluating its usefulness for irrigation. Whether water can be used successfully for irrigation depends on many factors including the total concentration of dissolved salts and the concentrations and relative proportions of individual constituents. Among other factors to be considered are the nature and composition of the soil and subsoil, amount of water used, methods of application, type of crop, and climate.

Typically, the suitability of water for irrigation is evaluated with respect to four factors (U.S. Salinity Laboratory Staff, 1954): the total concentration of soluble salts; the relative proportion of sodium to calcium and magnesium; the amount of boron (or other elements toxic to plants); and under some conditions, the bicarbonate content as related to calcium and magnesium content. These four conditions have been termed, respectively: the salinity hazard, the sodium (alkali) hazard, the boron hazard, and the bicarbonate ion hazard.

The salinity hazard is evaluated normally in terms of specific conductance. A widely used diagram for this purpose is by the U.S. Salinity Laboratory (1954), reproduced as Figure 46. Specific conductance is plotted on one axis of the graph and is used to rate the degree to which a particular water may give rise to salinity problems. The specific conductance of much of the Seymour water is between 750 and 2,000 mmhos/cm which is in the high salinity hazard portion of the graph, even though the Seymour water is generally satisfactory for irrigation.

The Seymour water has been used for irrigation continuously for many years, and no widespread salinity problems have developed. The salinity hazard has been reduced, most likely, due to the generally sandy, permeable, and well-drained soils and the cultivation of crops which have a relatively high salt tolerance.

The sodium adsorption ratio (SAR) is used to evaluate the sodium (alkali) hazard. The sodium adsorption ratio for water from the Seymour is typically less than 10. This indicates normally that the water can be used for irrigation in almost all soils with little danger.

The boron content of the Seymour water is typically less than 1.0 mg/l. The water is considered good to excellent according to the most widely used standards for rating the suitability of irrigation water for various crops on the basis of boron concentration (U. S. Salinity Laboratory Staff, 1954).

The bicarbonate ion hazard is evaluated by calculating the residual sodium carbonate (RSC: Defined as twice the amount of carbonate or bicarbonate a water would contain after subtracting an amount equivalent to the calcium plus the magnesium content.). Values for the Seymour water are typically less than 1.25 meq/l which is considered a safe level.

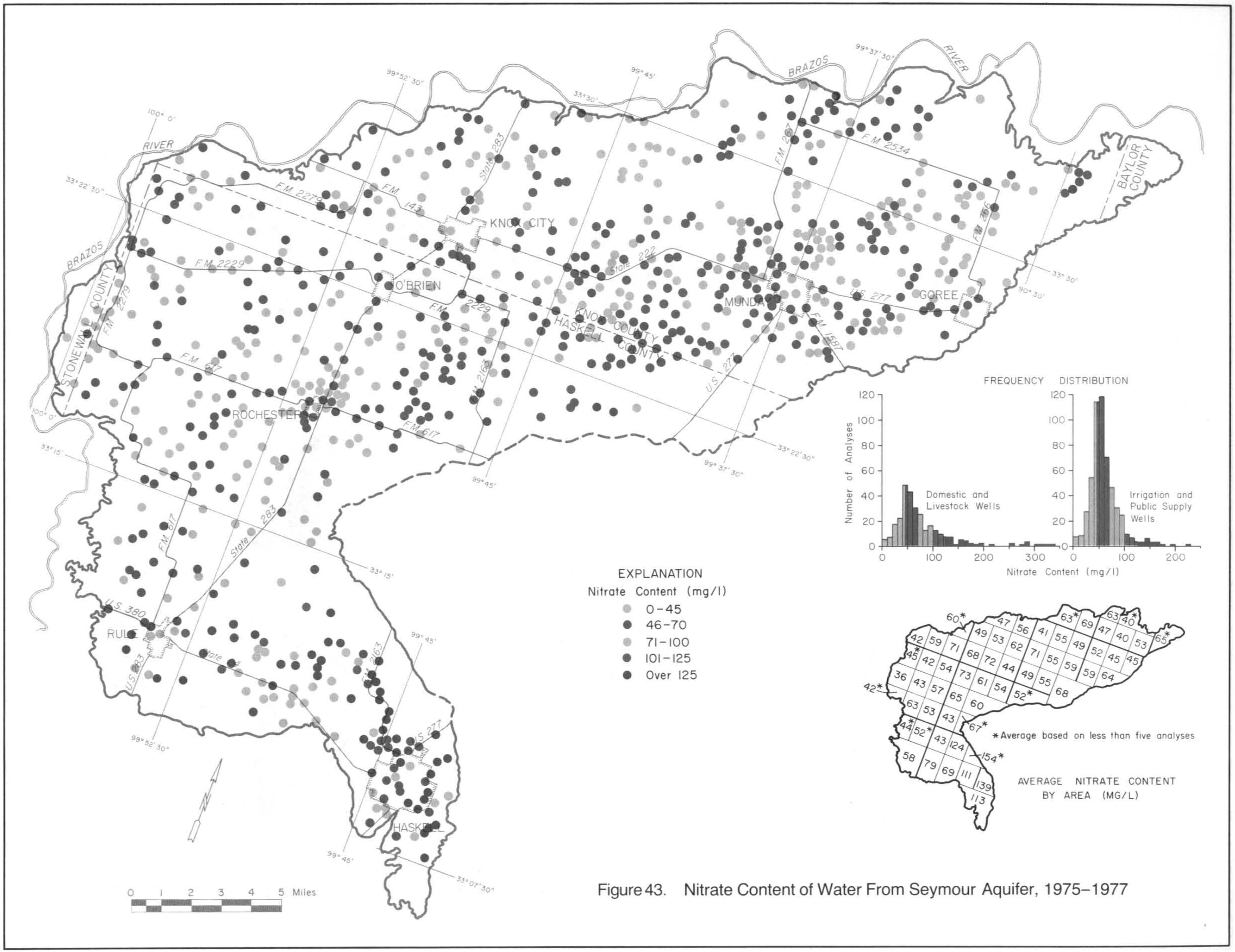

Figure 43. Nitrate Content of Water From Seymour Aquifer, 1975–1977

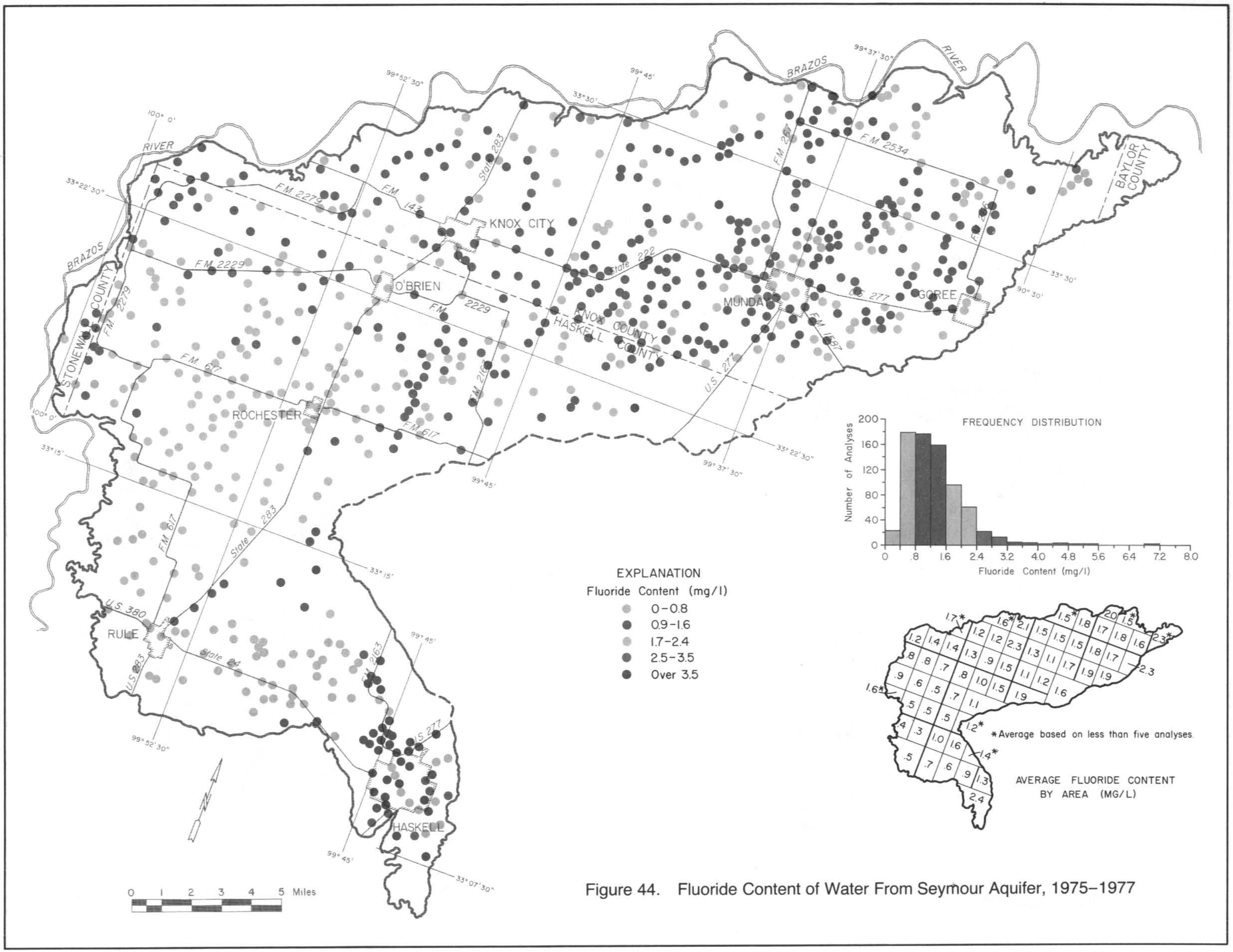

Figure 44. Fluoride Content of Water From Seymour Aquifer, 1975–1977

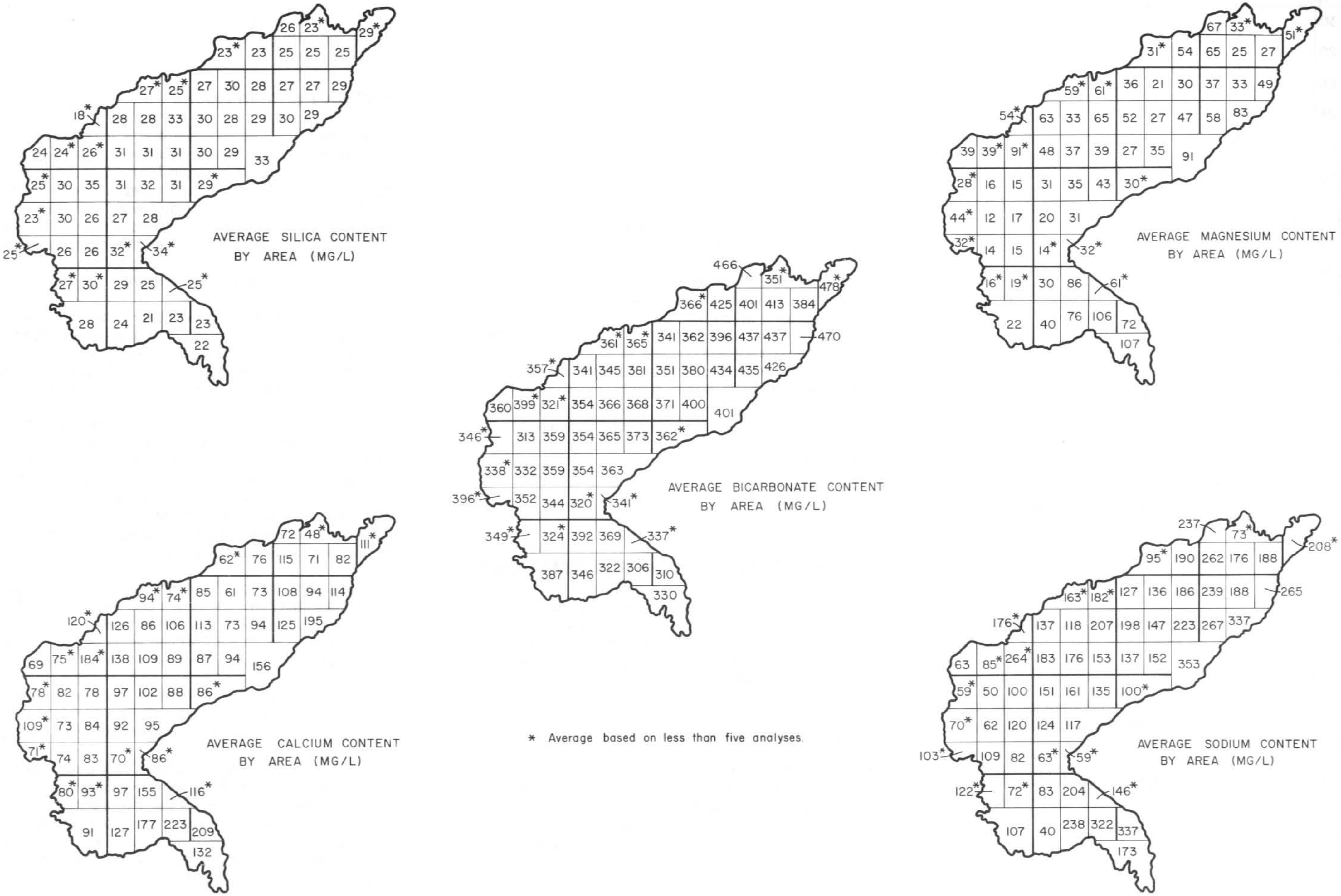

Figure 45. Average Silica, Bicarbonate, Calcium, Magnesium, and Sodium Content of Water From Seymour Aquifer, 1975–1977

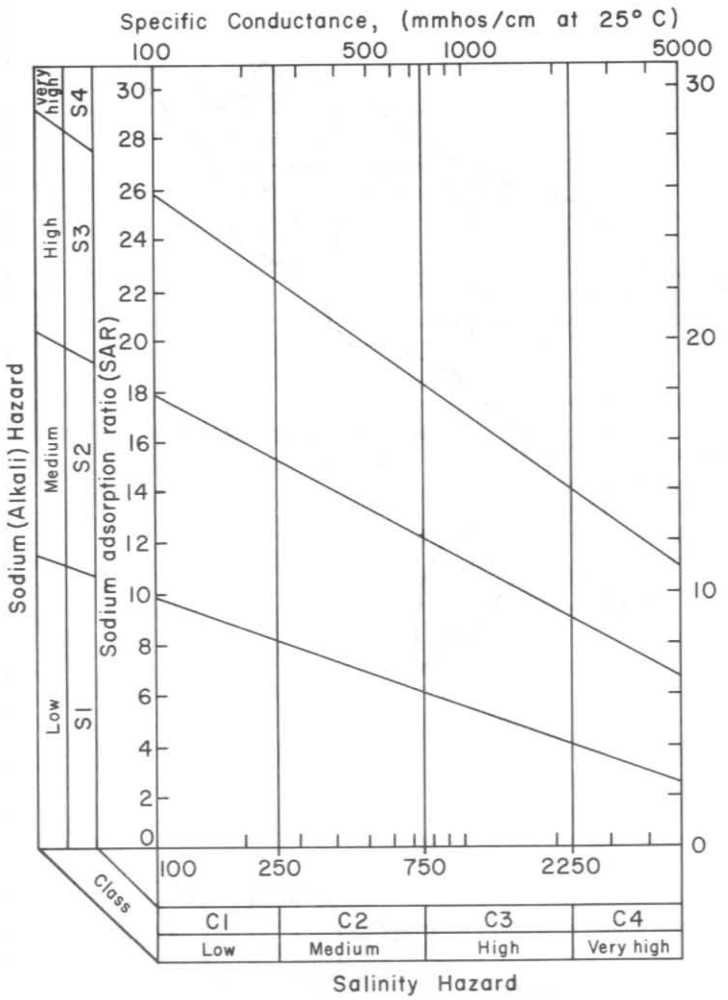

Figure 46. Diagram for Classification of Irrigation Waters

Public Supply

Current standards of the Texas Department of Health (1977) for the inorganic chemical suitability of drinking water include the following limits:

Maximum Limits for Inorganic Constituents

Constituent	Limit (mg/l)
Arsenic	0.05
Barium	1.
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as NO_3)	45.
Selenium	0.01
Silver	0.05
Fluoride (based on an annual average maximum daily air temperature between 70.7 and 79.2°F.)	1.6

Recommended Limits for Inorganic Constituents

Constituent	Limit (mg/l)
Chloride	300
Copper	1.0
Hydrogen sulfide	0.05
Iron	0.3
Manganese	0.05
Sulfate	300
Total dissolved solids	1,000
Zinc	5.0

In some areas and individual localities, the water from the Seymour contains constituents in excess of the recommended limits. Those items which more commonly exceed the limits include nitrate, fluoride, and, less commonly, dissolved solids, sulfate, and chloride. Figures 38, 39, 40, 43, and 44 show the locations which both comply with and exceed the recommended maximum limits for dissolved solids, chloride, sulfate, nitrate, and fluoride content. Most samples for which analyses of other limiting constituents are available meet the recommended limits for public supply. However, no analyses are available for the trace metals. From general experience in other areas, it is considered unlikely that trace metals are present in the Seymour water in amounts exceeding the maximum limits.

GROUND WATER IN OTHER FORMATIONS

Some water occurs in the shallow Permian formations adjacent and beneath the Seymour and in younger terrace and alluvial deposits adjacent to the Seymour. The Permian occurrences are not important from a quantitative standpoint, and the other units are not connected to the Seymour.

Younger Terrace and Alluvial Deposits

The younger terrace and alluvial deposits occur in the floodplain and associated terraces along the Brazos River. The limited areas of these deposits are shown on Figure 13. The deposits occur at elevations lower than the Seymour Formation according to comparisons of topographic maps and the elevation of the base of the Seymour. They are not connected to the Seymour or related to its hydrology.

The terrace and alluvial deposits are composed of sands, gravels, silts, and clays. Their maximum thickness is estimated to be approximately 40 feet. Moderate water supplies are available locally, but only a few wells draw water from the younger terrace or alluvial deposits. The pumping rate of one irrigation well was measured at 220 gpm.

The water in the terrace and alluvial deposits tends to be much more mineralized than the Seymour water. Three analyses range in chloride content from 740 mg/l to 2,560 mg/l, in sulfate content from 855 mg/l to 2,300 mg/l, and in dissolved solids content from 2,691 mg/l to 5,562 mg/l.

Shallow Permian Rocks

Records for about 70 wells and 4 springs drawing from Permian rocks were obtained during the present investigation. The wells range in depth from 20 to 90 feet, but are mostly between 30 and 50 feet in depth. Slightly over half of the wells are large-diameter dug wells; the rest are drilled wells which have casings of 6 inches or less in diameter. The wells are dispersed widely over the study area and are evidence of the difficulty in obtaining satisfactory quality and quantities of water from the Permian.

Over half of the Permian wells furnish water used only for livestock purposes. The remaining wells are used for domestic supply, even though most yield poor quality water not used normally for drinking. Well yields are low, and only small supplies are available from the Permian rocks.

In investigating the Permian water quality, previous chemical quality data were obtained, and sampling of additional wells was done for those areas located within approximately 5 miles of the edge of the Seymour aquifer. The data obtained indicate a wide range in quality for Permian waters. Very little of the water is fresh. Most is slightly to moderately saline and normally contains moderate to large concentrations of both sulfate and chloride.

Sulfate contents for 26 out of 43 analyses are in excess of 500 mg/l with 17 in excess of 1,000 mg/l. The sulfate content ranges up to 2,730 mg/l. The higher sulfate values are more common for those Permian wells located in the western parts of the area for which Permian data were obtained.

The chloride contents of Permian samples range from less than 100 to 3,760 mg/l. Approximately 25 percent of the wells sampled have chloride contents in excess of 500 mg/l.

The shallow Permian rocks have very poor water-bearing characteristics. Most of the rocks are shales which are essentially impermeable. Even the thin sandstone, siltstone, gypsum, and limestone zones have low permeabilities, and little water moves through the Permian. Essentially, the Permian is separate from the Seymour aquifer because of the great difference in permeability.

Minor leakage from the Permian to the Seymour and from the Seymour to the Permian probably occurs locally. The amounts are unimportant quantitatively, but enough leakage from the Permian to the Seymour may occur in some areas to affect water quality. Principal areas where this may occur are along the extreme southeastern border of the aquifer, southeast of Munday, and in a few small areas located near the boundary between the younger and older Seymour deposits. The largest of these is located approximately 3 miles west of Knox City. The water quality in these areas appears abnormally high in both sulfate and chloride content. The most likely source appears to be the Permian.

Rises in water levels in the Permian formations adjacent to the Seymour aquifer over the last 10 to 20 years were noted during this investigation. The rise in water levels has been caused by the same factors which are responsible for the rise in water levels in the Seymour, namely, above normal precipitation and farming practices. In many localities where water levels have risen sufficiently to cause salty spots on the land surface, the soil is damaged and unproductive. The soil salinization is due to naturally saline water in the Permian or evaporation from the water table which causes a concentration of dissolved salts.

There have been numerous complaints reported regarding salty land. All are on the Permian outcrop outside the Seymour area. None were found or reported on the Seymour. Typically, local residents blame oil field injection operations for the problem. However, the hydrology, location of the areas, and number of complaints preclude the oil field activities being the cause of most of the complaints. The salty land condition is a natural problem for which no economic solution is available.

POLLUTION AND THE SEYMOUR AQUIFER

Introduction

The Seymour is the only source of fresh water throughout the area of its occurrence. No alternative fresh supplies exist from deeper formations, and essentially no surface water supplies exist on the Seymour, except those which must be piped in from long distances. A large number of users are dependent on the Seymour water supply for municipal, irrigation, domestic, and stock purposes. Consequently, the prevention of pollution and protection of this significant water source are important to both present and future users.

This section of the report deals primarily with ground-water pollution caused by mineralized water. Some information is presented on pollution from hydrocarbons including pesticides, but hydrocarbon pollution is of little significance in the area. Information on biological pollution (bacteria and viruses) is not included. Normally, these micro-organisms are removed by adsorption and filtration and do not travel great distances in sediments similar to the Seymour.

Susceptibility to Pollution

The Seymour aquifer is susceptible to pollution from both surface and near surface sources. Its infiltration potential, depth to the water table, thickness, geologic character, and rate of natural ground-water movement are all factors which render the aquifer susceptible to pollution. Infiltration potential is high due to the sandy character of the surface soils. The aquifer is not protected by overlying impermeable zones; consequently, pollutants can move from the surface or near surface to the water table. Because of the shallow water table, pollutants can reach the water table relatively quickly, and little attenuation may occur. The generally thin saturated thickness and absence of impermeable layers within the aquifer results in essentially the entire aquifer thickness being affected at a pollution site. The relatively high rate of natural ground-water movement and the coarse-grained character of the lower part of the formation result in pollution plumes which spread relatively fast and far. However, when a pollution source to the aquifer ceases to exist, these same characteristics become desirable. They cause the remaining pollutants to be flushed from the aquifer more quickly than if the sediments were finer-grained and the ground-water movement slower.

Movement of Pollutants

The basic principles of ground-water flow govern the movement of pollutants in the Seymour. When an undesirable fluid reaches the water table, ground-water pollution begins. The fluid may have leaked from an unlined waste pit, from a surface spill, or from other surface operations including sewage treatment plants, landfills and dumps, feedlots, or leaky storage tanks. Other sources of contamination discharge pollutants directly to the subsurface. These include septic tanks, leaky underground pipelines, defective injection wells, and improperly plugged holes.

Once a pollutant reaches the water table, local ground-water movement becomes the primary determining factor of the path the pollutant will take through the aquifer. When pollutants enter natural ground-water systems, only minor mixing normally occurs. Typically, a plume or track of polluted water is formed in the direction of ground-water flow. Pollution plumes are elongate in the direction of ground-water flow. Normally, they do not fan out from a source. The dispersal across the direction of flow is quite small in proportion to the distance of travel in the direction of flow. The direction and rate of movement of the pollutants is governed by the configuration and the slope of the water table (hydraulic gradient) and the permeability of the materials through which the pollutants move.

Natural ground water is constantly moving from areas of recharge to points of discharge. Pollutants contained in and moving with normal ground-water flow have the same flow pattern. In special cases, other factors can affect the flow pattern. For example, hydrocarbons tend to float on the water table, while brines tend to sink vertically under the influence of gravity, even though the direction of ground-water flow is essentially horizontal. Also, where pumping from wells changes water levels in an aquifer, the rate and direction of ground-water travel is modified. The hydraulic gradient near pumping wells is toward the wells, and flow lines converge toward pumping wells. Consequently, pollutants can be drawn toward and reach pumping wells.

Typically, ground-water contamination is discovered when a pollutant reaches a pumping well. Because of the relative slow movement of ground water, there can be a lag of years or even decades between the time a pollutant enters an aquifer such as the Seymour and when it arrives at a pumping well or at a natural discharge point such as a spring. Ground-water pollution may go undetected until a pollution source has been active a relatively long time or until considerable damage has been done. Discoveries of pollution caused by sources which no longer exist can continue for years and even decades after the sources have been inactive. Normally, it takes very long periods of time for an aquifer to be flushed of a pollutant by natural flow.

Past Pollution Complaints

There have been many complaints related to water pollution in the area. As a part of the present study, a tabulation was made of the number of complaints and the type of problems that have occurred in the past. Records of the Texas Railroad Commission and the Texas Department of Water Resources (including predecessor agencies) were checked. Table 8 lists the complaints to these state agencies from 1951 through 1977 in two categories, those mentioning some type of observed water problem and those objecting to oil field activities or other industrial operations as a source of pollution. Through the years, there has been an increase in the number of both types of complaints. About half of the complaints concern some type of water problem, primarily salty well water. The other half of the complaints are related to oil field activities.

Pollution Source Inventory

A detailed inventory was made of the more important pollution sources, the potential causes of pollution, and the methods of waste disposal on the Seymour. The inventory included current sources and, to the extent possible, past sources. The individual items inventoried are listed in Table 9 and mapped in Figures 48, 49, and 54. No detailed inventories were made of those sources listed in Table 9 for which the number of sources is not given. These items were not inventoried because to do so was impossible, cost prohibitive, or because initial evaluation indicated the source was insignificant.

Table 9 lists those pollution sources which have affected wells as indicated by water sampling. Also, the relative impact of the various sources on the Seymour is given. By far, the largest pollution impact on the aquifer has been from the former disposal of oil field brine into unlined surface pits. Moderate effects are indicated for brines leaking from improperly plugged and abandoned holes and from faulty injection wells. Impact from septic tanks is considered moderate, inasmuch as more than 9 percent of the domestic wells sampled show effects of pollution from sources high in nitrate content. All other sources are estimated to have a low impact.

Sources of Pollution and Indicated Water Quality Changes

Oil Fields

Many oil fields are present in the area, and oil activities are significant to the economy of the area. Most of the oil fields were discovered during the 1950's. Oil producers in the area are primarily independent operators, although a few major companies are represented. The 1976 production was slightly less than 3 million barrels. The cumulative oil production to January 1977 was about 131 million barrels. Production depths range from about 1,600 feet for the shallowest production (Tannehill) to over 5,800 feet for the deepest production (Strawn, Bend Conglomerate).

Figure 47 shows the locations of the oil fields on the Seymour. It also shows the locations of dry and abandoned oil tests, past or current producing oil wells, and past or current locations used for injection or disposal of salt water. There is a total of 2,446 locations shown, including 1,152 dry holes, 909 oil wells, and 385 injection or disposal wells.

Pollution from oil activities is due normally to either salt water or hydrocarbons. The amount of contamination of ground water by hydrocarbons is of almost no significance in the area. Though the potential for pollution appears to be large because of the large number of sources where crude oil or refined products are stored or piped (Figure 48), only three water wells in the area were reported to contain hydrocarbons. Two of the wells could be sampled, and results were negative.

Table 8. Number of Complaints to State Agencies Related to Water Pollution In and Near Area of Seymour Aquifer

Type of Complaint	Period 1951–1955	1956–1960	1961–1965	1966–1970	1971–1977	TOTAL
Water Problems:						
Salt in water from well	3	7	10	7	11	38
Oil in water from well					3	3
Salty spot or seep at land surface			2	3	2	7
Nitrate in water from well					1	1
Oil Field Operations:						
Disposal pit		2	4	2	1	9
Leaky well	1		5	8	12	26
Miscellaneous (mostly saltwater spills)		2	1	4	5	12
Other Industrial Operations:				1		1
TOTAL	4	11	22	25	35	97

In recent years, it has been a required practice to report hydrocarbon spills greater than five barrels to the Texas Railroad Commission. A summary of these reports is as follows:

Year	Number of Spills Reported	Amount Lost (bbls)
1970	0	---
1971	9	224
1972	1	20
1973	9	416
1974	3	75
1975	5	211
1976	2	108

Because the reports represent Haskell and Knox Counties in their entirety, only a part of the spills reported would be applicable to the Seymour. Some pollution due to spills or leaks of hydrocarbons has occurred in the past and will occur in the future, but the estimated impact on the aquifer is very low.

Production of crude oil is accompanied by the production of salt water. Improper disposal of produced brines can result in significant pollution of fresh ground water. The amount of the salt water produced is quite variable. It reportedly ranges from less than 1 barrel of brine per barrel of oil to over 50 barrels of brine per barrel of oil for individual leases. The ratio of produced water to oil probably averages between 1 and 5 barrels of water per barrel of oil for individual fields. The ratio increases typically with the age of a field.

Chemical analyses of the oil field brines sampled during this investigation are shown in Table 26. All the waters are highly concentrated sodium chloride brines. Chloride contents range from about 63,000 to 139,000 mg/l. Because of these high chloride concentrations, even if only small quantities of brine are mixed with Seymour water, the resultant mixture can be very high in chloride content.

Sources

Sources or potential sources of brine pollution from oil field activities include unlined surface disposal pits, improperly plugged abandoned oil tests, faulty injection wells and oil wells, spills, and unplugged seismic and stratigraphic holes.

Disposal Pits

Unlined surface pits were a common method of disposal

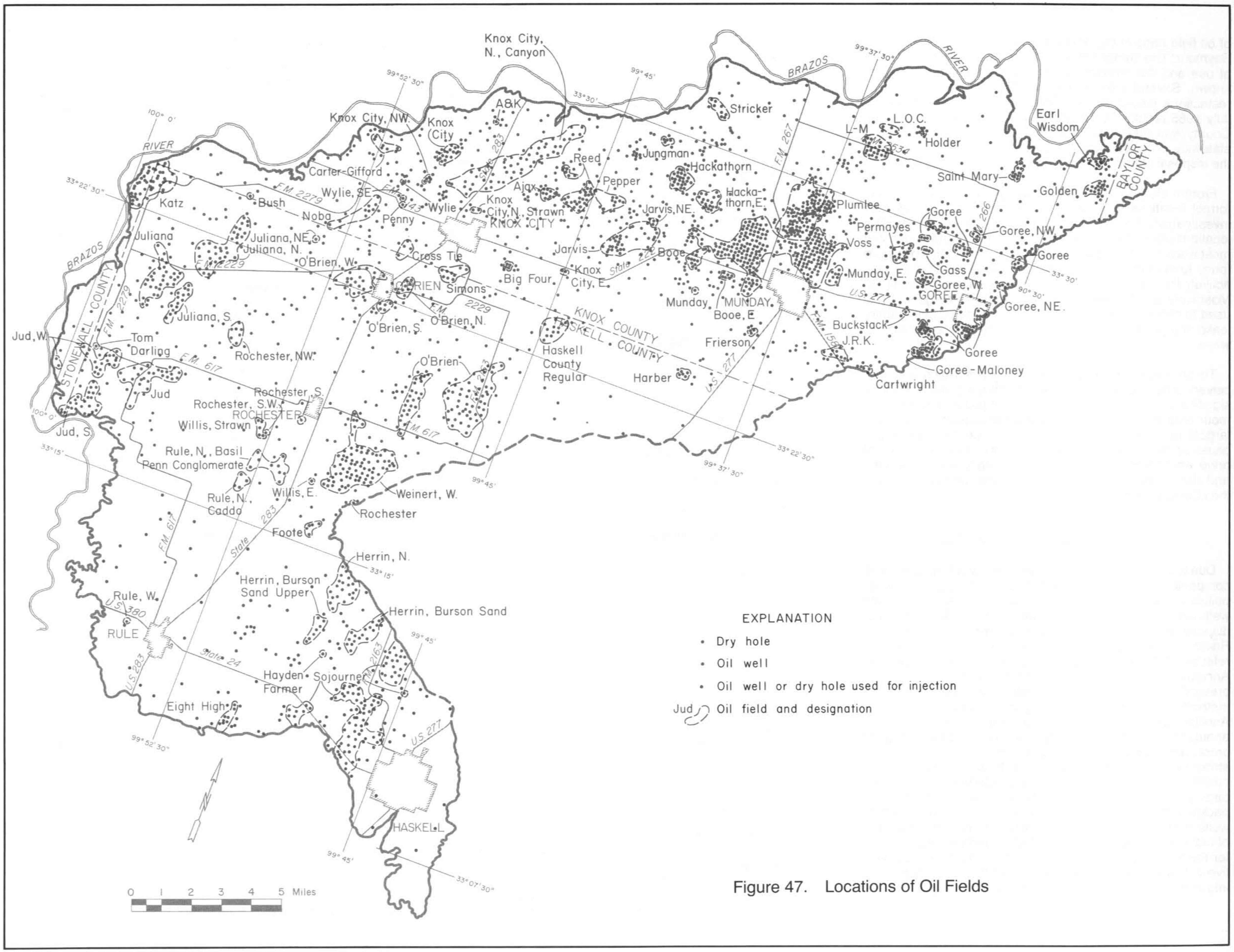

Figure 47. Locations of Oil Fields

of oil field brine in the earliest days of oil production on the Seymour. The number of pits was large, but the time periods of use and the amounts of disposed brine are largely unknown. Several fields in Haskell County were covered by restrictions issued by the Texas Railroad Commission in July 1955 prohibiting the use of unlined disposal pits. Knox County was subject to an order effective June 1966, and a statewide order banning the use of unlined surface pits for the disposal of brine was effective January 1969.

From a study of past aerial photographs (Table 32), 258 former locations of disposal pits were mapped during this investigation. The locations are shown on Figure 49. The locations are believed to include a few lined surface pits, but most were unlined. During 1975–1977, 23 disposal pits were found to exist in the area. Apparently none were being used actively for the disposal of oil field brine; only two were lined. Most were considered by operators to be "emergency" pits used to collect fluids in the event of pipeline or tank battery leaks or equipment failure. Several of the pits contained salt water.

Those existing and former disposal pits which have received large quantities of oil field brine are considered very significant with respect to ground-water pollution of the Seymour aquifer. The surface pits are considered to have the largest pollution impact of any source on the aquifer because of the numerous pit locations, the large quantities of brine which apparently were placed into some of the pits, and also partly due to the number of water wells which show the effects of oil field pollution.

Injection Wells and Abandoned Holes

Due to the ban on unlined surface pits, and because many companies recognized originally the danger of ground-water pollution due to surface pit disposal, the use of injection wells has been common in the area. Three different types of disposal or injection wells have been permitted by the Texas Railroad Commission in the past. The three kinds are referred to as annular, long string, and tubing and packer. Annular disposal is the poorest type with respect to the prevention of ground-water pollution. The tubing and packer method is the best and currently is the only type allowed. Annular disposal consists of injecting salt water into the annulus (bradenhead) between the surface casing and the production casing on operating or abandoned oil wells. Long string injection is the injection of fluids down the production casing of abandoned oil wells or injection wells. Tubing and packer injection is done by injection through tubing and packer set inside the production casing of abandoned oil wells or specially constructed injection wells. The advantage of tubing and packer injection is that by monitoring pressures for the tubing, production casing, and surface casing, positive indications are obtained if the injected fluids are going into zones other than the intended injection zone.

Table 9. Summary of Pollution Sources and Relative Impact on Seymour Aquifer

Sources (Actual and Potential)	Number in Area	Number of Sites For Which Water Sampling Indicates Affected Well(s)	Estimated Relative Impact on Aquifer[1]
Industrial, Oil			
Pipelines, Crude & Product	See Figure 48	1 Reported	3
Petroleum Storage Facilities:			
Existing[2]	44		3
Destroyed[3]	10	1 Reported	3
Tank Batteries:			
Existing[4]	248		3
Destroyed[3]	152		3
Disposal Pits:			
Existing[5]	23		2
Destroyed[6]	258	Numerous	1
Abandoned Oil Tests (dry holes)	1,152	14 Known	2
Injection Wells	385	7 Known	2
Oil Wells	909		3
Seismic Holes and Stratigraphic Holes	—		3
Spills:			
Brine	12	Few	3
Oil	—		3
Industrial, Other			
Former Slaughterhouse Disposal Pit	1	1 Known	3
Former Delinting Plant Disposal Pit	1		3
Fertilizer Storage	7		3
Aerial Spraying Service	6	1 Known	3
Rural Domestic			
Septic Tanks and Cesspools	—	More than 9 percent of domestic wells	2
Municipal			
Sewage Effluent	5		3
Landfill or Dump	3		3
Agricultural			
Crop Applicants:			
Fertilizers	—		3
Pesticides	—		3
Return Flow	—		3
Animal Wastes:			
Abandoned Feedlot	1		3
Barnyards	—		3
Miscellaneous			
Evapotranspiration	See Figure 30		3

[1] 1—High 2—Moderate 3—Low
[2] Including gas stations and bulk stations present in 1975–1977
[3] Not present in 1975–1977
[4] Present in 1975–1977
[5] Including lined and unlined brine disposal pits and emergency pits present in 1975–1977
[6] Including abandoned and destroyed, lined and unlined, brine disposal pits and emergency pits not present in 1975–1977

To generally appraise the time periods and amount of disposal that may have occurred by the various types of injection in the past, a tabulation of Texas Railroad Commission injection permits was made. Figure 50 shows the number of permits and the time period during which the various types of permits were issued. Frequently, permits covered more than one well and, consequently, the total number of permits is smaller than the total number of injection wells shown in Table 9. The overall permit history indicates a gradual decreasing potential for ground-water pollution due to injection activities.

Even with properly designed and constructed injection wells, brine disposal is not without real or potential problems with respect to ground-water pollution. Most of the problems result from the use of pressure for injection and the nature and amount of earlier exploration, especially the inadequate plugging of abandoned oil tests, oil wells, and injection wells. There are 1,152 recorded abandoned, dry holes in the area. Oil wells and wells used for injection purposes total approximately 1,300. In the absence of proper plugging or construction, more than 2,400 sites exist where vertical pathways can occur between the deeper subsurface formations and the Seymour aquifer.

Based primarily on investigations of saltwater pollution complaints by Texas Railroad Commission personnel, there are about 21 known occurrences where either improperly plugged dry holes or injection wells were the source of pollution of water wells in the area. In 14 cases, the source of the pollution appeared to be improperly plugged abandoned holes and in seven cases, faulty injection wells were believed to be the cause. Essentially then, approximately 1 percent of the abandoned oil tests and 2 percent of the injection wells are indicated to have caused ground-water pollution. Undoubtedly, additional instances are yet to be discovered. Probably, the actual percentages which have caused pollution are a few times larger than is indicated presently. Improperly plugged and faulty wells are considered to have a moderate pollution impact on the aquifer, but are believed to be less significant than the former use of unlined surface pits.

Other Sources

Improperly plugged seismic holes, stratigraphic holes, and improper surface casing in oil wells can be responsible under some conditions for ground-water pollution. Formation pressure in shallow Permian strata in excess of Seymour pressure is required, as well as a connection between these zones. No cases of pollution due to such sources were found during this study. These sources are not considered particularly important in regard to the Seymour aquifer.

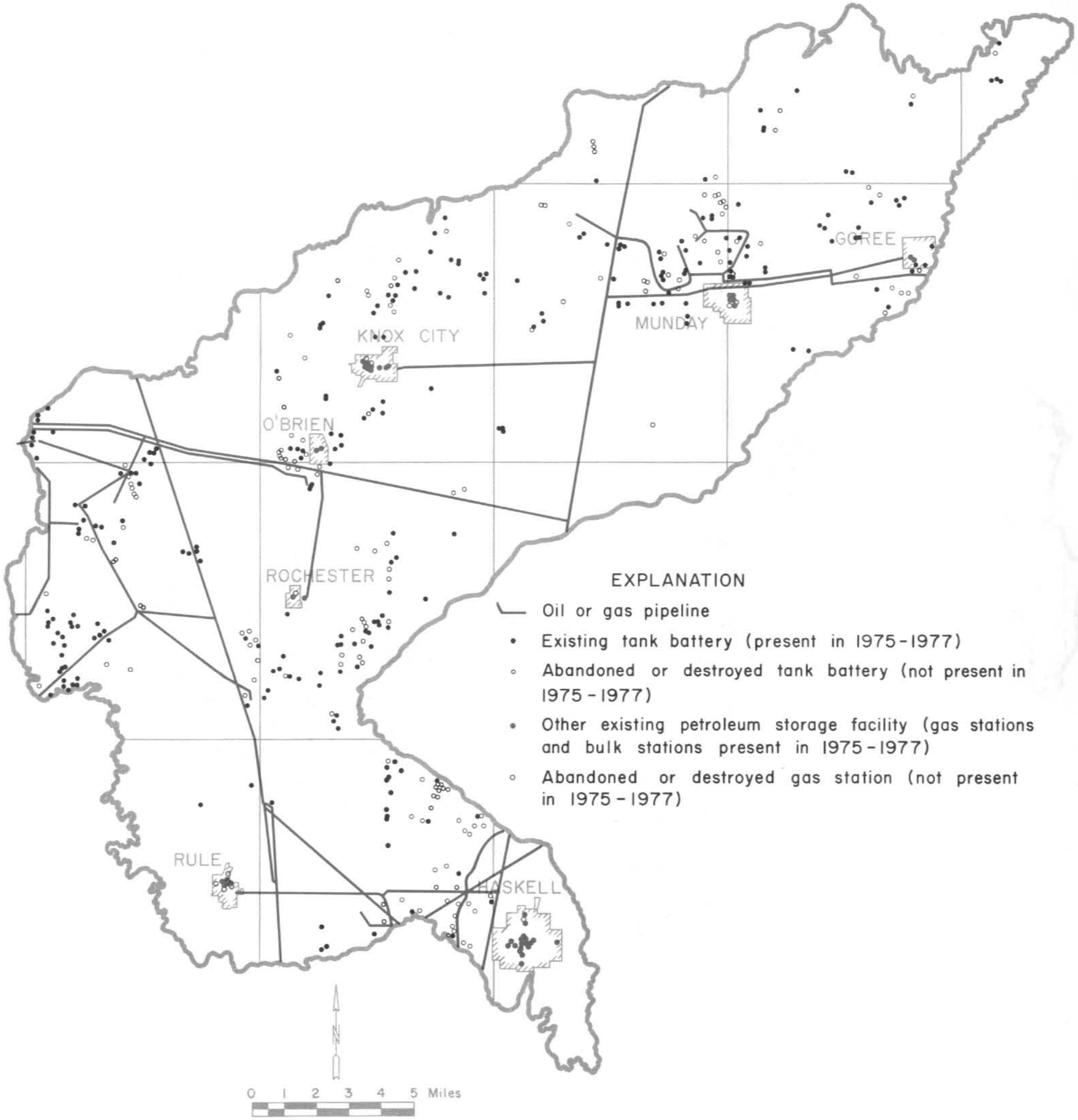

Figure 48. Locations of Pipelines, Tank Batteries, and Other Petroleum Facilities

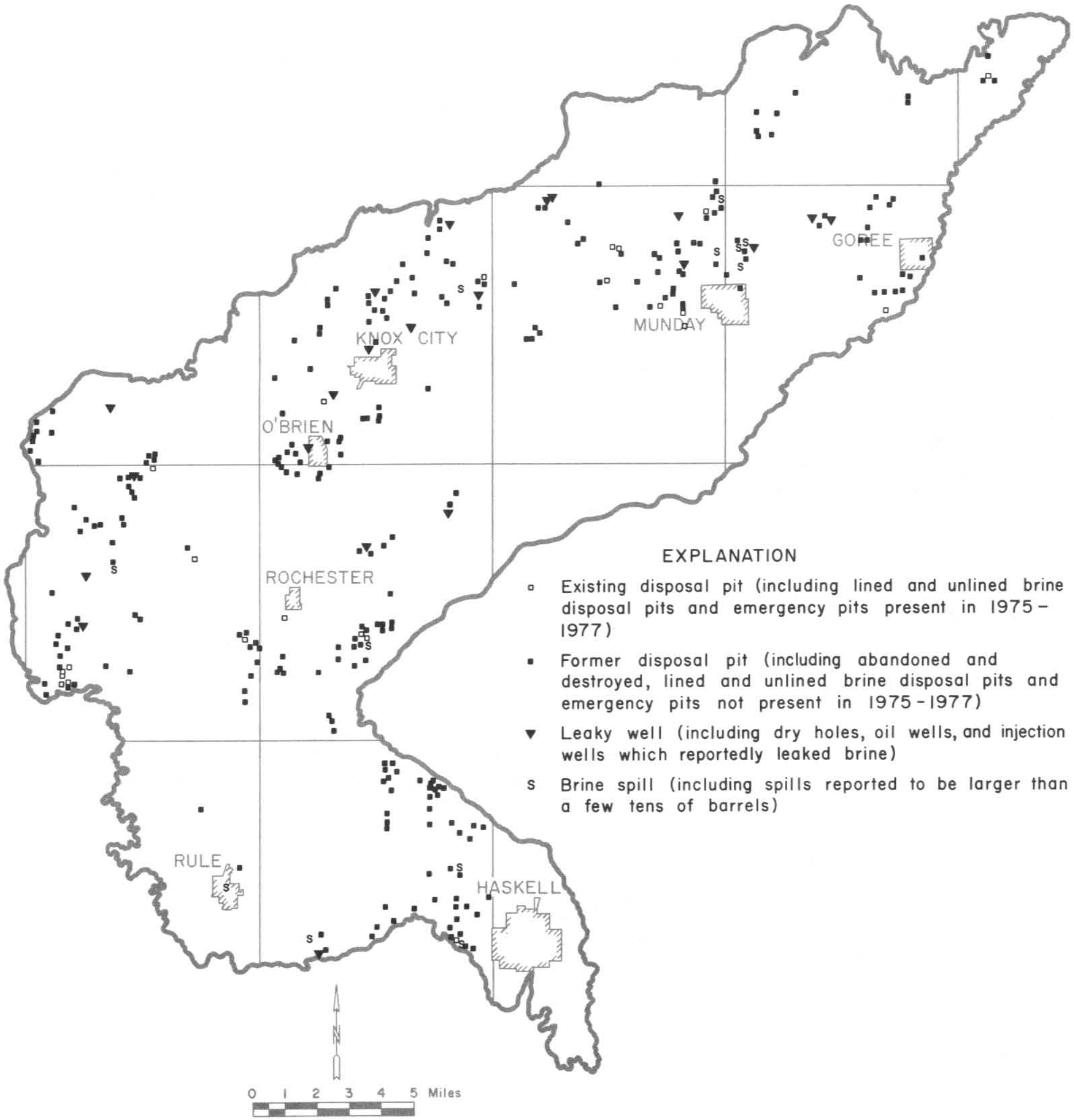

Figure 49. Locations of Disposal Pits, Leaky Wells, and Brine Spills

Production and Disposal of Produced Brine

Few records are available on the amounts of brine produced and methods of disposal except from inventories conducted by the Texas Railroad Commission for 1956, 1961, and 1967. Data from these inventories for the oil fields on the Seymour are given in Table 33. The table indicates the discovery date of the field and the date of the first injection well permit according to permit files. Presumably, surface pits may have been used between the time of discovery of the field and the time of the first permitted injection well. The table also shows the total cumulative oil production to January 1977. This information is useful in estimating the total amount of brine that may have been produced by the field. Typically, those fields producing the smallest amount of oil produced the smallest amount of brine.

Total reported brine production and disposal methods for all fields partly or entirely on the Seymour are as follows:

Disposal Method	Reported Brine Production (bbls/day)		
	1956	1961	1967
Pits	1,033	209	0
Injection	7,749	15,206	16,259
Trucked	329	0	1,003
Miscellaneous	0	135	0
Total	9,111	15,550	17,262

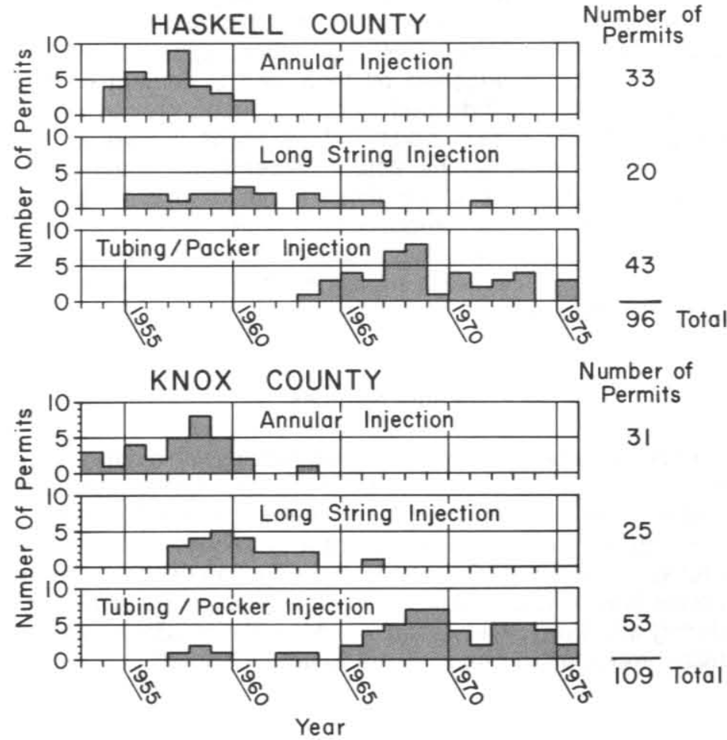

Figure 50. History of Injection Permits

Potential pollution sources are listed by field in Table 33. The table also shows by field the estimated impact on the Seymour of all brine disposal activities. The ratings are based on the apparent or reported amounts of brine disposed of into pits and the number of leaky wells and spills.

Though Table 33 reflects general conditions, some of the information shown is partly inaccurate because of the records on which it is based. For example, for some of the fields, the first injection well permit date is later in time than the reported use of injection wells according to the 1956 inventory. Such inconsistencies are due to either inaccurate reporting or incomplete records.

Recognition of Oil Field Brine Pollution

Several criteria are useful in recognizing oil field brine pollution in water samples from the Seymour aquifer. When oil field brines are mixed with the native Seymour water, the chloride content of the water increases. The sodium content increases also, as it is the largest other single constituent in oil field brine. However, the concentrations of calcium, magnesium, and sodium are subject to modification by base-exchange reactions with Seymour sediments. When such reactions occur, calcium and magnesium are substituted for part of the sodium. This results in polluted water containing abnormally higher amounts of calcium and magnesium in relation to sodium than would be predicted based on straight mixing of Seymour water with oil field brine. For this reason, calcium, magnesium, and sodium normally are secondarily used as indicators of oil field brine pollution, and the chloride increase is considered to be the primary indicator.

The ratio of chloride to sulfate content is also an important indicator. It is useful in separating wells affected by oil field brine pollution from those affected by other highly mineralized waters. The chloride/sulfate ratio will be higher in Seymour water affected by oil field brines. Oil field brines are extremely high in chloride content and are not high in sulfate content. Thus, mixtures show an increase in chloride content which is not accompanied by a proportional increase in sulfate content. This indicates oil field brine pollution. Conversely, naturally poor quality Seymour water having high chloride content is normally also high in sulfate content. Typically, the chloride/sulfate ratio will vary only within reasonably narrow limits within a local area, even though chloride concentrations may vary considerably. Thus, high chloride content and a normal chloride/sulfate ratio for an area is indicative of naturally poor quality water and not oil field brine pollution.

Because of the large natural variation in amounts of chloride in Seymour water, chloride content alone cannot be used indiscriminately as an indicator of oil field brine pollution. The most common and widely recognized criteria for the recognition of brine pollution is the use of chloride content and chloride/sulfate ratios in conjunction with careful comparisons of analyses from nearby wells.

Locations Affected

Figure 51 shows the locations of water wells which have shown the effects of chloride pollution. The wells have had abnormally high chloride contents as well as abnormally high chloride/sulfate ratios. There are 152 separate locations shown on Figure 51 having atypical chloride contents. Nearly all of these wells are believed to be affected by brine pollution, although a few appear to be affected by septic tank pollution and a few probably have improved substantially in water quality since last sampled. Most are down gradient from oil fields with known or potential pollution sources and are about the proper distance from such sources considering normal ground-water movement rates.

In addition to the locations shown on Figure 51, there is a reasonably large but undetermined number of wells in the Haskell area and immediately to the northwest of Haskell, which are believed to have been affected by oil field brine pollution. The native water quality in the Seymour aquifer northwest of Haskell is considerably poorer than in most other areas. A determination of which wells are affected by oil field brine pollution and which have naturally mineralized water is more difficult in this area with the number of available analyses, especially to the same degree of certainty that is possible in other areas of the Seymour. Consequently, locations of affected wells are not shown east of a line on Figure 51 in quadrangle 21–50.

Undoubtedly, there are additional locations other than those shown on Figure 51 where the Seymour aquifer has been affected by oil field brine pollution. It is estimated that about 30 to 50 more locations could be found by sampling a large number of additional Seymour wells. Also, it is certain that additional pollution plumes exist which have yet to reach wells. More detailed investigations, including sampling of available wells and test drilling, will be required to more thoroughly define the present extent of oil field brine pollution.

Severity and Historical Trends

The general severity of the pollution is indicated partly by the chloride content of water from wells shown on Figure 51 as having atypical chloride contents. The following list shows this information:

Chloride Interval (mg/l)	Number of Wells
0 - 250	42
251 - 500	51
501 - 1,000	37
1,001 - 1,500	6
1,501 - 2,000	2
2,001 - 2,500	1
2,501 - 5,000	5
5,001 - 10,000	3
10,001 - 68,500	5
Total	152

About 43 percent of the wells have chloride contents less than 500 mg/l. About 14 percent have chloride contents between 2,500 and 68,500 mg/l. These values are common for areas experiencing pollution from oil field brine. The wells which are highly polluted are more directly in the path of movement from a source. The large number of wells which are affected only moderately either are affected by low volume chloride sources, or are on the edge of pollution plumes, or are in locations through which the main pollution plumes have already passed. This last reason appears to be the case at a reasonably large number of the locations, as chloride contents have been monitored at some locations and are lower at present than in the past.

Figure 52 shows typical results of monitoring the chloride content in wells affected by oil field brine pollution. Some show increasing pollution (higher chloride levels) during the earlier periods of record. Most show decreasing amounts of pollution during later periods, indicating the pollution source was not active for long periods of time and that the main pollution plume moved down gradient from the affected well.

Figure 53 shows data on the city of Rochester well LP 21-42-401. Water from this well had low chloride and sulfate contents in 1944 prior to any oil activities in the area. The chloride content was slightly below 50 mg/l. Prior to 1963, the well became moderately affected by a source high in chloride content and low in sulfate content. The chloride increased to over 300 mg/l in 1964. It has since declined to about 150 mg/l, but is still about three times higher than originally. The sulfate content throughout the period of record shows little change. No detailed studies have been made in the Rochester area, and the exact source of the pollution is unknown.

The results of chloride monitoring confirm two important aspects of brine pollution for the Seymour. First, individual sources have tended to exist for only a few to several years as opposed to much longer periods of time. Thus, because the average rate of natural ground-water movement in the Seymour is as fast as it is, pollution plumes from short-lived sources tend to move to and past nearby wells in relatively short periods of time. Secondly, the character of the formation and rate of ground-water flow tends to allow the pollution to clear at most sites after several years. Thus, the pollution tends to be more temporary than is normally the case in many other ground-water formations.

Other Industrial Activities

Other industrial activities in the area which have been sources of pollution include two locations used formerly to dispose of waste products (Figure 54). One was a cotton seed delinting plant in which sulfuric acid waste was placed in an unlined pit. Presently, no wells are known to be affected by the waste disposal in the delinting plant pit. The other location was an area (probably a pit) used reportedly for the disposal of slaughterhouse wastes. Water from one

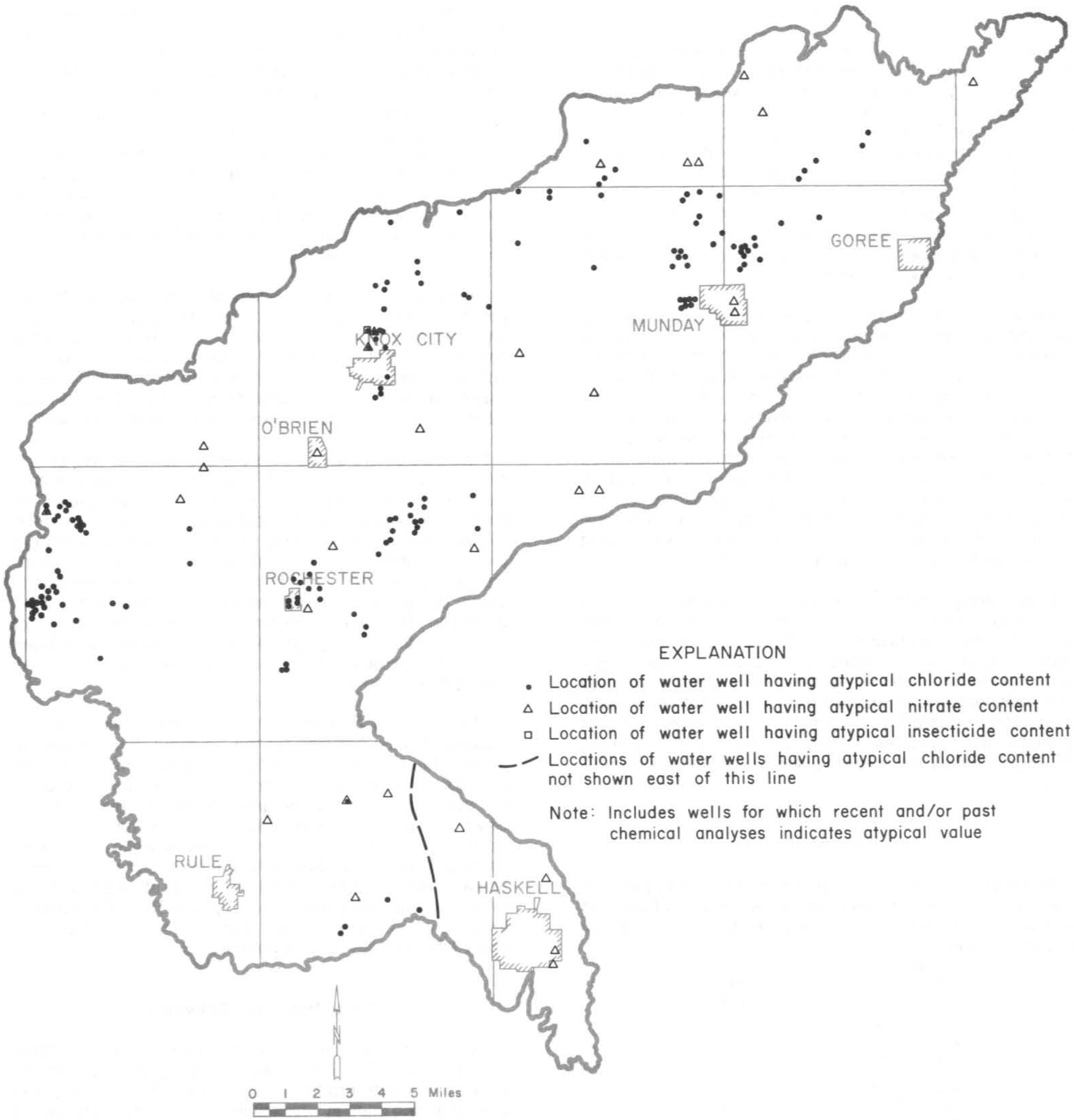

Figure 51. Locations of Water Wells Showing Effects of Pollution

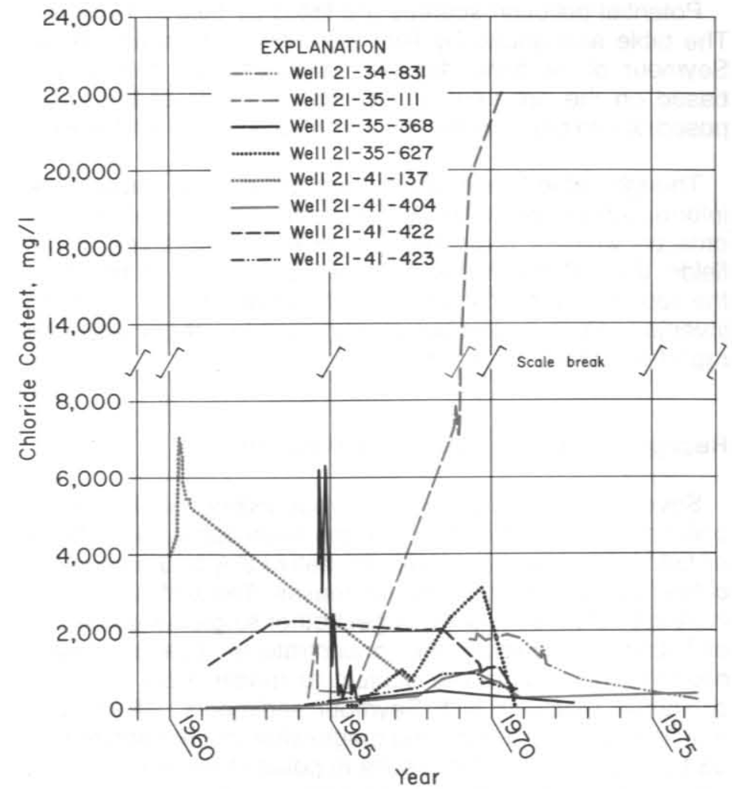

Figure 52. Chloride Content of Polluted Wells

well (LP 21-41-409) near the slaughterhouse disposal area has a nitrate content in excess of 900 mg/l. Only this one well is known to be affected by this source; the extent of the pollution is unknown.

There are seven fertilizer storage localities on the Seymour aquifer, but none appear to be sources of pollution. The potential exists, however, if large quantities of fertilizer are spilled on the surface, and infiltration carries dissolved constituents to the Seymour.

The six aerial spraying service facilities in the area are potential contributors to ground-water pollution, mostly from spills, handling and washing practices, and storage facilities. Results of sampling wells at the facilities are presented in the discussion of pesticides.

Septic Tanks and Cesspools

Effluent discharged from septic tank systems and cesspools can increase the concentration of minerals in ground water. Figure 55 shows a diagram of a typical septic tank and soil absorption system. Table 10 shows the normal range of mineral increases in domestic sewage.

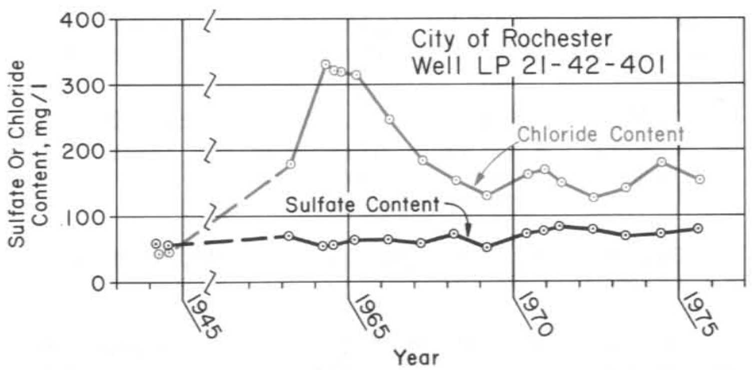

Figure 53. Historical Water Quality for Well LP 21-42-401

Table 10. Normal Range of Mineral Increase in Domestic Sewage
(Feth, 1966)

Constituent	Range (mg/l)
Dissolved solids	100 - 300
Boron (B)	0.1 - 0.4
Sodium (Na)	40 - 70
Potassium (K)	7 - 15
Magnesium (Mg)	3 - 6
Calcium (Ca)	6 - 16
Nitrate (NO_3)	85 - 180
Sulfate (SO_4)	15 - 30
Chloride (Cl)	20 - 50
Alkalinity (as $CaCO_3$)	100 - 150

Nitrate is the principal pollutant found in ground water affected by septic tank discharge, although common salts can become objectionably high if recirculation via a domestic well is occurring. It is common to have some base-exchange reactions and phosphate depletion occurring to septic tank discharge prior to its reaching the water table. However, other common constituents such as chlorides, nitrates, sulfates, and bicarbonates are not removed from the water and can move downward to the Seymour aquifer.

The use of septic tanks and cesspools occurs at many widely scattered rural locations and also in unsewered areas in towns in the area. All the rural population and an estimated percentage ranging from 5 to 25 percent of the population of individual towns use septic tanks or cesspools, largely septic tanks.

Figure 51 shows those wells which have a high nitrate content in relation to surrounding ground-water quality. Nearly all are domestic wells. Approximately 9 percent of the domestic wells sampled during 1975–1977 had nitrate

Figure 54. Locations of Other Known and Potential Pollution Sources

values above 150 mg/l. This is due principally to septic tank pollution. Wells which have nitrate content above 150 mg/l are as follows:

Well Number	Nitrate Content (mg/l)
RS 21-27-813	306
RS 21-27-938	155
RS 21-27-939	180
RS 21-28-409	172
RS 21-28-711	230
RS 21-29-408	163
LP 21-33-916	183
RS 21-34-513	154
RS 21-34-515	258
LP 21-34-947	386
RS 21-35-803	314
RS 21-36-401	183
RS 21-36-404	158
LP 21-41-202	222
LP 21-41-315	158
LP 21-42-106	273
LP 21-42-305	270
LP 21-42-409	935
LP 21-43-202	303
LP 21-43-203	199
LP 21-50-108	254
LP 21-50-202	165
LP 21-50-206	200
LP 21-50-304	174
LP 21-50-516	331
LP 21-51-412	178
LP 21-51-726	316
LP 21-51-739	281

The overall effect on the Seymour aquifer of septic tank discharge has been small. Locally, the effects are important at a significant number of locations, but only at locations down gradient and reasonably close to a source. Prior to the existence of municipal sewer systems, there was a larger population using septic tanks and cesspools. Certainly some of the nitrate content of Seymour water down gradient from towns is due to past septic tank discharge, but calculations indicate the amounts are low and not discernible in the chemical quality data.

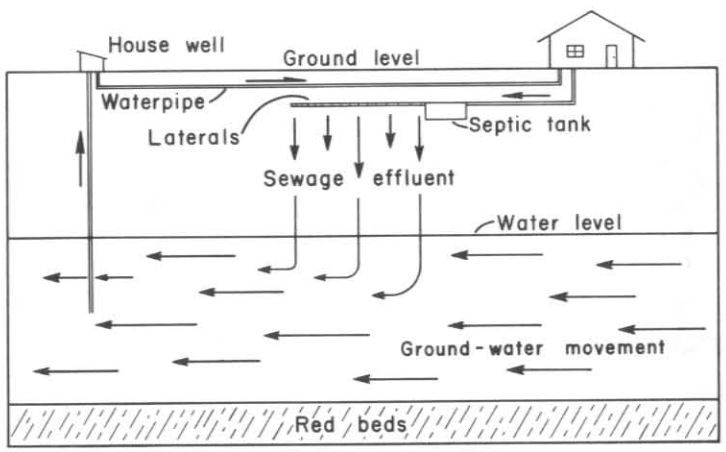

Figure 55. Contamination of a Domestic Ground-Water Supply From a Septic Tank

Sewage Treatment Plant Discharge

Five towns in the area discharge effluent on the Seymour Formation from sewage treatment plants. Munday, Rochester, and Haskell have oxidation ponds on the Seymour. However, the Haskell plant is located on the extreme edge of the aquifer and has little effect on the Seymour. Knox City and O'Brien discharge to surface drainage and to a surface depression, respectively. Goree and Rule have treatment plants, but they are located off the outcrop of the Seymour.

The discharge from the plants is disposed of by evaporation and seepage to the Seymour. Some is used for irrigation of farmland adjacent to the Munday, Rochester, and Haskell plants.

The chemical quality of the sewage effluent sampled during the present investigation is shown in Table 22. The analyses indicate a small mineral pickup when compared with the respective municipal water supplies. Also, as water moves through the various oxidation ponds at the Munday and Rochester plants, a general increase in mineralization occurs due to evaporation. Also, the analyses show that nitrogen removal is essentially complete in the ponds. The removal is due to algae and other plants in the oxidation ponds.

From a pollution standpoint, the sewage effluent areas are considered to have a low impact on the aquifer. The analyses show that the mineral content of the sewage effluent is not very concentrated in comparison to native ground water. Also, the volumes of effluent are small, particularly in comparison to the likely ground-water underflow beneath the effluent discharge areas. Comparative calculations of the amounts of ground-water flow beneath the discharge areas and of the maximum leakage rates indicate that only very small increases in mineralization of ground water are likely beneath the effluent seepage areas. Moreover, sampling of those wells in the vicinity of the treatment plants shows natural water quality variations in the Seymour are relatively large, essentially large enough to mask effects of the sewage plant discharge.

Landfills and Dumps

Landfills and dumps are sometimes sources of significant ground-water pollution because of leachate production which occurs when sufficient water from precipitation or surface drainage infiltrates and dissolves decomposition products. Normally, leachate from municipal landfills contains high concentrations of total dissolved solids, calcium, magnesium, chloride, iron, and nitrate. The amount of precipitation, surface-water runoff, and especially solid waste are important factors in determining leachate production from landfills and dumps.

Two landfills and a dump are located on the Seymour Formation. All receive small amounts of solid waste. They are:

Town	Location	Type	Date Started
Rochester	6 miles NW	Trench Landfill	1940's
O'Brien	1 mile N	Trench Landfill	1970
Knox City	1 mile NW	Dump	Old

Landfills for other towns in the area are located off the Seymour Formation.

The facilities are considered to have a low to negligible impact on the Seymour aquifer. The rate of natural ground-water flow beneath the solid waste disposal operations is likely to be large in relation to the amount and quality of leachate produced. Most probably, pollutants reaching the ground water from these facilities are diluted substantially by underflow. Even so, it is probably important to minimize infiltration at the sites and not to dispose of highly toxic wastes.

Agricultural Operations

The pollution of ground water can occur from a number of activities associated with agriculture. Agricultural chemicals which pose the largest threats are fertilizers and pesticides.

Fertilizers

Large quantities of fertilizers were not used on the Seymour Formation until the 1950's. Application rates of fertilizers have increased over the years. At present and in the past, more fertilizer has been used on irrigated farmland than on non-irrigated farmland. Current application rates for the major crops in terms of pounds of actual nitrogen per acre are about 30 to 50 pounds per acre for wheat and cotton and 80 to 120 pounds per acre for grain sorghum. Rates for coastal Bermuda grass and potatoes range from 150 to 400 pounds per acre, but the total acreage of these crops is only a few thousand acres.

Chemical analyses of water samples from areas of highest fertilizer applications (potatoes and Bermuda grass) do not show concentrations of nitrate indicating pollution from overfertilization. Also, analyses for public supply wells, having periods of record ranging up to approximately 25 years, do not show any long-term increases in nitrate content attributable to overfertilization.

The 1936 chemical quality data for Knox County lacks nitrate determinations (Figure 37). Consequently, very few chemical analyses are available with nitrate determinations prior to 1944, and later data for comparisons of nitrate content are limited. Comparisons between chemical analyses of samples taken in 1944 from a few wells with those taken in

1975–1977 from the same wells indicate no significant changes in nitrate values. Chemical analyses of samples taken in 1956 and again in 1975–1977 from the same 16 wells are available. The wells are distributed over the formation and consist of seven irrigation and nine public supply wells. The nitrate concentration in 12 of the wells was higher in 1975–1977 than it was in 1956. Increases range from 8 to 59 mg/l and average 18 mg/l. The average nitrate content for all 16 wells in 1956 was 54 mg/l and in 1975–1977 was 64 mg/l, an average change of 10 mg/l in about 20 years. The analyses indicate that overly large increases in nitrate content are not occurring. The data are considered inconclusive as to whether small increases are occurring. This is because the number of wells for which past comparative analyses are available is limited. Also, there are contributing factors which make it difficult to evaluate the long-term effect from fertilizers with available data. These mostly include the precision of analyses and the types and locations of wells for which data are available.

Wendt, et al (1976), based upon studies of test plots using various types of irrigation and methods of applying fertilizer, concluded that current fertilization practices are not causing major increases in the nitrate level in the Seymour. Kreitler (1978) has interpreted differences in nitrogen isotope values for the Seymour aquifer and for unfertilized cultivated areas in Runnels County, Texas, as indicating some contribution to the Seymour's nitrate content from fertilizers. However, a quantitative indication of percent contributed from fertilizer as opposed to natural soil nitrate from cultivation could not be made.

It appears a careful monitoring program will be necessary to evaluate long-term quality changes due to fertilization.

Return Flow

Contamination of ground water often results from return flow which is irrigation water that finds its way back into the aquifer. Dissolved minerals in water can undergo significant changes in concentration and composition as a result of irrigation operations.

Past chemical analyses were analyzed to determine if they indicate any large overall increases in concentrations of minerals in the Seymour water due to irrigation return flow. The available analyses indicate no large changes, but the numbers of past comparative analyses are too few to determine the occurrence of small changes. Present indications are that return flows are a minor part of the hydrologic system, quantitatively. Significant changes in mineralization of Seymour water from return flows are unlikely, except over many decades. A careful, long-term monitoring program will be required to determine effects on water quality from irrigation return flow.

Pesticides

Pesticide contamination of ground water from agricultural use is far less common than nitrate pollution. Pesticides are applied usually in very limited quantities and only a few times a year. Probably, the danger of pollution is more from spills, handling practices, and storage facilities than from land application.

Eleven water samples from wells were obtained for analysis of pesticides (Table 23). Wells sampled included those at all the flying services which apply pesticides commercially and a few miscellaneous wells. All sample results showed amounts less than or near detectable limits, except for one sample obtained from a well located at an aerial spraying service. The well sample (RS 21-34-532) showed 6.7 micrograms per liter of toxaphene which, although low, surpasses drinking water standards which specify a maximum level of 5.0 micrograms per liter. The occurrence of toxaphene in the well water indicates pollution from a close source, perhaps surface spills or washing of tanks and containers.

Animal Wastes

Nitrate pollution of the Seymour aquifer from feedlots and barnyards is considered unimportant. Reportedly, only one feedlot has been located in the area. It is currently abandoned. The number of barnyards and animals involved is small. The nitrate content at some localities probably is partly due to animal waste from present or past barnyards; however, there are no indications that the amounts are very significant to the aquifer.

Evapotranspiration in Areas of Natural Discharge

Evapotranspiration can cause concentration of minerals in ground water. This appears to occur only in a few areas of natural discharge mostly along and near the edges of the Seymour aquifer. These localities, however, are not very important to the water quality in the Seymour as the more mineralized water soon discharges from the aquifer by seeps and springs. Areas of evapotranspiration, which are away from the edge of the aquifer, show no recognizable effects on water quality. Accordingly, evapotranspiration is not considered an important water quality determinant.

Future Extent and Significance of Pollution

It is estimated that about 2 percent of the water in the Seymour aquifer is affected presently by pollution. The pollution is due principally to past pollution sources and activities and not to current practices. It is estimated that the relative importance of the various sources is approximately as follows:

Source	Type of Pollution	Estimated Percent of Existing Pollution
Oil Field Disposal Pits	Brine	75
Injection Wells and Unplugged Holes	Brine	20
Septic Tanks	Nitrate	4
All Others	Various	1

The portions of the aquifer affected by pollution will increase in the future due to the natural movement of ground water and to spreading effects caused by pumping wells. However, the portions of the aquifer affected by significant pollution will not become extremely large in the future. Significant pollution problems mostly will be confined to individual properties as opposed to large areas of the aquifer.

Existing pollution plumes from past and current pollution sources will continue to move in the direction of ground-water movement as depicted generally on Figure 31. Movement rates will be governed by local hydraulic gradients and permeabilities. Additional wells further from the original sources will be affected eventually. As each plume moves farther from its source, more lateral dispersion will occur. Intermittent pumping of irrigation wells will hasten the lateral dispersion. Very gradually, concentrations of pollutants will decrease.

Pollution plumes consisting of waters having only moderately higher concentrations than natural Seymour waters will tend to loose their identity before they travel long distances. This is the case for most septic tank pollution. However, plumes consisting of large quantities of highly concentrated pollutants can move long distances with little significant change in pollutant concentration. Accordingly, additional brine pollution will occur in the future at locations increasingly farther from original sources.

Some pollution plumes, mostly originating from past oil field activities, are presently relatively near and moving toward the edge of the aquifer. At such locations, the pollution will be discharged from the formation within a relatively short time and present no further threat to wells in the aquifer. However, other significant pollution plumes are located such that long to very long time periods will be required for the pollutants to either move to natural discharge points or be dispersed naturally and by pumping from wells.

To generally depict the minimum time required for the natural flushing of the aquifer from various locations, calculations have been made of travel times from various points in the aquifer to the edge of the aquifer. The calculations are based on an average hydraulic gradient (7.6 feet per mile) and permeability (4,200 gpd/ft^2), and a porosity of 30 percent. This results in a movement rate of 983 feet per year. Based on this rate, representative minimum travel times are shown on Figure 56 for several locations. The travel times to the edge of the aquifer from locations nearer the edge of the aquifer range up to about 20 years, whereas those from other areas range up to 140 years. Figure 56 is indicative generally of the minimum travel times from various points in the aquifer to areas of natural discharge assuming no pumping from wells. The effects of pumping will lengthen the time period required for the pollution to move to the edge of the aquifer. For short paths, the effects may be small. For the longest paths, the effects will be large, so large that some pollution plumes will be dispersed, diluted, and pumped from the aquifer before ever reaching the edge of the aquifer.

Methods of Controlling Pollution

The best way to deal with pollution and the Seymour aquifer is on the basis of prevention rather than correction. The Seymour, like most ground-water reservoirs, is slow acting. Correcting existing pollution can take years, or even decades, and is generally very costly. Thus, the elimination of current pollution sources is of particular importance.

Tanks, pipelines, and injection and water flood wells should be inspected and/or tested periodically. Quarterly checks are recommended for these potential sources, if they are not checked more frequently. Existing unlined waste disposal and "emergency" pits should be eliminated. Generally, elimination of septic tanks is impractical except in those areas where municipal sewer systems can be used. For wells in rural areas, the most practical way to cope with a water well showing the effect of septic tank discharge is to relocate the well. The well should be located generally up gradient from septic tanks and at a sufficient distance to avoid drawing in any septic tank discharge. Normally, 150 feet is sufficient for aquifers similar to the Seymour, but this depends on local conditions.

For past pollution sources, it is only possible to deal with the resulting pollution plumes either by removal or avoidance measures. Generally, pollution removal measures in the case of the Seymour involve pumping by wells to remove the pollutants from the aquifer. Typically, this is impractical due to the large volumes of water that must be pumped and the relatively long pumping times required. Occasionally, such pumping can be an effective way of dealing with pollution, but normally, only if there is some practical use for the pumped water such as water flooding. Typically, if the water is not used for water flooding and is so highly polluted that it cannot be blended with other water and used for irrigation, then disposal of the pumped water becomes an unbearable cost factor. Avoidance methods include relocating wells affected by pollution or selective pumping and blending to obtain a quality of water that can be used. These can be effective methods if the pollution is not severe or if the property involved is large, and large quantities of unpolluted water can be obtained.

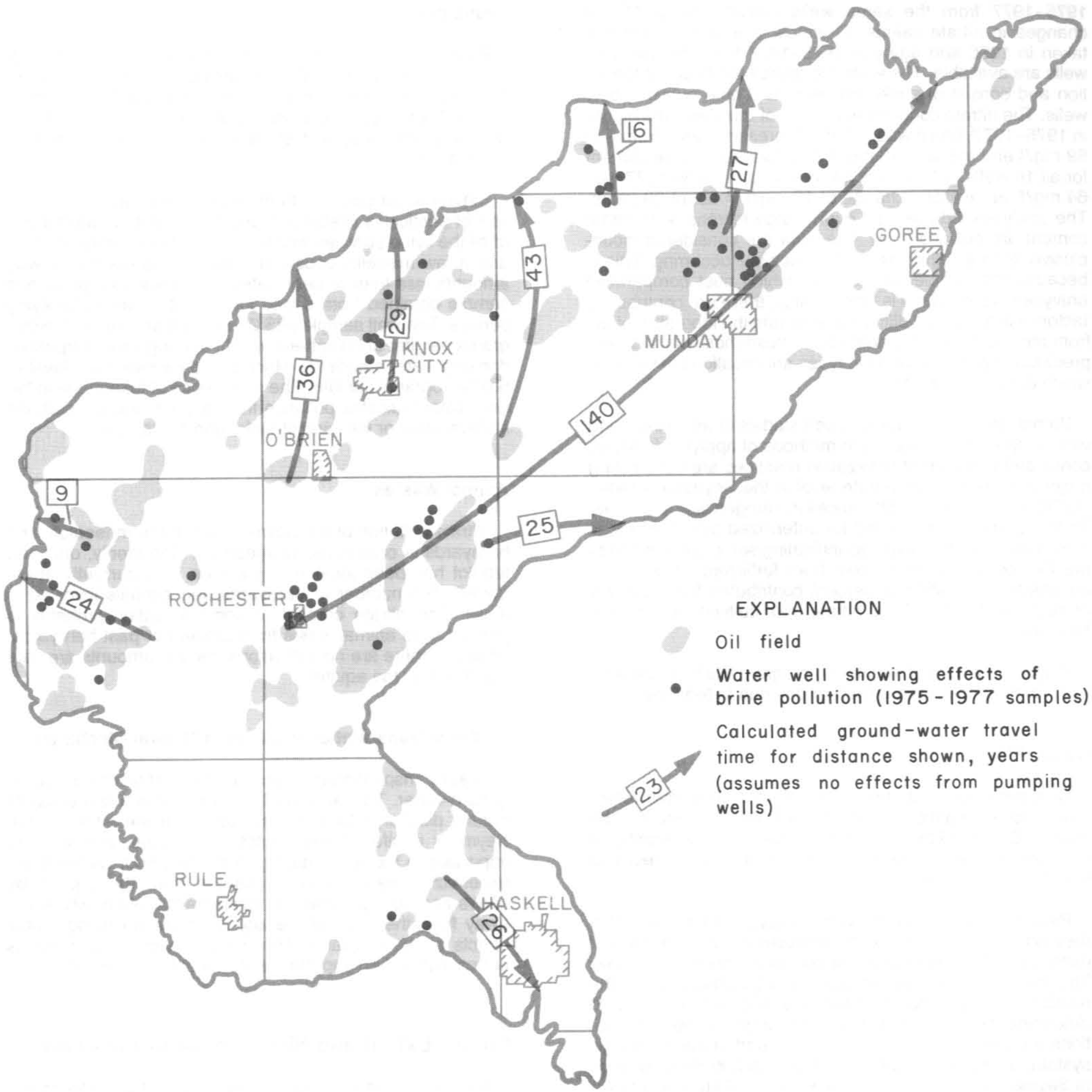

Figure 56. Calculated Travel Times for Pollution

RECOMMENDATIONS FOR MONITORING PROGRAM

At present, annual water-level measurements are made by the Texas Department of Water Resources in approximately 38 wells in the Seymour aquifer in Haskell and Knox Counties. It is recommended that the present program be modified to provide more representative coverage of the aquifer and to include those areas developed for irrigation which currently have no observation wells. It is recommended that the following wells be included in an annual water-level observation program:

RS 21-27-801	RS 21-35-602	LP 21-42-104
RS 21-27-913	RS 21-35-535	LP 21-42-201
RS 21-28-401	RS 21-36-103	LP 21-42-409
RS 21-28-813	RS 21-36-201	LP 21-42-502
RS 21-28-910	RS 21-36-303	LP 21-42-701
RS 21-29-405	RS 21-36-415	LP 21-43-109
RS 21-33-707	RS 21-36-501	LP 21-49-301
RS 21-33-901	LP 21-34-702	LP 21-49-502
RS 21-34-202	LP 21-34-902	LP 21-49-601
RS 21-34-501	LP 21-35-801	LP 21-50-106
RS 21-34-601	LP 21-41-138	LP 21-50-307
RS 21-35-102	LP 21-41-318	LP 21-50-401
RS 21-35-201	LP 21-41-501	LP 21-50-506
RS 21-35-301	LP 21-41-616	LP 21-51-710
RS 21-35-402	LP 21-41-801	

The annual municipal pumpage survey of the Texas Department of Water Resources is satisfactory, but annual pumpage for irrigation purposes should be estimated and updated approximately at 5-year intervals.

It is recommended that the water quality of municipal wells be checked annually to determine any changes important for public supply purposes and to keep abreast of overall long-term quality. Other programs of water-quality monitoring can be instigated as needed to evaluate special concerns such as long-term effects of fertilizers and return flow, and specific local pollution problems. For all investigations of brine pollution problems, it is recommended that analyses include sulfate determinations as well as chloride determinations and that the locations of samples be noted on 7½-minute topographic maps.

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Cedar Mountain	1:24,000
Dudleys Creek	1:24,000
Haskell	1:24,000
Hefner	1:24,000
Irby	1:24,000
Jud	1:24,000
Kiowa Peak	1:24,000
Kiowa Peak NE	1:24,000
Knox City	1:24,000
Knox City NW	1:24,000
Lake Stamford East	1:24,000
Lake Stamford West	1:24,000
Mattson	1:24,000
Munday East	1:24,000
Munday West	1:24,000
Old Glory	1:24,000
Pinkerton	1:24,000
Rhineland	1:24,000
Rochester	1:24,000
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APPENDIX

EFFECTS ON HUMANS AND ANIMALS OF NITRATE CONCENTRATIONS IN WATER SUPPLIES AS RELATED TO THE SEYMOUR AQUIFER

INTRODUCTION

In response to the concern of the citizens of Haskell and Knox Counties regarding the relatively high level of nitrate in their water supplies, a literature survey was conducted on the effects on humans and animals of high nitrate consumption. The purpose of the survey was to apply the knowledge which is currently known about nitrate consumption and its effects on humans and animals to the situation as it now exists in Haskell and Knox Counties.

The literature was compiled and reviewed by R. W. Harden & Associates with the help of Dr. Robert Darrow, Southwestern Medical School, using a computerized reference network. This paper is based on articles which were readily available and which are listed in the references and bibliography sections of this appendix. The bibliography is a comprehensive list of representative publications on health and nitrate-related topics. Due to the scarcity of some of the articles, not all were consulted as part of this review.

OCCURRENCE OF NITROGEN

Nitrogen occurs naturally and artificially. Humans and animals come into contact with several forms of nitrogen through water and food supplies. The occurrence of nitrogen in ground water is usually in the form of nitrate. Nitrate in ground water can result from natural mineral deposits, soil nitrate, and contaminating sources such as septic tanks, feedlots, sewage disposal plants, and fertilizers. Consumed in excessive amounts, nitrate can be hazardous to humans and animals because chemical processes of the body can change nitrate to nitrite, another form of nitrogen which can have adverse effects on health.

The following table shows the different ways in which the different forms of nitrogen can be expressed and also provides equivalent values and conversion methods.

Conversion Methods and Equivalent Values
for Different Forms of Nitrogen

Nitrate as nitrate (NO_3) x .226 = nitrate as nitrogen (N)
Nitrate as nitrogen (N) x 4.43 = nitrate as nitrate (NO_3)

Example: 45 mg/l nitrate as nitrate
is equivalent to
10 mg/l nitrate as nitrogen

Nitrite as nitrite (NO_2) x .304 = nitrite as nitrogen (N)
Nitrite as nitrogen (N) x 3.29 = nitrite as nitrite (NO_2)

Example: 10 mg/l nitrite as nitrite
is equivalent to
3 mg/l nitrite as nitrogen

Normally, chemical analyses of ground water express the amount of nitrate present as nitrate or as nitrogen. In this review, amounts of nitrate are expressed in milligrams per liter (mg/l) of nitrate as nitrate.

NITRATE AS A HEALTH HAZARD

Methemoglobinemia

Methemoglobinemia is the major concern whenever excessive amounts of nitrate are consumed. It can occur in humans and animals. In humans, nitrate toxicity is related primarily to age and health, while in animals the toxicity is related primarily to the species involved. However, many variables such as body chemistry and diet affect susceptibility to methemoglobinemia. These variables are significant in evaluating the causes of this disease as they are the reasons why some animals and/or humans are affected by a given level of nitrate consumption while others are not affected by the same levels.

In condensed and simplified description, acute toxicity of nitrate occurs as a result of its reduction to nitrite, a process which occurs in the stomach and the mouth by bacterial action. Nitrite changes hemoglobin, the oxygen-carrying element in the blood, to methemoglobin, which cannot carry oxygen (Gass, 1978). The incapability of the methemoglobin to carry oxygen results in "cellular suffocation" referred to as methemoglobinemia. This illness is not usually serious if diagnosed by a doctor; however, an untreated case could result in death. Methemoglobinemia is treated with methylene blue, and in almost all instances a rapid recovery follows, usually within a few hours. In some cases, the condition is remedied by merely discontinuing ingestion of the contaminated water (Ridder and Oehme, 1974).

Methemoglobinemia in Humans

In 1945, Comly was the first to diagnose methemoglobinemia in humans resulting from the consumption of an excessive amount of nitrate. Since Comly's report, only about 2,000 cases have been reported world-wide (Shearer and others, 1972). Unfortunately, in recent years, little attention has been given to methemoglobinemia and consumption of high nitrates in medical literature (Miller, 1971). It is known, however, that the most dominant type of this illness is infantile methemoglobinemia. In general, infants of less than three months of age are most susceptible. The susceptibility of the infant to this disease is dependent on a number of factors, mainly the quantity of nitrate consumed, the duration of exposure to the nitrate, diet, and the general health of the child. Also, there is some evidence that bacterial contamination in a baby's formula might elevate the methemoglobin level of the child (Shearer and others, 1972).

Normal, healthy adults do not appear to be susceptible to methemoglobinemia with the exception of pregnant women and those people on dialysis machines (Ridder and Oehme, 1974 and Carlson and Shapiro, 1970). If the dialysate is made from water high in nitrates, methemoglobinemia can occur.

A symptom of methemoglobinemia in humans is a blue or brownish tint to the fingers, toes, and around the mouth which spreads eventually to the entire body. This symptom is often accompanied by headaches, shortness of breath, and general weakness. Blood samples taken from methemoglobinemia patients are often chocolate-brown in color (Bosch and others, 1950).

The exact concentrations of nitrate which cause methemoglobinemia are unknown. The problem is that this concentration seems to vary from person to person because of individual characteristics as previously mentioned. Statistics from Sattelmacher (1962) and Simon and others (1964) are summarized below.

Distribution of Reported Cases of Infantile Methemoglobinemia by Nitrate Concentration in the Water

Sattelmacher, 1962

	Reported Cases	Deaths	Unknown	Known	Nitrate Concentration in Water, mg/l 0-40	41-80	81-100	>100
Numerical	1,060	83	593	467	14	16	19	418
Percent	100	7.8	56.0	44.0	3.0*	3.4*	4.1*	89.5*

Simon and Others, 1964

	Reported Cases	Deaths	Unknown	Known	Nitrate Concentration in Water, mg/l <50	50-100	>100
Numerical	745	64	496	249	11	29	209
Percent	100	8.6	66.5	33.5	4.4*	11.8*	83.8*

*Percent of cases with nitrate concentration known.

Currently, most state and federal agencies recommend a maximum nitrate concentration of 45 mg/l for drinking water. Since cases of methemoglobinemia have occurred where the nitrate concentrations were lower than 45 mg/l, some authors feel even this limit may not provide an adequate margin of safety (Gass, 1978).

Methemoglobinemia in Animals

As in humans, the exact nitrate concentrations which cause health problems in livestock are not known. A study by Emerick in 1964 concluded that 100 mg/l is well within the range that can be considered safe for all classes of livestock; higher nitrate levels have been used satisfactorily, but such use is not without inherent risks. As with humans again, the degree of susceptibility to methemoglobinemia by livestock depends on numerous variables including the type of animal, health, and the amount and speed of consumption of the contaminated water (Ridder and others, 1974). The nutritional quality of the animal's diet is important also: Rations high in vitamin A and carbohydrates seem to reduce the effects of nitrate while rations high in nitrate such as oat hay and corn stalks aggravate and/or cause nitrate toxicity (Ridder and Oehme, 1974).

Cud-chewing animals such as deer, goats, sheep, and especially cattle are much more susceptible to methemoglobinemia than are the single-stomach (monogastric) species such as pigs, dogs, and horses. Symptoms in cattle are generally shortness of breath, grinding of teeth, and a lowered blood pressure.

Pigs, being monogastric, are less likely to contract methemoglobinemia because their blood oxidation rate is much slower, resulting in a slower process of transition of hemoglobin to methemoglobin (Ridder and others, 1974). Pigs also seem to be unable to transform nitrate into the more dangerous nitrite form; accordingly, they are susceptible only to nitrite formed prior to consumption as in some moist feeds (Ridder and Oehme, 1974). In cases where methemoglobinemia is contracted by a pig, it terminates rapidly in death (Smith and Beutler, 1966). Treatment is difficult because pigs frequently show no external signs of the condition, and there is a lack of response to methylene blue treatments (Ridder and Oehme, 1974 and Smith and Beutler, 1966). Nitrate ingestion by swine also causes erosion of the gastric mucous which usually causes the actual death of the pig before the methemoglobinemia.

The effect of methemoglobinemia on poultry is a function of the age of the affected animal. Results of studies show that as the level of nitrate in feed increased to 200 mg/l, there were corresponding decreases in water and feed consumption, and growth of poults. The same level of nitrate had very little affect on feed and water consumption, blood methemoglobin, and mortality of chicks. In a study of layers, levels up to 300 mg/l nitrate failed to consistently affect rate of lay, egg quality, daily water consumption, and mortality. In general, 300 mg/l nitrate seems to be safe for poultry, and chicks, poults, and layers have been recorded to tolerate doses of nitrate in excess of 1,300 mg/l (Adams and others, 1966).

Chronic Nitrate Toxicity in Humans and Animals

Chronic nitrate toxicity due to long-term, low-level nitrate intake is recognized, but documented reports are inconsistent. Some controversial signs of chronic nitrate toxicity reportedly observed are vitamin A deficiency in humans, cattle, swine, chickens, and dogs; thyroid dysfunction in cattle, poults, chicks, and humans; reduced rates of growth in cattle, poults, chicks, and swine; reproduction difficulties, lowered milk production, diarrhea, and shortened life span in cattle; and arthritic conditions and iron deficiencies in swine (Ridder and Oehme, 1974).

Attention has been given to the possible formation of nitrosamines, some of which may be carcinogenic (cancer-causing) in humans and animals, as a result of nitrate consumption (Gass, 1978 and *The Lancet*, 1968).

The literature reviewed was inconsistent regarding which of the above ailments were related directly to what levels of nitrate consumption. However, all articles stated consistently that further studies are needed to better define the nature and consequences of chronic nitrate toxicity.

CONCLUSIONS

In regard to what levels of nitrate are safe for humans and animals, the results of the reports reviewed differ somewhat because of variations in research design and study environments. Generally, the literature indicates that nitrate concentrations of 45 mg/l and 100 mg/l are considered reasonably safe for humans and animals, respectively. However, because humans and animals have been recorded as tolerating somewhat higher concentrations of nitrate with seemingly no ill effects, it is evident that safe limits are difficult to establish due to many variables which affect individual tolerances. The general consensus of the articles reviewed is that more study is needed on the topic of nitrate consumption.

Nitrate Levels in the Seymour Aquifer

Over 70 percent of 820 wells in the Seymour aquifer tested recently exceed the recommended nitrate level for drinking water of 45 mg/l. Most values are between 30 and 90 mg/l.

Nitrate values for wells furnishing municipal needs have the following ranges:

	Number of Wells	Range in Nitrate Content (mg/l)
Aspermont	3	56-57
Benjamin	2	41-51
Goree	3	40-53
Haskell	11	71-148
Knox City	3	75-78
Munday	4	50-60
O'Brien	1	118
Rochester	1	63
Rule	4	40-73
Weinert	2	50-52

Munday, Goree, Haskell, and Knox City will have alternate water supplies available from Millers Creek Reservoir.

Approximately 9 percent or 23 of the domestic and stock wells sampled during this investigation show nitrate contents in excess of 150 mg/l. Present evidence indicates these wells are affected by nearby sources of pollution, mostly septic tanks. Undoubtedly, a number of domestic wells with nitrate concentrations lower than 150 mg/l are affected also by pollution from septic tanks.

To meet current drinking water standards when nitrate levels in a water supply are greater than 45 mg/l requires alternate sources of water or water treatment to remove the offending nitrate. However, as in many areas of the United States, these are not always practicable solutions for the people of Haskell and Knox Counties. At this time, there is no method considered economical by most water users of removing nitrate from ground water, and obtaining alternate sources of water is often cost-prohibitive, also.

In the absence of cost-effective alternatives, use of the present water supply must be continued. Fortunately, the nitrate levels in the Seymour aquifer are not necessarily dangerous to the health of humans and animals if the citizens are alert to the situation and take the proper precautions.

Precautions

It is important for each person to know the nitrate concentration of his water supply. In the case of municipal supplies, this information is provided. If an individual is using water from a private well, a chemical analysis should be made on water from the well.

If large concentrations of nitrate are found, a physician should be consulted as to the concentration's effect on certain individuals. It is important to remember that small children, pregnant women, and dialysis patients are particularly prone to nitrate toxicity. In the case of infants, formulas which are mixed with water should be discontinued as a method of feeding the child in favor of breast-feeding or the use of undiluted pasteurized cow milk. Care should be taken in these areas also as cases of methemoglobinemia have been reported in infants being breast-fed by mothers drinking contaminated water and in infants drinking cow milk from animals using water with increased nitrates (Older, 1969). In some instances, it may be necessary to obtain alternate drinking water supplies depending on the amount of nitrate in the affected water.

Animals have a higher nitrate tolerance than humans, but a veterinarian should be consulted when elevated nitrate concentrations are discovered in a water supply. Animals should be prohibited from rapidly consuming large quantities of highly nitrated water as this is particularly dangerous. Also, the nutritional quality of the animal's feed seems to be important in relation to nitrate-related illnesses. Much of the literature records vitamins C, D, E, and especially A, as having properties capable of decreasing susceptibility to nitrate toxicity and helping to remedy already occurring cases of the disease. As with humans, there is the possibility that high nitrate concentrations in some water supplies may render the water unacceptable for animal use.

Certain precautions against nitrate contamination can be taken in locating a Seymour water well. The well should be located up the hydraulic gradient and in the opposite direction of ground-water flow from pollution sources such as septic tanks, barnyards, and feedlots. Bosch and others (1950) report that 150 feet is a minimum distance at which a well supply should be located from any type of nitrate contamination source. For a Seymour domestic well, this distance, if up the hydraulic gradient, is adequate in most cases to avoid drawing significant amounts of nitrate from a pollution source. However, the distance depends generally on the pumping rate of the well, the characteristics of the formation, and in some instances, partly on the quantity of the nitrate.

In conclusion, it appears the citizens of Haskell and Knox Counties have reason for concern, but not extreme alarm regarding the typical nitrate levels in their water supplies. Nitrate in ground water is a potential health hazard to humans and animals, but at present, the problem probably can be dealt with most economically by closely monitoring nitrate levels and taking appropriate precautionary measures.

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