Report 297

# Ground-Water Resources of Rusk County, Texas

April 1987

Texas Water Development Board

# TEXAS WATER DEVELOPMENT BOARD

## REPORT 297

# GROUND-WATER RESOURCES OF RUSK COUNTY, TEXAS

By

W. M. Sandeen
U.S. Geological Survey

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## FOREWORD

Effective September 1, 1985, the Texas Department of Water Resources was divided to form the Texas Water Commission and the Texas Water Development Board. A number of publications prepared under the auspices of the Department are being published by the Texas Water Commission. To minimize delays in producing these publications, references to the Department will not be altered except on their covers and title pages.

# ABSTRACT

Fresh to slightly saline water is available in most parts of Rusk County, which is located in the Piney Woods region of northeast Texas. The Wilcox aquifer, which underlies the entire county, was the source of most of the ground water withdrawn during 1980. Other units capable of yielding fresh ground water are the Carrizo, Queen City, and Sparta aquifers and the Reklaw Formation.

About 5.4 million gallons per day of ground water was used for all purposes during 1980. Of this amount, about 78 percent was used for public supply, 10 percent for mining, 8 percent for industrial purposes, and 4 percent for rural domestic use. Water levels have declined extensively at the city of Henderson, which used about 38 percent of all ground water consumed in Rusk County.

Generally, the ground water is of acceptable quality. Water in some of the near-surface beds and some of the deeper sands in the Wilcox aquifer may have become mineralized because of oilfield operations. Ground-water contamination by oilfield brines at Henderson Oil Field has been documented. Two separate instances of streamflow contamination at Striker Creek and Henderson Oil Field have been documented.

Moderate amounts of ground water are available for development. The amount that is available perennially is not known, but it is greater than that being withdrawn. Assuming a hydraulic gradient of about 8 feet per mile, at least 12 million gallons per day of fresh ground water is being transmitted through the Wilcox and about 3 million gallons per day through the Carrizo. About 20 million acre-feet of fresh ground water is available from storage in the Wilcox and about 4 million acre-feet from storage in the Carrizo. Additional amounts of slightly saline water are available from the major aquifers. Smaller but undetermined amounts of fresh ground water are available from the Sparta and Queen City aquifers and from the Reklaw Formation. Properly constructed wells in the Wilcox and Carrizo aquifers can be expected to yield more than 500 gallons per minute if the wells are properly spaced. Development of additional resources around the city of Henderson and the Mount Enterprise Fault System should be considered cautiously because of the probability of saltwater encroachment. Ground water in other parts of the county is practically undeveloped.

Some mineralization of ground water is due to natural causes. Other mineralization of ground water is due to contamination. A program needs to be initiated to determine the extent and cause of mineralization that has taken place in freshwater sands. Water-quality data are needed at Henderson in order to monitor saltwater encroachment.

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# GROUND-WATER RESOURCES OF RUSK COUNTY, TEXAS

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# INTRODUCTION

## Location and Extent of Area

Rusk County, located in the Piney Woods region of northeast Texas, is bordered by Gregg and Harrison Counties on the north, Panola and Shelby Counties on the east, Nacogdoches County on the south, and Cherokee and Smith Counties on the west (Figure 1). The city of Henderson, the county seat and largest city in the county, is about 135 miles east of Dallas and about 75 miles west of Shreveport, Louisiana. Rusk County has an area of 939 square miles. Altitude of the land surface ranges from 227 feet near the Sabine River to 709 feet near the town of Mount Enterprise.

## Purpose and Scope

This is a report of a detailed investigation of the ground-water resources of Rusk County begun during 1979 by the U.S. Geological Survey in cooperation with the Texas Department of Water Resources. After about 5 months of initial work, the project was deferred for lack of funds. The project was resumed during 1981, which made it necessary to update the 1979 data. The report now reflects 1981 water levels.

The purpose of the investigation was to determine the occurrence, availability, dependability, quality, and quantity of ground water present in the county. Special emphasis was placed upon describing the quantity and quality of ground water suitable for public supply and industrial use.

The investigation included determining the extent of sands containing freshwater; documenting the chemical quality of the water; estimating the quantities of water being withdrawn; determining the effects of withdrawals on ground-water levels; estimating the hydraulic characteristics of the water-bearing sands; rating the area on the basis of ground-water availability; and determining the potential sources of contamination.

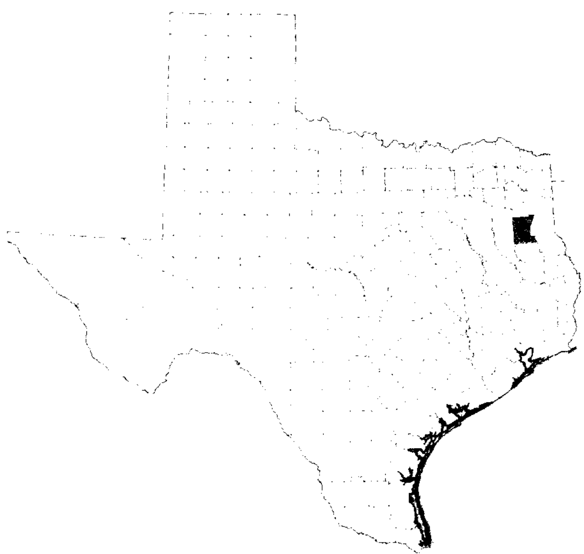

**Figure 1.—Location of Rusk County**

## Methods of Investigation

Field data for this report were collected during March through June 1979, and during March through July 1981. Data from older reports were included, the earliest of which was written in 1932, shortly after the discovery of East Texas Oil Field. Basic information, including depths of wells, water levels, methods of well construction, type of lift, yield characteristics, and use of water was collected for 365 wells. In addition, water samples were collected for chemical analysis. All relevant information previously collected by the Texas Department of Water Resources and the Geological Survey was used.

Basic data used in describing the hydrologic characteristics and features of the various aquifers in this report are derived from the field inventory of existing water wells, drillers' logs of representative wells, measurement of water levels in these wells, collection and analysis of water samples from the wells, and aquifer tests. The well inventories are compiled in Table 8, drillers' logs in Table 9, water levels in Table 10, and water-quality analyses in Tables 11 and 12.

Most data relating to the quantity of ground water withdrawn for public supply and industrial uses were obtained from records of the Texas Department of Water Resources. Some quantities were estimated on the basis of the number of users and normal rates of use.

The map of the geologic units is from the Geologic Atlas of Texas, which was prepared by the University of Texas, Bureau of Economic Geology (1965, 1968). Electric logs of oil, gas, and water wells commonly were used for control in preparation of the geologic sections and for maps showing the altitudes of aquifers, the base of fresh and slightly saline water, and approximate thickness of sands containing freshwater. Additional subsurface information was provided by drillers' logs of wells. In some instances, projections of fault blocks from the surface to the subsurface were made to show relationships existing along the Mount Enterprise Fault Zone.

Representative results of aquifer tests from previously published data in adjacent counties were analyzed by the Theis nonequilibrium method as modified by Cooper and Jacob (1946) and the Theis recovery method (Wenzel, 1942). Data relating to secondary recovery, saltwater production, surface casing, and oil production in oil and gas fields were acquired from records of the Railroad Commission of Texas and the East Texas Salt Water Disposal Company.

Altitudes not previously determined were interpolated from available Geological Survey 7½ and 15-minute topographic maps having a contour interval ranging between 10 feet and 20 feet in the study area.

## Physiography, Drainage, and Climate

Rusk County is in the West Gulf Coastal Plain physiographic province (Fenneman, 1939) and a part of the Piney Woods region of East Texas. The most prominent physiographic feature is the Mount Enterprise Fault System, which extends along an east-west axis across the southern part of the county. The system forms a series of hills, some of which attain an altitude in excess of 600 feet, extending from due east of Mount Enterprise to near Reklaw, where the system is somewhat offset to the north. The land surface slopes away from these high ridges, generally to the north and to the south, interrupting a regional surface sloping in an easterly and southerly direction. Substantial growths of pine and hardwood occur throughout much of the county.

Springs commonly are found at higher and intermediate altitudes. Streams in the northeastern part of the county drain to the Sabine River whereas those in the southwestern part drain to the Neches River. Striker Creek and Bowles Creek drain into the Striker Creek Lake, Beaver Run and Tiawichi Creek into Lake Cherokee, and Martin Creek into Martin Lake.

Rusk County has a warm, semihumid climate. Annual precipitation at Henderson for 1909-80 ranged from 23 inches during 1963 to 68 inches during 1957 and averaged 38.8 inches as shown in Figure 2. According to the National Oceanic and Atmospheric Administration, the monthly precipitation at Henderson for 1941-70 ranged from 2.81 inches during July to 5.79 inches during May and averaged 3.94 inches as shown in Figure 3.

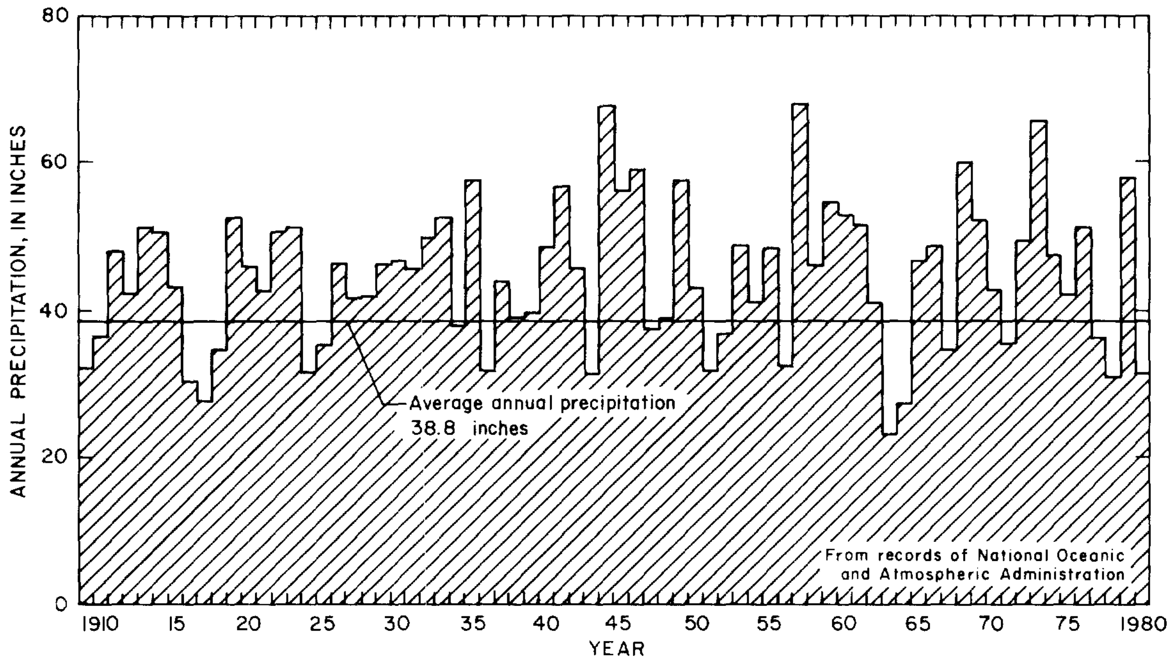


**Figure 2.—Annual Precipitation at Henderson, 1909-80**

The average-annual temperature at Henderson (Figure 3) is 18.7°C (65.3°F). Dates of the first and last freezes are about November 14 and February 20; the average growing season lasts about 250 days. The average-annual gross-lake surface evaporation in Rusk County for 1940-65 was 45.9 inches (Kane, 1967).

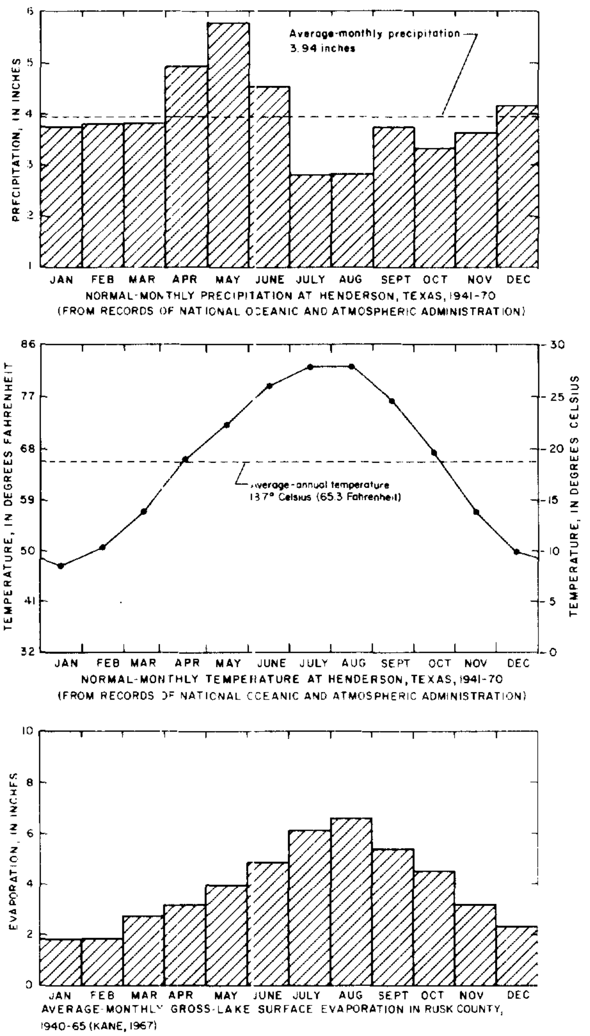


**Figure 3.—Average-Monthly Precipitation and Temperature at Henderson and Average-Monthly Gross-Lake Surface Evaporation in Rusk County**

## Economic Development

During 1980, oil and gas, lignite leasing, lumbering, agriculture, and clay products provided the main sources of income for Rusk County. Until 1930, lumbering and agriculture provided the mainstay for the economy of the area. The beginning of the oil and gas industry in the county occurred during 1929 when "Dad" Joiner (Figure 4) started his No. 3 Daisy Bradford well in northwest Rusk County. The well was completed during 1930 as the first discovery well for East Texas Oil Field (Rusk, Gregg, Upshur, and Smith Counties). The location of this field and others are shown in Figure 5. Since that time, oil and gas and the processing of petroleum and related products have been the most significant industry.

Completion of the No. 3 Daisy Bradford, however, came at an awkward time just before the height of the depression. Independents drilled hundreds of wells, many of which were on town lot spacing. So much crude was produced from East Texas that the price of oil fell to 10 cents a barrel. When riots started, Governor Ross Sterling called out the National Guard to preserve order. It also was at this time that he appointed E. O. Thompson to the Texas Railroad Commission and delegated to him the responsibility of regulating oil and gas production in Texas.

By 1980, East Texas Oil Field had produced over 4.622 billion barrels of oil and was responsible for making Rusk County rank among the larger oil producing counties in Texas. The field also had produced substantial quantities of saltwater. According to a 1961 oilfield-brine disposal inventory prepared by the Texas Water Commission and Texas Water Pollution Control Board (1963), 156.7 million barrels of saltwater was produced that year. This was an average of 0.427 million barrels a day, 99 percent of which was disposed of through injection wells.

## Population

Rusk County has a population of 41,382 according to the U.S. Department of Commerce, Bureau of Census (1980). Henderson, the county seat, has a population of 11,473. Populations of


**Figure 4.—C. M. (Dad) Joiner, Dr. Lloyd, H. L. Hunt, and Drilling Crew of No. 3 Daisy Bradford, Discovery Well of East Texas Oil Field (1930)**
***Photo Courtesy of YOUTH SPEAKS***

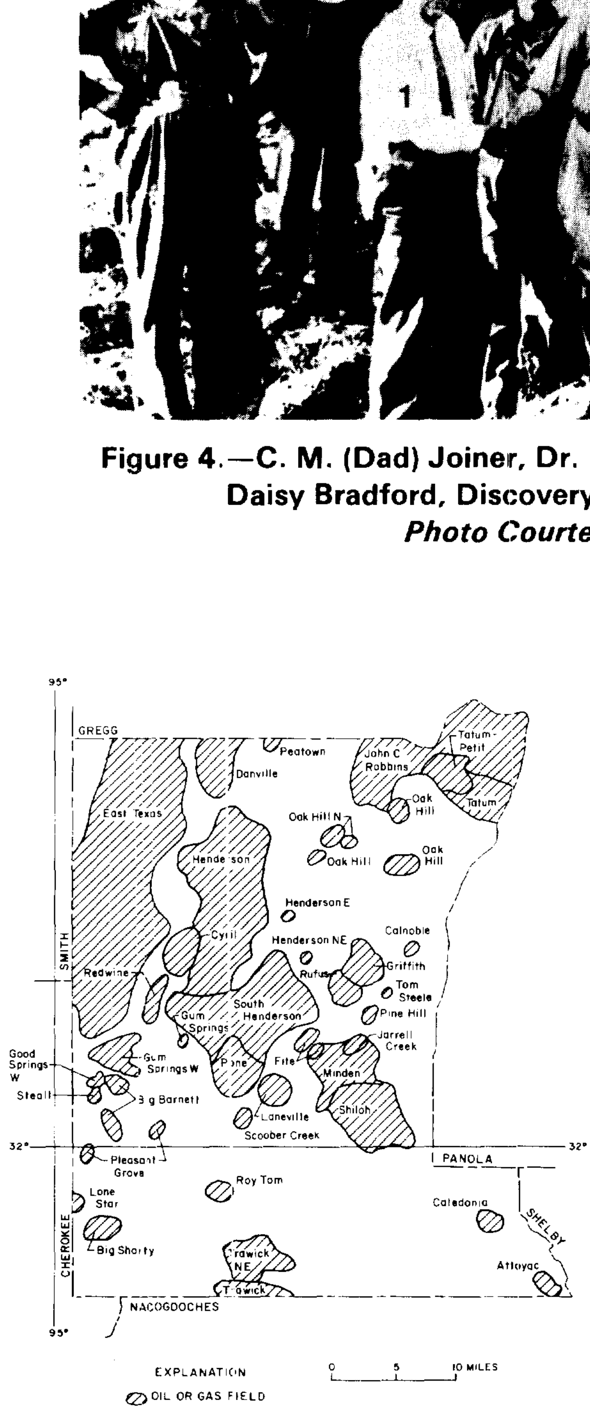


**Figure 5.—Location of Significant Oil and Gas Fields**

other towns are: Overton, 2,430; Tatum, 1,614; New London, 942; and Mount Enterprise, 485. The 1980 census also shows that 2,543 of the people living in Kilgore (Gregg and Rusk Counties) reside in Rusk County.

## Previous Investigations

Deussen (1914) mentioned the existence of several springs and water wells in his study of the southeastern part of the Texas Coastal Plain including more than 20 Texas counties. Turner (1932) compiled a report on ground water in East Texas Oil Field that covered parts of Gregg, Rusk, Smith, and Upshur Counties. He concluded that saltwater contamination of the freshwater-bearing zones probably had not occurred at that time. Turner suggested that the possibility of bacteriological contamination of ground water existed and recommended that all "abandoned oil wells that yield a flow of the well number. The well location on a map is shown by listing only the last three digits of the well number adjacent to the well location. The second two digits are shown in the northwest corner of each 7½-minute quadrangle, and the first two digits are shown by the large double-line numbers.

In addition to the seven-digit well number, a two-letter prefix is used to identify the county. The prefixes for Rusk and adjacent counties are as follows:

| County | Prefix | County | Prefix |
|---|---|---|---|
| Cherokee | DJ | Panola | UL |
| Gregg | KU | Rusk | WR |
| Harrison | LK | Shelby | XB |
| Nacogdoches | TX | Smith | XH |

For example, well WR-35-50-801, which supplies water for the city of Henderson, is in Rusk County (WR) in the 1-degree quadrangle (35), in the 7½-minute quadrangle (50), in the 2½-minute quadrangle (8), and was the first well (01) inventoried in that 2½-minute quadrangle (Figure 6). Well numbers used by Lyle (1937) and Follett (1943) and the corresponding numbers used in this report are given in Table 1 ("old number"). The location of wells, springs, and selected test holes used in this report are shown in Figure 24.

The Geological Survey's national site identification system uses the latitude-longitude coordinate system. The combination of the 6-digit latitude number, the 7-digit longitude number, and a 2-digit sequence number forms a 15-digit site identification number. For example, the first site at latitude 32°15'42" and longitude 94°34'23" gives a site-identification number of 321542094342301. A cross reference between the local and national systems for the wells in this report is given in Table 1.

## Definitions of Terms

In this report certain technical terms, including some that are subject to different interpretations, are used. For convenience and clarification, these terms are defined as follows:

*Acre-foot*—The volume of water required to cover 1 acre to a depth of 1 foot (43,560 $ft^3$ or 325,851 gallons).

*Acre-foot per year*—One (1) acre-foot per year equals 892.13 gal/d.

*Aquifer*—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

*Aquifer test, pumping test*—The test consists of the measurement, at specific intervals, of the discharge and water level of the well being pumped and the water levels in nearby observation wells. Formulas have been developed to show the relationship of the yield of a well, the shape and

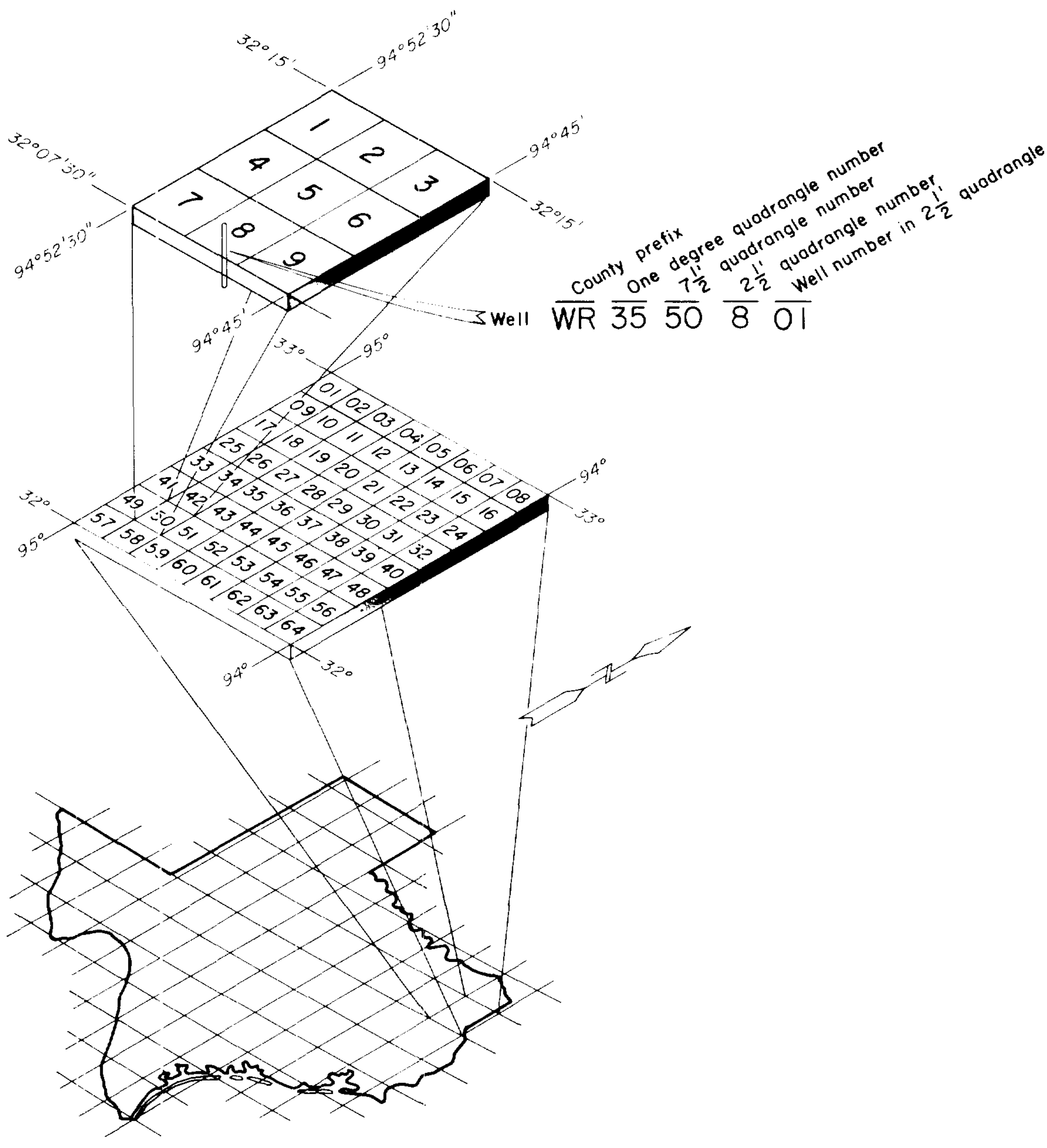


**Figure 6.—Well-Numbering System**

extent of the cone of depression, and the properties of the aquifer such as the specific yield, porosity, hydraulic conductivity, transmissivity, and storage coefficient.

*Artesian aquifer, confined aquifer*—Artesian (confined) water occurs where an aquifer is overlain by rock of lower hydraulic conductivity (e.g., clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the level at which it was first encountered in the well. The well may or may not flow.

*Barrel*—A volume of 42 gallons.

## Table 1.--Cross Reference of Well Numbers in Rusk County

| Old number | New number | Site identification | Old number | New Number | Site identification | Old number | New number | Site identification |
|---|---|---|---|---|---|---|---|---|
| 4 | WR-35-41-101 | 322038094581701 | 248 | WR-35-50-703 | 320910094505001 | 567 | WR-37-10-101 | 315101094503301 |
| 7 | WR-35-41-401 | 321859094585701 | 251 | WR-35-50-701 | 320855094522401 | 571 | WR-37-02-803 | 315234094493701 |
| 14 | WR-35-41-708 | 321633094581101 | 255 | WR-35-50-702 | 320925094491801 | 575 | WR-37-02-401 | 315510094501401 |
| 16 | WR-35-41-705 | 321632094583702 | 260 | WR-35-50-403 | 321120094414601 | 576 | WR-37-02-501 | 315707094492401 |
| 17 | WR-35-41-707 | 321631094583401 | 289 | WR-35-49-509 | 321143094552501 | 577 | WR-37-02-601 | 315718094471501 |
| 22a | WR-35-41-706 | 321524094584601 | 294 | WR-35-49-304 | 321352094540301 | 578 | WR-37-02-602 | 315712094472401 |
| 31 | WR-35-41-510 | 321751094564301 | 299a | WR-35-41-810 | 321501094560301 | 579 | WR-37-02-604 | 315520094472901 |
| 31a | WR-35-41-509 | 321752094565101 | 310 | WR-35-49-101 | 321448094583201 | 583 | WR-37-03-701 | 315255094444401 |
| 32 | WR-35-41-505 | 321844094565301 | 313 | WR-35-49-103 | 321408094582001 | 585 | WR-37-11-203 | 325204094422801 |
| 40 | WR-35-41-202 | 322100094555601 | 315 | WR-35-49-102 | 321413094573001 | 588 | WR-37-02-603 | 315710094450401 |
| 47a | WR-35-41-308 | 322000094540001 | 316a | WR-35-49-205 | 321415094562501 | 589 | WR-37-03-401 | 315714094440001 |
| 50 | WR-35-41-508 | 321939094552101 | 327 | WR-35-49-303 | 321338094545901 | 590 | WR-37-03-402 | 315620094432001 |
| 62 | WR-35-41-902 | 321625094540701 | 336a | WR-35-49-510 | 321146094564401 | 593 | WR-37-03-503 | 315520094413401 |
| 70 | WR-35-41-903 | 321539094163601 | 343 | WR-35-57-803 | 320115094564601 | 594 | WR-37-03-504 | 315507094410201 |
| 75 | WR-35-41-904 | 321609094531401 | 367 | WR-35-57-504 | 320302094563901 | 596 | WR-37-03-901 | 325430094394101 |
| 80 | WR-35-42-402 | 321750094500201 | 369 | WR-35-57-601 | 320310094532501 | 598 | WR-37-11-301 | 325051094385501 |
| 82 | WR-35-42-403 | 321941094500401 | 375 | WR-35-57-301 | 320647094541701 | 607 | WR-37-04-402 | 325708094352201 |
| 88 | WR-35-41-201 | 322125094554001 | 384 | WR-35-49-807 | 320910094553701 | 608 | WR-37-04-201 | 325740094333501 |
| 90 | WR-35-42-601 | 321952094472901 | 393 | WR-35-49-604 | 321022094523901 | 609 | WR-37-04-301 | 325802094315501 |
| 92 | WR-35-42-501 | 321811094475601 | 398 | WR-35-49-902 | 320852094525301 | 619 | WR-37-12-201 | 315055094332501 |
| 100 | WR-35-42-904 | 321703094454301 | 402 | WR-35-59-402 | 320410094441801 | 621 | WR-37-12-303 | 325054094304501 |
| 103 | WR-35-42-602 | 321757094453701 | 409 | WR-35-50-805 | 320701094484401 | 629 | WR-35-41-304 | 322140094542201 |
| 108 | WR-35-43-401 | 321826094442801 | 415 | WR-35-50-910 | 320908094440201 | 631 | WR-35-41-309 | 322113094542901 |
| 111 | WR-35-42-303 | 322147094452901 | 416 | WR-35-50-901 | 320852094470701 | 634 | WR-35-41-307 | 322020094534301 |
| 114 | WR-35-42-302 | 322036094461501 | 420 | WR-35-50-911 | 320816094461501 | 642 | WR-35-41-507 | 321951094553401 |
| 126 | WR-35-43-801 | 321651094411101 | 423 | WR-35-58-302 | 320522094451801 | 652 | WR-35-41-703 | 321632094583701 |
| 130 | WR-35-43-901 | 321628094382001 | 426 | WR-35-59-501 | 320440094415501 | 653 | WR-35-41-803 | 321616094554301 |
| 132 | WR-35-44-702 | 321718094370501 | 427 | WR-35-59-603 | 320414094392101 | 654 | WR-35-41-802 | 321617094554201 |
| 136 | WR-35-44-403 | 321856094361501 | 429 | WR-35-59-302 | 320510094392601 | 656 | WR-35-49-203 | 321457094555801 |
| 140 | WR-35-44-503 | 321954094344801 | 433 | WR-35-59-203 | 320654094404201 | 658 | WR-35-49-201 | 321427094562101 |
| 146 | WR-35-44-302 | 322015094302501 | 434 | WR-35-51-902 | 320911093383601 | 661 | WR-35-41-704 | 321532094580001 |
| 151 | WR-35-44-604 | 321904094322501 | 505 | WR-35-59-904 | 320222094383201 | 669 | WR-35-49-208 | 321321094550101 |
| 152 | WR-35-44-605 | 321836094316801 | 507 | WR-35-60-701 | 320138094362001 | 671 | WR-35-49-209 | 321309094551501 |
| 165 | WR-35-51-903 | 320844094381101 | 519 | WR-35-59-701 | 320224094433501 | 682 | WR-35-49-503 | 321217094561801 |
| 168 | WR-35-52-702 | 320946094372401 | 524 | WR-37-03-101 | 315950094443101 | 684 | WR-35-49-504 | 321222094571101 |
| 175 | WR-35-51-603 | 321055094394701 | 528 | WR-35-58-801 | 320200094480501 | 694 | WR-35-49-508 | 321126094562201 |
| 176 | WR-35-51-503 | 321044094411402 | 532 | WR-37-02-102 | 315756094502701 | 697 | WR-35-49-507 | 321048094550901 |
| 177 | WR-35-51-802 | 320908094421202 | 534 | WR-37-02-206 | 315915094484901 | 698 | WR-35-49-603 | 321045094533401 |
| 179 | WR-35-50-913 | 320930094450201 | 535 | WR-37-02-101 | 315929094502301 | 704 | WR-35-49-506 | 321049094561501 |
| 179a | WR-35-50-912 | 320928094450801 | 536 | WR-35-58-702 | 320154094510101 | 711 | WR-35-49-505 | 321036094570001 |
| 183 | WR-35-51-102 | 321413094424001 | 538 | WR-35-58-701 | 320154094515801 | 722 | WR-35-49-402 | 321105094575301 |
| 185 | WR-35-50-303 | 321319094454701 | 547 | WR-37-01-103 | 315949094583701 | 730 | WR-35-49-403 | 321004094574801 |
| 187 | WR-35-59-203 | 320654094404201 | 548 | WR-37-01-202 | 315959094561701 | 736 | WR-35-49-808 | 320954094553801 |
| 191 | WR-35-50-205 | 321309094474601 | 549 | WR-37-01-203 | 315754094551501 | 742 | WR-35-49-801 | 320809094562901 |
| 206 | WR-35-50-601 | 321007094470401 | 551 | WR-37-01-401 | 315728094584301 | 752 | WR-35-49-702 | 320858094581801 |
| 218 | WR-35-50-404 | 321032094502001 | 558 | WR-37-01-701 | 315438094574201 | 758 | WR-35-50-902 | 320908094470201 |
| 224 | WR-35-50-101 | 321452094512801 | 559 | WR-37-01-803 | 315402094561201 | 760 | WR-35-50-803 | 320851094480901 |
| 225 | WR-35-50-102 | 321339094505901 | 563 | WR-37-01-601 | 315513094533201 | 761 | WR-35-50-804 | 320833094473401 |
| 230 | WR-35-50-103 | 321253094515801 | 564 | WR-37-01-901 | 315322094542301 | 762 | WR-35-50-903 | 320902094470501 |
| 240a | WR-35-50-402 | 321117094504901 | 565 | WR-37-09-201 | 315114094553801 | | | |

*Brine*—Water containing more than 35,000 mg/L (milligrams per liter) dissolved solids (Winslow and Kister, 1956, p. 5).

*Cone of depression*—Depression of the water table or potentiometric surface surrounding a discharging well or group of wells (usually shaped like an inverted cone).

*Dip of rocks, attitude of beds*—The angle or amount of slope at which a bed is inclined from the horizontal; direction also is expressed (for example, 1 degree southeast or 90 ft/mi southeast).

*Drawdown*—The lowering of the water table or potentiometric surface caused by pumping (or artesian flow). In most instances, it is the difference, in feet, between the static level and the pumping level.

*Electric log*—A graph showing the variation in relationship between the electrical properties of the rocks and their fluid contents penetrated in a well. The electrical properties are natural potentials and resistivities to induced electrical currents, some of which are modified by the presence of the drilling mud.

*Freshwater*—Water containing less than 1,000 mg/L dissolved solids (Winslow and Kister, 1956, p. 5).

*Groundwater*—Water in the ground that is in the saturated zone from which wells, springs, and seeps are supplied.

*Head, static*—The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point.

*Hydraulic conductivity*—The rate of flow of a unit volume of water in unit time at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head over unit length of flow path. Formerly called field coefficient of permeability.

*Hydraulic gradient*—The change in static head per unit of distance in a given direction.

*Moderately saline water*—Water containing 3,000 to 10,000 mg/L dissolved solids (Winslow and Kister, 1956, p. 5).

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

*Potentiometric surface*—A surface which represents the static head. As related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface.

*Slightly saline water*—Water containing 1,000 to 3,000 mg/L dissolved solids (Winslow and Kister, 1956, p. 5).

*Specific capacity*—The rate of discharge of water from a well divided by the drawdown of water level in the well. It generally is expressed in gallons per minute per foot of drawdown for a specified period after discharge ceases.

*Specific yield*—The quantity of water that an aquifer will yield by gravity if it is first saturated and then allowed to drain; the ratio expressed in percentage of the volume of water drained to volume of the aquifer drained.

*Storage coefficient*—The volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

*Transmissivity*—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer. Formerly called coefficient of transmissibility.

*Very saline water*—Water containing 10,000 to 35,000 mg/L dissolved solids (Winslow and Kister, 1956, p. 5).

*Water level; static level or hydrostatic level*—In an unconfined aquifer, the distance from the land surface to the water table. In a confined (artesian) aquifer, the level to which the water will rise either above or below land surface.

*Water table*—The water table is that surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enought to hold standing water. In wells which penetrate to greater depths, the water level will stand above or below the water table if an upward or downward component of ground-water flow exists.

*Yield*—The rate of discharge, commonly expressed as gallons per minute, gallons per day, or gallons per hour. In this report, yields are classified as small, less than 50 gal/min; moderate, 50 to 250 gal/min; and large, more than 250 gal/min.

## Metric Conversions

For those readers interested in using the metric system, the inch-pound units of measurements used in this report may be converted to metric units by the following factors:

| From | Multiply by | To obtain |
| --- | --- | --- |
| acre | 0.4047 | hectare |
| acre-foot | 0.001233 | cubic hectometer ($hm^3$) |
| barrel | 0.1590 | cubic meter ($m^3$) |

| From | Multiply by | To obtain |
|---|---|---|
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| foot | 0.3048 | meter (m) |
| foot per day (ft/d) | 0.3048 | meter per day (m/d) |
| foot per mile (ft/mi) | 0.189 | meter per kilometer (m/km) |
| foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day ($m^2/d$) |
| gallon per day (gal/d) | 0.003785 | cubic meter per day ($m^3/d$) |
| gallon per minute (gal/min) | 0.06308 | liter per second (L/s) |
| | 0.003785 | cubic meter per minute ($m^3/min$) |
| inch | 25.4 | millimeter (mm) |
| micromhos per centimeter at 25° Celsius | 1.00 | microsiemens per centimeter at 25° Celsius |
| mile | 1.609 | kilometer (km) |
| million gallons per day (million gal/d) | 0.04381 | cubic meter per second ($m^3/s$) |
| | 3,785 | cubic meter per day ($m^3/d$) |
| square mile | 2.590 | square kilometer ($km^2$) |

Temperature data in this report are in degrees Celsius (°C) and may be converted to degrees Fahrenheit (°F) by the following formula:

$$°F = 1.8(°C) + 32.$$

# GEOLOGIC FRAMEWORK AND PHYSICAL CHARACTERISTICS OF THE GEOLOGIC UNITS

Rusk County is in an area affected by several regional structural features—the Sabine Uplift, Mount Enterprise Fault System, and East Texas Embayment (Figure 7). Geologic units, ranging in age from Paleocene and Eocene (Wilcox Group) through the Holocene (alluvium) crop out at the

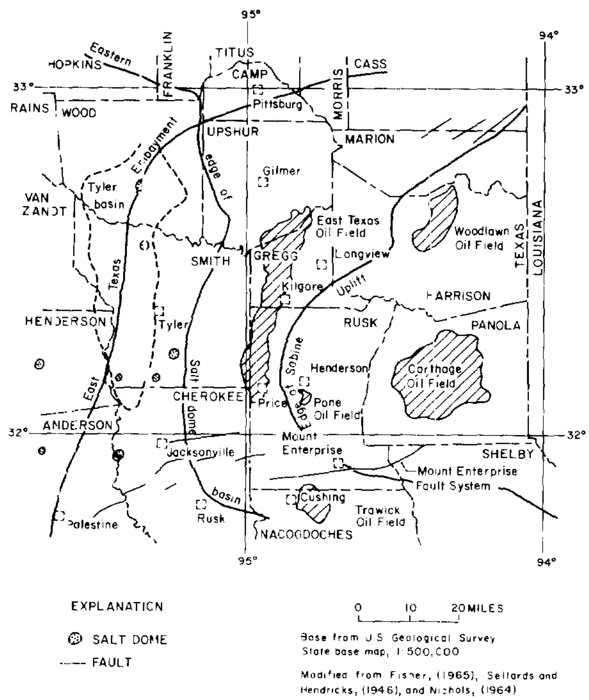


**Figure 7.—Location of Principal Geologic Structural Features in East Texas**

surface as shown in Figure 8. Beds of the Carrizo Sand, which crop out over about a third of the county, are slightly more extensive than those of the older Wilcox Group. A description of the geologic units and their water-bearing characteristics is given in Table 2. Stratigraphic and structural relationships in the subsurface are shown on the geologic sections (Figures 25-27).

The Sabine Uplift (Figure 7) is a structurally complicated area in northeast Texas and northwest Louisiana. The western boundary extends into Rusk County. Sands, red beds, and shales of the Cretaceous Woodbine Formation were deposited over this uplift and later eroded. East Texas Oil Field, a stratigraphic trap, produces oil from the Woodbine at a depth of about 3,650 feet. About 20-25 miles west of the eastern edge of East Texas Oil Field lies the nadir of the East Texas Embayment, into which the Woodbine thickens. Such features were at times instrumental in controlling the deposition of the Wilcox.

The Mount Enterprise Fault System trends east-west across southern Rusk County. The Queen City Sand, Weches Formation, and Sparta Sand are preserved in the downthrown side of this system. Eaton (1956, p. 83) notes that there was moderate movement along this system in Midway time, considerable movement during Claiborne time, and a marked movement during post-Claiborne time. An earthquake of 7 on the Richter scale was reported at Rusk (Cherokee County), during 1891 but is questioned by von Hake (1977). Collins, Hobday, and Kreitler (1980, p. 16) suggest that the event may have been seismic. They use releveling data to conclude that the system has been active during the past 30 years.

Further information on the geologic relationships existing in this area is available from Sellards, Adkins, and Plummer (1932) and from Kreitler and others (1980). For a generalized regional appraisal relating to the structural and depositional altitude of the Wilcox Group, the reader is referred to Jones and others (1976).

## Midway Group

The Midway Group, mostly marine in origin, is composed chiefly of calcareous clay, which locally may contain thin stringers of limestone and glauconitic sand. In places, the unit is silty and slightly sandy in the uppermost part of the section.

The altitude of the top of the Midway, which coincides with the base of the Wilcox Group (Figure 9), ranges from about 300 feet below sea level in the northeastern part of the county to about 1,600 feet below sea level in the southwestern part of the county. In the northern part of the

## Table 2.--Geologic Units and Their Water-Bearing Properties in Rusk County

| System | Series | Group | Unit | Approximate range in thickness (feet) | Composition | Water-bearing properties |
|---|---|---|---|---|---|---|
| Quaternary | Holocene | | Alluvium | 0-35 | Sand, silt, clay, and some gravel. | May yield small quantities of water to shallow dug wells. |
| | Pleistocene | | Terrace deposits | 0-30 | Sand, silt, and clay. | Not known to yield water to wells. |
| Tertiary | Eocene | Claiborne | Sparta Sand | 0-100 | Interbedded sand, clay, and silt. | Feeds springs; may yield some water to dug wells. |
| | | | Weches Formation | 0-50 | Glauconite, glauconitic clay and sand. Secondary deposits of limestone in outcrop. | Not known to yield water to wells in Rusk County. |
| | | | Queen City Sand | 0-130 | Sand, silt, clay, and some lignite. | Yields small to moderate quantities of freshwater. |
| | | | Reklaw Formation | 0-130 | Glauconitic clay, some sand, weathers to a red clayey soil, limonite seams, iron concretions. | Yields small quantities of water to wells. |
| | | | Carrizo Sand | 0-135 | Gray to white. Often massive sand, clay lenses; may be predominantly clayey. | Yields large to moderate quantities of freshwater. In hydrologic continuity with the Wilcox. |
| | Eocene / Paleocene | Wilcox | | 625-1,550 | Thin, sometimes massive beds of sand; clay and lignite. Beds often discontinuous. | Yields large to moderate quantities of fresh to slightly saline water. |
| | Paleocene | Midway | | 850-1,000 | Calcareous clay and minor amounts of limestone, silt, and glauconitic clay. | Not known to yield water to wells in Rusk County; upper sand may contain some slightly saline water. |

county, the beds dip at a rate of about 30 ft/mi to the west. In the southern part of the county, they dip about 50 ft/mi to the southwest.

The Midway Group is not known to yield water to wells in the area. Nevertheless, the unit is hydrologically significant because the Midway Group forms the basal confining unit for the overlying Wilcox Group. There is also a sand body about 30 feet thick within the uppermost 200 feet that may contain small amounts of slightly saline water. In a few instances, the base of slightly saline water has been picked at the base of this sand bed from electric logs.

## Wilcox Group

The Wilcox Group is exposed on the surface in northeastern and east-central Rusk County and comformably overlies the Midway. It consists mainly of thin, but sometimes massive beds of sand, silt, and clay with minor amounts of lignite and secondary deposits of limonite. Typically, the sands are gray, fine-grained and silty. Often the beds are fluvial and deltaic in nature. Due to facies changes, individual beds often are difficult to correlate from well to well. However, some beds of coarse-grained sand attain a thickness of nearly 200 feet (well WR-35-59-901). Other beds cannot be correlated from well to well as is clearly shown in the geologic sections (Figures 25-27).

The altitude of the top of the Wilcox Group is depicted in Figure 10. Except where interrupted by the Mount Enterprise Fault System, these beds dip at the rate of about 30 ft/mi in a direction away from the Sabine Uplift.

## Carrizo Sand

The Carrizo Sand uncomformably overlies the Wilcox Group and crops out more extensively than any other geologic unit in the county. It attains a maximum thickness of about 135 feet. Surface exposures usually are reddish in color and often cross-bedded. In the subsurface, the Carrizo is a massive, fine- to medium-grained white quartz sand. It also contains a few clay lenses, but rarely is predominantly clay. In electrical logs, the Carrizo is distinguished from the overlying Reklaw and underlying Wilcox by a markedly higher resistivity. In places, however, the contacts are difficult to pick. As does the Wilcox Group, the Carrizo Sand dips away from the Sabine Uplift into the East Texas Embayment at a rate of about 30 ft/mi except where interrupted by the Mount Enterprise Fault System.

## Reklaw Formation

The Reklaw Formation conformably overlies the Carrizo Sand. The Reklaw attains a maximum thickness of about 130 feet and is exposed primarily in the northern part of the county and north of the Mount Enterprise Fault System. The formation consists of glauconitic clay and minor amounts of sand and lignite. The basal part of the Reklaw contains a silty, glauconitic fine-grained quartz sand that is often difficult to distinguish from the underlying Carrizo using electric logs. In the outcrop, the Reklaw forms a red clay soil characterized by limonite seams and iron concretions, easily distinguished from the underlying gray sandy soil of the Carrizo.

## Queen City Sand

The Queen City Sand, which overlies the Reklaw Formation, consists mostly of alternating beds of very fine- to fine-grained quartz sand and clay. The Queen City Sand crops out over an area of about 100 square miles and attains a maximum thickness of about 130 feet where overlain by the Weches Formation. The maximum thickness occurs mainly in the downdropped blocks associated with the Mount Enterprise Fault System. Elsewhere, the Queen City is eroded and relatively thin There is not enough control to adequately map the Queen City Sand.

## Weches Formation

The Weches Formation, consisting of interbedded glauconitic clay and sand, crops out as scattered outliers in the Mount Enterprise Fault System area. The Weches attains a maximum thickness of about 50 feet, but is not known to yield water to wells in Rusk County.

## Sparta Sand

The Sparta Sand consists of fine sand and sandy clay and silt, attains a thickness of about 100 feet, and is exposed only in the area of the Mount Enterprise Fault System. Numerous springs issue from the contact of the Sparta with the underlying Weches. The formation yields small quantities of freshwater to wells in adjacent counties. Springs issuing from the Sparta yield moderate quantities of ground water to the base flow of small streams in southern Rusk County.

## Terrace Deposits and Alluvium

Terrace deposits, probably of Pleistocene age, are present at several places along the Sabine and Angelina Rivers. These beds are remnants of a formerly more extensive surface that has been largely removed by erosion. The terrace deposits are in continuity with the underlying Eocene beds but are considered hydrologically insignificant.

Alluvium is present in and around the flood plains of the principal streams (Figure 8). These deposits, consisting of fine sand, silt, clay, and possibly gravel, have an estimated maximum thickness of about 35 feet. Alluvial deposits are capable of yielding at least small amounts of water to wells. At least one well in Rusk County is completed in the alluvium.

# HYDROLOGIC UNITS

In order to simplify the discussion of hydrology in the area, the following previously described geologic units are designated as aquifers in Rusk County: Wilcox Group, Carrizo Sand, Queen City Sand, and Sparta Sand. The other geologic units are designated as confining beds and are: Midway Group, Reklaw Formation, and Weches Formation. A number of dug wells tap the thin basal sand of the Reklaw.

## Wilcox Aquifer

Broom (1969) noted that the Carrizo and Wilcox have similar hydrologic properties and are in hydrologic continuity in Gregg County. Consequently, he considered them to function as a single aquifer. W. F. Guyton and Associates (1970, 1972) considered the two aquifers to be separate units in Cherokee and Nacogdoches Counties. In this report, the Carrizo and Wilcox are treated as two distinct aquifers.

The Wilcox aquifer is present throughout Rusk County and is the most significant hydrologic unit. Substantial withdrawals occur from the middle and lower sands at Henderson and in the area of East Texas Oil Field. Many of the upper sands in the Wilcox are thin, fine-grained and silty. By contrast, the lower beds are sometimes massive and coarse-grained. Often individual beds are discontinuous.

The quality of water in the Wilcox varies both vertically and laterally from fresh to slightly saline. In rare instances, the water may be moderately saline. In places, the shallower sands may not necessarily contain the best quality water.

The thickness of freshwater-bearing sands in the Wilcox is shown in Figure 11. The thickness of sands containing freshwater are based on the interpretation of electric logs. The thickness ranges from about 170 feet to about 400 feet. The altitude of the freshwater is shown in Figure 12 and the base of the slightly saline water is shown in Figure 13.

## Carrizo Aquifer

Another significant water-bearing unit is the Carrizo aquifer, which is present in about 70 percent of the county. In places, however, the Carrizo sands may be interbedded with clay as shown in Figure 14, which shows ground water seeping from the Carrizo sands at the Ross clay pit of Henderson Clay Products north of the city of Henderson.

The Carrizo aquifer has an average sand thickness of about 80 feet in the subsurface and 50 feet in the outcrop area. However, a sand thickness map was not constructed because data were inadequate.

## Other Aquifers

Only a few small-capacity wells draw water from the Queen City aquifer because of its near surface occurrence and small aerial extent. Except for a few isolated exposures in the northwestern part of Rusk County, the Queen City is present only in downdropped blocks associated with the Mount Enterprise Fault System. The Sparta is present only in the area along the Mount Enterprise Fault System. The Sparta is not an important aquifer in Rusk County. Both the Queen City and Sparta feed numerous small springs in Rusk County.

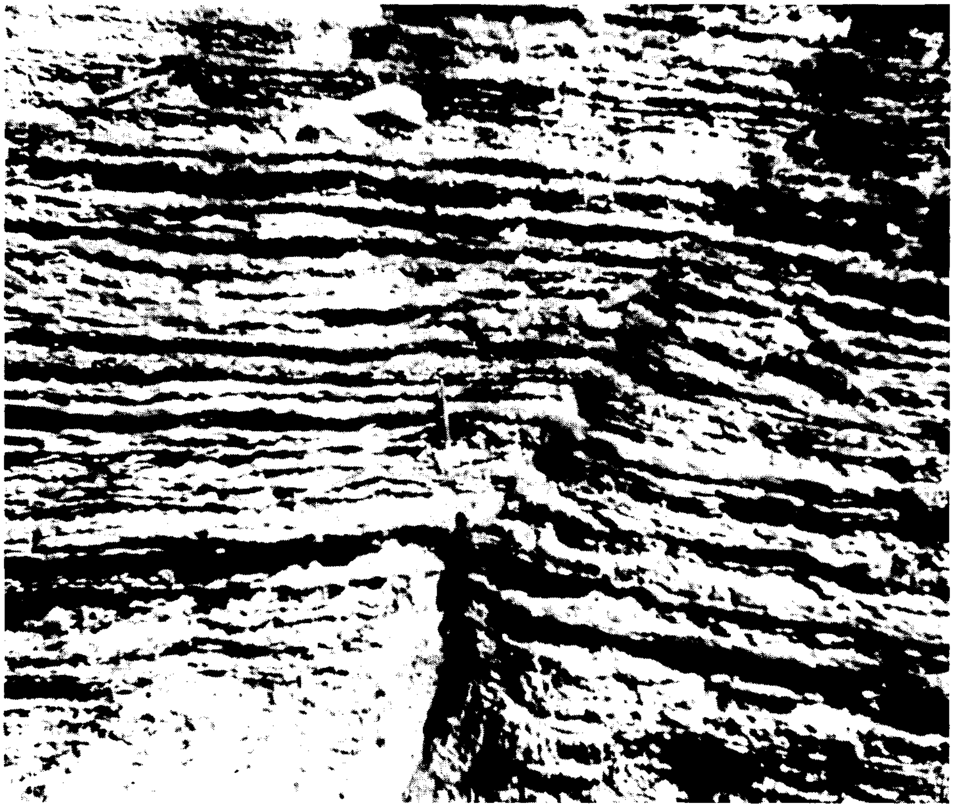

**Figure 14.—Ground Water Seeping From Sand Layers in the Carrizo Aquifer at the Ross Clay Pit North of the City of Henderson**

# GROUND-WATER HYDROLOGY

## Source and Occurrence

Precipitation is the source of all fresh ground water. Most precipitation on the land surface runs off, is consumed by evaporation, or is stored in the soil, later to be evaporated or transpired. A part of the water infiltrates through the pores of the soil and subsoil to the zone of saturation by the forces of gravity and molecular attraction. The zone of saturation is the zone below the water table where the interstices are filled with fluid.

Ground water in the area occurs under water-table and artesian conditions. Under water-table conditions the water is unconfined. When tapped by a well, the unconfined water does not rise above the zone of saturation in the aquifer. Under artesian conditions, the water is confined. When tapped by a well, the confined water rises, due to hydrostatic pressure, above the level at which it is first encountered.

Fresh ground water occurs throughout Rusk County and often in at least several water-bearing sands. The most prolific water-producing zones are the artesian sands of the Wilcox, which are developed for municipal and industrial purposes. All significant withdrawals are from the artesian part of the Carrizo and Wilcox aquifers. Less productive shallow wells that tap the first saturated sand below the land surface are often used for livestock and domestic purposes.

Water in these beds usually occurs under water-table conditions at a depth of less than 50 feet below land surface. Detailed information on individual wells is given in Table 8.

## Recharge, Movement, and Discharge of Ground Water

Recharge, the addition of water to an aquifer by natural or artificial processes, occurs mainly from the infiltration of rainfall into the outcrop. Recharge also may occur by percolation of water from streams and ponded areas. There is a large potential for recharge in Rusk County because the Wilcox and Carrizo crop out in about 60 percent of the area. Although the actual rate of recharge is not known, it is probably less than 1 inch per year.

Ground water moves slowly through the aquifers under the force of gravity from areas of recharge to areas of discharge. The movement under water-table conditions is lateral to discharge areas which, under natural conditions, are topographically lower than the recharge area. The movement under artesian conditions is toward areas of lower pressure head, normally downdip in the aquifer. Water then moves vertically upward into the lower pressured shallow material. Natural discharge also may occur through a seep or spring; artificial discharge may occur through a well. The rate of movement in the aquifers, either laterally or vertically, is dependent on the hydraulic gradient and conductivity of the material. Rates of movement probably are a few hundred feet per year.

The direction of movement in Rusk County in the water-table parts of the aquifers generally is toward the streams. The direction of movement in the artesian parts of the principal aquifers, the Carrizo and Wilcox, is from the outcrop toward the southeast and locally, toward the cones of depression at Henderson, East Texas Oil Field, and Tatum as shown in the potentiometric-surface map for the Wilcox (Figure 15).

## Hydraulic Characteristics of the Aquifers

The importance of an aquifer as a source of water depends upon "its ability to store and transmit water" according to Ferris and others (1962, p. 70). These characteristics are expressed in terms of storage coefficient and transmissivity.

No aquifer tests were conducted in Rusk County because of a lack of controlled conditions. Aquifer tests, however, have been performed using wells completed in the Wilcox, Carrizo, and Queen City aquifers in Cherokee County (W. F. Guyton and Associates, 1972), Gregg County (Broom, 1969), and Nacogdoches County (W. F. Guyton and Associates, 1970). The test data were analyzed either by the Theis nonequilibrium method (Theis, 1935) or the modified Theis recovery method (Wenzel, 1942, p. 95). The results are given in Table 3.

To estimate the expected range of transmissivities of the Wilcox and Carrizo aquifers in Rusk County, the following assumptions were made:

1. The hydraulic conductivities of the sands in the three adjacent counties (Table 3) are representative of the sands in these same aquifers in Rusk County;

**Table 3.--Results of Aquifer Tests in Cherokee, Gregg, and Nacogdoches Counties[1]**

County prefixes: DJ - Cherokee; KU - Gregg; TX - Nacogdoches

| Well | Sand thickness of pumped well (feet) | Discharge (gallons per minute) | Specific capacity (gallons per minute per foot of drawdown) | Hydraulic conductivity (feet per day) | Storage coefficient | Remarks |
|---|---|---|---|---|---|---|
| | | | Carrizo aquifer | | | |
| DJ-37-01-401 | 75 | 343 | 5.4 | 19.4 | -- | Recovered for 24 hours. |
| 402 | 60 | 350 | 5.4 | 25.5 | -- | Do. |
| | 75 | 350 | -- | 22 | 0.0001 | Drawdown of observation well DJ-37-01-401. |
| 09-101 | 2/52 | 43 | 4.5 | 28.4 | -- | Recovered for 2 hours. |
| 33-202 | 2/70 | 102 | 1.2 | 63.8 | -- | Do. |
| 38-06-603 | 80 | 692 | 13.1 | 31.0 | -- | Do. |
| 604 | 90 | 621 | 10.3 | 18.9 | -- | Recovered for 12 hours. |
| 15-102 | 2/36 | 36 | 2.1 | 15.7 | -- | Recovered for 2 hours. |
| 502 | 101 | 473 | 7.1 | 20.6 | -- | Recovered for 24.5 hours. |
| | | | Queen City aquifer | | | |
| DJ-38-32-903 | 2/45 | 50 | 1.8 | 9.0 | -- | Recovered for 2 hours. |
| | | | Carrizo-Wilcox aquifer | | | |
| KU-35-26-705 | 64 | -- | -- | 11.4 | .00006 | Drawdown of observation well. |
| 706 | 105 | 300 | 2.8 | 5.7 | -- | Drawdown of pumped well. |
| 708 | 75 | 100 | -- | 5.5 | -- | Recovered for 5 months. |
| | | | Wilcox aquifer | | | |
| DJ-34-64-402 | 90 | 63 | 6.1 | 19.4 | -- | Recovered for 2 hours. |
| 37-09-102 | 2/94 | 75 | 7.1 | 18.2 | -- | -- |
| 38-08-105 | 90 | 102 | 7.4 | 36.4 | -- | -- |
| TX-37-10-403 | 55 | 110 | 1.0 | 2.7 | -- | Recovered for 2 hours. |
| 11-901 | 50 | 85 | 1.6 | 6.7 | -- | -- |
| 13-402 | 30 | 123 | 1.0 | 5.0 | -- | -- |
| | 2/30 | 123 | -- | 5.0 | .0007 | Drawdown of observation well TX-37-13-401. |
| 404 | 58 | 180 | 3.6 | 13.4 | -- | Recovered for 2 hours. |

1/ Modified from Broom (1969) and W. F. Guyton and Associates (1970, 1972).
2/ Length of screen.

2. The sands opposite the screen are similar to the unscreened sands; and

3. The thickness of sands containing freshwater ranges from about 100 to 370 feet for the Wilcox aquifer.

Based on these assumptions, the transmissivities of the Wilcox aquifer would range from 270 to 13,500 $ft^2/d$; and based on a maximum sand thickness of 100 feet in the Carrizo aquifer, the estimated maximum transmissivity is 6,400 $ft^2/d$.

Downdip from the outcrops where the Wilcox and Carrizo aquifers are under artesian conditions, the storage coefficients range from about 0.00006 to 0.0007, as indicated in Table 3. Although no data are available for the area, the storage coefficients for the aquifers under water-table conditions would be expected to range from 0.1 to 0.2

The transmissivities and storage coefficients must be known to predict the drawdown of water levels caused by pumping a well or group of wells. The theoretical relationship of drawdown to transmissivity and distance is shown in Figure 16. Calculations of drawdown are made on the basis of a group of wells pumping 1 million gal/d continuously for 1 year from an extensive aquifer.

The relationship of drawdown to time and distance caused by a well or group of wells pumping 1 million gal/d from an artesian aquifer of infinite extent having a storage coefficient of 0.0001 and a transmissivity of 10,000 $ft^2/d$ is shown in Figure 17. The rate of drawdown decreases with time, but the water level declines indefinitely until a source of recharge is intercepted to offset the withdrawal and establish equilibrium in the aquifer. Because the drawdown is directly proportional to the rate of withdrawal, the drawdown for other than 1 million gal/d can be determined by multiplying the drawdown value shown in Figure 17 by the proper multiple or fraction of 1,000,000.

Note that Figures 16 and 17 show that the drawdown caused by the pumping well is greatest near the well and decreases as distance from the pumping well increases. This is the practical reason for properly spacing wells; mutual interference is decreased and, consequently, pumping costs are reduced.

## QUALITY OF GROUND WATER

Chemical constituents found in ground water originate principally from the soil and rocks through which the water has passed. Consequently, the chemical character of the water reflects, in a general way, the nature of the geologic formations that have been in contact with the water. Usually ground water in confined aquifers is free from contamination by organic matter. Sometimes, however, ground water in unconfined aquifers may become contaminated when contaminated water percolates from the land surface.

Those factors determining the suitability of water for a particular use are the quality of the water and the limitations imposed by the use. Important criteria used in establishing limitations are bacterial content, temperature, color, taste, odor, and concentration of chemical constituents

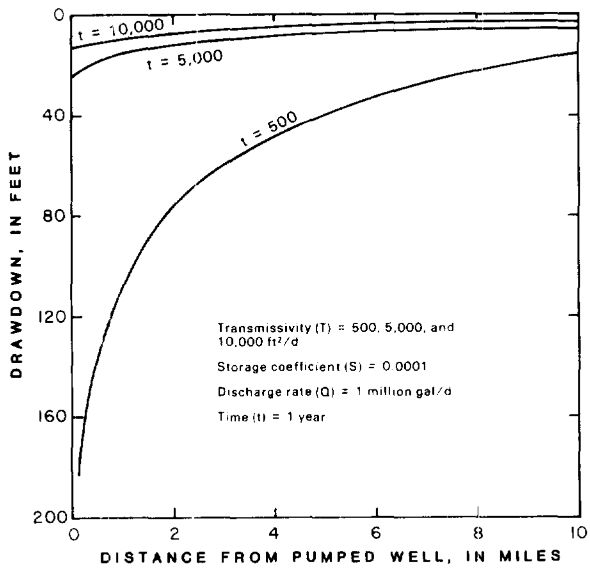


**Figure 16.—Relationship of Drawdown to Transmissivity and Distance**

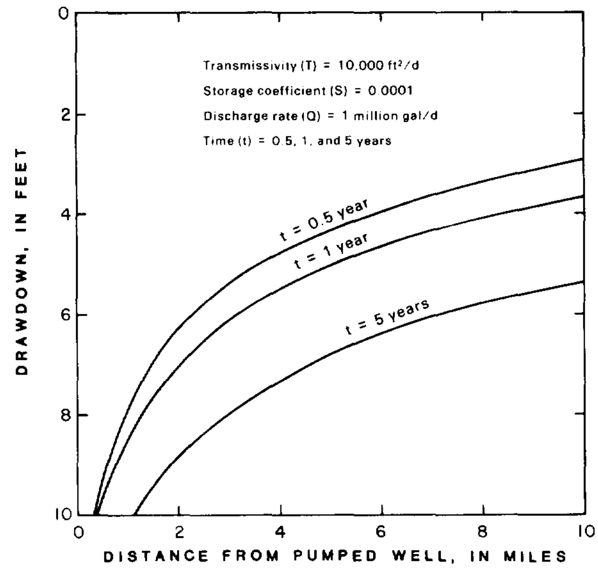


**Figure 17.—Relationship of Drawdown to Time and Distance as a Result of Pumping Under Artesian Conditions**

in the water. Pesticides, if present, also may be a factor in limiting use. A general listing of sources and the significance of dissolved mineral constituents and properties are presented in Table 4.

Wells in Rusk County for which water-quality data are available are listed in Table 8. Results of these analyses, showing the source and amount of dissolved constituents are listed in Table 11. Data for certain metals and trace elements are listed in Table 12. The analyses included those made by the Geological Survey, other government agencies, and commercial laboratories.

Three samples of ground water were analyzed for pesticides. Water from springs WR-35-57-403 (Big Springs) and WR-37-02-904 (Sulfur Springs) and from well WR-37-03-202 (Mount Enterprise) was analyzed for 28 insecticides and herbicides. None of these water samples contained pesticides in excess of the suggested limits.

For many purposes, the dissolved-solids concentration places a major limitation on the use of ground water. A general classification of water based on the dissolved-solids concentration is as follows (modified after Winslow and Kister, 1956, p. 5):

| Description | Dissolved-solids concentration (milligrams per liter) |
| --- | --- |
| Fresh | Less than 1,000 |
| Slightly saline | 1,000—3,000 |
| Moderately saline | 3,000—10,000 |
| Very saline | 10,000—35,000 |
| Brine | More than 35,000 |

## Table 4.--Source and Significance of Selected Constituents and Properties Commonly Reported in Water Analyses[1]

(mg/L, milligrams per liter; µg/L, micrograms per liter; micromhos, micromhos per centimeter at 25° Celsius)

| Constituent or property | Source or cause | Significance |
|---|---|---|
| Silica ($SiO_2$) | Silicon ranks second only to oxygen in abundance in the Earth's crust. Contact of natural waters with silica-bearing rocks and soils usually results in a concentration range of about 1 to 30 mg/L; but concentrations as large as 100 mg/L are common in waters in some areas. | Although silica in some domestic and industrial water supplies may inhibit corrosion of iron pipes by forming protective coatings, it generally is objectionable in industrial supplies, particularly in boiler feedwater, because it may form hard scale in boilers and pipes or deposit in the tubes of heaters and on steam-turbine blades. |
| Iron (Fe) | Iron is an abundant and widespread constituent of many rocks and soils. Iron concentrations in natural waters are dependent upon several chemical equilibria processes including oxidation and reduction; precipitation and solution of hydroxides, carbonates, and sulfides; complex formation especially with organic material; and the metabolism of plants and animals. Dissolved-iron concentrations in oxygenated surface waters seldom are as much as 1 mg/L. Some ground waters, unoxygenated surface waters such as deep waters of stratified lakes and reservoirs, and acidic waters resulting from discharge of industrial wastes or drainage from mines may contain considerably more iron. Corrosion of iron casings, pumps, and pipes may add iron to water pumped from wells. | Iron is an objectionable constituent in water supplies for domestic use because it may adversely affect the taste of water and beverages and stain laundered clothes and plumbing fixtures. According to the National Secondary Drinking Water Regulations proposed by the U.S. Environmental Protection Agency (1977b), the secondary maximum contamination level of iron for public water systems is 300 µg/L. Iron also is undesirable in some industrial water supplies, particularly in waters used in high-pressure boilers and those used for food processing, production of paper and chemicals, and bleaching or dyeing of textiles. |
| Calcium (Ca) | Calcium is widely distributed in the common minerals of rocks and soils and is the principal cation in many natural freshwaters, especially those that contact deposits or soils originating from limestone, dolomite, gypsum, and gypsiferous shale. Calcium concentrations in freshwaters usually range from zero to several hundred milligrams per liter. Larger concentrations are not uncommon in waters in arid regions, especially in areas where some of the more soluble rock types are present. | Calcium contributes to the total hardness of water. Small concentrations of calcium carbonate combat corrosion of metallic pipes by forming protective coatings. Calcium in domestic water supplies is objectionable because it tends to cause incrustations on cooking utensils and water heaters and increases soap or detergent consumption in waters used for washing, bathing, and laundering. Calcium also is undesirable in some industrial water supplies, particularly in waters used by electroplating, textile, pulp and paper, and brewing industries and in water used in high-pressure boilers. |
| Magnesium (Mg) | Magnesium ranks eight among the elements in order of abundance in the Earth's crust and is a common constituent in natural water. Ferromagnesian minerals in igneous rock and magnesium carbonate in carbonate rocks are two of the more important sources of magnesium in natural waters. Magnesium concentrations in freshwaters usually range from zero to several hundred milligrams per liter; but larger concentrations are not uncommon in waters associated with limestone or dolomite. | Magnesium contributes to the total hardness of water. Large concentrations of magnesium are objectionable in domestic water supplies because they can exert a cathartic and diuretic action upon unacclimated users and increase soap or detergent consumption in waters used for washing, bathing, and laundering. Magnesium also is undesirable in some industrial supplies, particularly in waters used by textile, pulp and paper, and brewing industries and in water used in high-pressure boilers. |
| Sodium (Na) | Sodium is an abundant and widespread constituent of many soils and rocks and is the principal cation in many natural waters associated with argillaceous sediments, marine shales, and evaporites and in sea water. Sodium salts are very soluble and once in solution tend to stay in solution. Sodium concentrations in natural waters vary from less than 1 mg/L in stream runoff from areas of high rainfall to more than 100,000 mg/L in ground and surface waters associated with halite deposits in arid areas. In addition to natural sources of sodium, sewage, industrial effluents, oilfield brines, and deicing salts may contribute sodium to surface and ground waters. | Sodium in drinking water may impart a salty taste and may be harmful to persons suffering from cardiac, renal, and circulatory diseases and to women with toxemias of pregnancy. Sodium is objectionable in boiler feedwaters because it may cause foaming. Large sodium concentrations are toxic to most plants; and a large ratio of sodium to total cations in irrigation waters may decrease the permeability of the soil, increase the pH of the soil solution, and impair drainage. |

**Table 4.--Source and Significance of Selected Constituents and Properties Commonly Reported in Water Analyses--Continued**

| Constituent or property | Source or cause | Significance |
|---|---|---|
| Potassium (K) | Although potassium is only slightly less common than sodium in igneous rocks and is more abundant in sedimentary rocks, the concentration of potassium in most natural waters is much smaller than the concentration of sodium. Potassium is liberated from silicate minerals with greater difficulty than sodium and is more easily adsorbed by clay minerals and reincorporated into solid weathering products. Concentrations of potassium more than 20 mg/L are unusual in natural freshwaters, but much larger concentrations are not uncommon in brines or in water from hot springs. | Large concentrations of potassium in drinking water may impart a salty taste and act as a cathartic, but the range of potassium concentrations in most domestic supplies seldom cause these problems. Potassium is objectionable in boiler feedwaters because it may cause foaming. In irrigation water, potassium and sodium act similarly upon the soil, although potassium generally is considered less harmful than sodium. |
| Alkalinity | Alkalinity is a measure of the capacity of a water to neutralize a strong acid, usually to pH of 4.5, and is expressed in terms of an equivalent concentration of calcium carbonate ($CaCO_3$). Alkalinity in natural waters usually is caused by the presence ob bicarbonate and carbonate ions and to a lesser extent by hydroxide and minor acid radicals such as borates, phosphates, and silicates. Carbonates and bicarbonates are common to most natural waters because of the abundance of carbon dioxide and carbonate minerals in nature. Direct contribution to alkalinity in natural waters by hydroxide is rare and usually can be attributed to contamination. The alkalinity of natural waters varies widely but rarely exceeds 400 to 500 mg/L as $CaCO_3$. | Alkaline waters may have a distinctive unpleasant taste. Alkalinity is detrimental in several industrial processes, especially those involving the production of food and carbonated or acid-fruit beverages. The alkalinity in irrigation waters in excess of alkaline earth concentrations may increase the pH of the soil solution, leach organic material and decrease permeability of the soil, and impair plant growth. |
| Sulfate ($SO_4$) | Sulfur is a minor constituent of the Earth's crust but is widely distributed as metallic sulfides in igneous and sedimentary rocks. Weathering of metallic sulfides such as pyrite by oxygenated water yields sulfate ions to the water. Sulfate is dissolved also from soils and evaporite sediments containing gypsum or anhydrite. The sulfate concentration in natural freshwaters may range from zero to several thousand milligrams per liter. Drainage from mines may add sulfate to waters by virtue of pyrite oxidation. | Sulfate in drinking water may impart a bitter taste and act as a laxative on unacclimated users. According to the National Secondary Drinking Water Regulations proposed by the Environmental Protection Agency (1977b) the secondary maximum contaminant level of sulfate for public water systems is 250 mg/L. Sulfate also is undesirable in some industrial supplies, particularly in waters used for the production of concrete, ice, sugar, and carbonated beverages and in waters used in high-pressure boilers. |
| Chloride (Cl) | Chloride is relatively scarce in the Earth's crust but is the predominant anion in sea water, most petroleum-associated brines, and in many natural freshwaters, particularly those associated with marine shales and evaporites. Chloride salts are very soluble and once in solution tend to stay in solution. Chloride concentrations in natural waters vary from less than 1 mg/L in stream runoff from humid areas to more than 100,000 mg/L in ground and surface waters associated with evaporites in arid areas. The discharge of human, animal, or industrial wastes and irrigation return flows may add significant quantities of chloride to surface and ground waters. | Chloride may impart a salty taste to drinking water and may accelerate the corrosion of metals used in water-supply systems. According to the National Secondary Drinking Water Regulations proposed by the Environmental Protection Agency (1977b), the secondary maximum contaminant level of chloride for public water systems is 250 mg/L. Chloride also is objectionable in some industrial supplies, particularly those used for brewing and food processing, paper and steel production, and textile processing. Chloride in irrigation waters generally is not toxic to most crops but may be injurious to citrus and stone fruits. |
| Fluoride (F) | Fluoride is a minor constituent of the Earth's crust. The calcium fluoride mineral fluorite is a widespread constituent of resistate sediments and igneous rocks, but its solubility in water is negligible. Fluoride commonly is associated with volcanic gases, and volcanic emanations may be important sources of fluoride in some areas. The | Fluoride in drinking water decreases the incidence of tooth decay when the water is consumed during the period of enamel calcification. Excessive quantities in drinking water consumed by children during the period of enamel calcification may cause a characteristic discoloration (mottling) of the teeth. According to the |

Table 4.--Source and Significance of Selected Constituents and Properties Commonly Reported in Water Analyses--Continued

| Constituent or property | Source or cause | Significance |
|---|---|---|
| Fluoride--Cont. | fluoride concentration in fresh surface waters usually is less than 1 mg/L; but larger concentrations are not uncommon in saline water from oil wells, ground water from a wide variety of geologic terranes, and water from areas affected by volcanism. | National Interim Primary Drinking Water Regulations established by the Environmental Protection Agency (1976) the maximum contaminant level of fluoride in drinking water varies from 1.4 to 2.4 mg/L, depending upon the annual average of the maximum daily air temperature for the area in which the water system is located. Excessive fluoride is also objectionable in water supplies for some industries, particularly in the production of food, beverages, and pharmaceutical items. |
| Nitrogen (N) | A considerable part of the total nitrogen of the Earth is present as nitrogen gas in the atmosphere. Small amounts of nitrogen are present in rocks, but the element is concentrated to a greater extent in soils or biological material. Nitrogen is a cyclic element and may occur in water in several forms. The forms of greatest interest in water in order of increasing oxidation state, include organic nitrogen, ammonia nitrogen ($NH_4$-N), nitrite nitrogen ($NO_2$-N) and nitrate nitrogen ($NO_3$-N). These forms of nitrogen in water may be derived naturally from the leaching of rocks, soils, and decaying vegetation; from rainfall; or from biochemical conversion of one form to another. Other important sources of nitrogen in water include effluent from wastewater treatment plants, septic tanks, and cesspools and drainage from barnyards, feed lots, and fertilized fields. Nitrate is the most stable form of nitrogen in an oxidizing environment and is usually the dominant form of nitrogen in natural waters and in polluted waters that have undergone self-purification or aerobic treatment processes. Significant quantities of reduced nitrogen often are present in some ground waters, deep unoxygerated waters of stratified lakes and reservoirs, and waters containing partially stabilized sewage or animal wastes. | Concentrations of any of the forms of nitrogen in water significantly greater than the local average may suggest pollution. Nitrate and nitrite are objectionable in drinking water because of the potential risk to bottle-fed infants for methemoglobinemia, a sometimes fatal illness related to the impairment of the oxygen-carrying ability of the blood. According to the National Interim Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 1976), the maximum contaminant level of nitrate (as N) in drinking water is 10 mg/L. Although a maximum contaminant level for nitrite is not specified in the drinking water regulations, Appendix A to the regulations (U.S. Environmental Protection Agency, 1976) indicates that waters with nitrite concentrations (as N) greater than 1 mg/L should not be used for infant feeding. Excessive nitrate and nitrite concentrations are also objectionable in water supplies for some industries, particularly in waters used for the dyeing of wool and silk fabrics and for brewing. |
| Dissolved solids | Theoretically, dissolved solids are anhydrous residues of the dissolved substance in water. In reality, the term "dissolved solids" is defined by the method used in the determination. In most waters, the dissolved solids consist predominantly of silica, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, and sulfate with minor or trace amounts of other inorganic and organic constituents. In regions of high rainfall and relatively insoluble rocks, waters may contain dissolved-solids concentrations of less than 25 mg/L; but saturated sodium chloride brines in other areas may contain more than 300,000 mg/L. | Dissolved-solids values are used widely in evaluating water quality and in comparing waters. The following classification based on the concentrations of dissolved solids commonly is used by the Geological Survey (Winslow and Kister, 1956).<br><br>Classification — Dissolved-solids concentration (mg/L)<br>Fresh — <1,000<br>Slightly saline — 1,000 - 3,000<br>Moderately saline — 3,000 - 10,000<br>Very saline — 10,000 - 35,000<br>Brine — >35,000<br><br>The National Secondary Drinking Regulations (U.S. Environmental Protection Agency, 1977b) set a dissolved-solids concentration of 500 mg/L as the secondary maximum contaminant level for public water systems. This level was set primarily on the basis of taste thresholds and potential physiological effects, particularly the laxative effect on unacclimated users. Although drinking waters containing more than 500 mg/L are undesirable, such waters are used in many areas where less mineralized supplies are not available without any obvious ill effects. Dissolved solids in industrial water |

**Table 4.--Source and Significance of Selected Constituents and Properties Commonly Reported in Water Analyses--Continued**

| Constituent or property | Source or cause | Significance |
|---|---|---|
| Dissolved solids--Cont. | | supplies can cause foaming in boilers; interfere with clearness, color, or taste of many finished products; and accelerate corrosion. Uses of water for irrigation also are limited by excessive dissolved-solids concentrations. Dissolved solids in irrigation water may adversely affect plants directly by the development of high osmotic conditions in the soil solution and the presence of phytoxins in the water or indirectly by their effect on soils. |
| Specific conductance | Specific conductance is a measure of the ability of water to transmit an electrical current and depends on the concentrations of ionized constituents dissolved in the water. Many natural waters in contact only with granite, well-leached soil, or other sparingly soluble material have a conductance of less than 50 micromhos. The specific conductance of some brines exceed several hundred thousand micromhos. | The specific conductance is an indication of the degree of mineralization of a water and may be used to estimate the concentration of dissolved solids in the water. |
| Hardness as $CaCO_3$ | Hardness of water is attributable to all polyvalent metals but principally to calcium and magnesium ions expressed as $CaCO_3$ (calcium carbonate). Water hardness results naturally from the solution of calcium and magnesium, both of which are widely distributed in common minerals of rocks and soils. Hardness of waters in contact with limestone commonly exceeds 200 mg/L. In waters from gypsiferous formations, a hardness of 1,000 mg/L is not uncommon. | Hardness values are used in evaluating water quality and in comparing waters. The following classification is commonly used by the Geological Survey.<br>Hardness (mg/L as $CaCO_3$) — Classification<br>0 - 60 — Soft<br>61 - 120 — Moderately hard<br>121 - 180 — Hard<br>>180 — Very hard<br>Excessive hardness of water for domestic use is objectionable because it causes incrustations on cooking utensils and water heaters and increased soap or detergent consumption. Excessive hardness is undesirable also in many industrial supplies. (See discussions concerning calcium and magnesium.) |
| pH | The pH of a solution is a measure of its hydrogen ion activity. By definition, the pH of pure water at a temperature of 25°C is 7.00. Natural waters contain dissolved gases and minerals, and the pH may deviate significantly from that of pure water. Rainwater not affected significantly by atmospheric pollution generally has a pH of 5.6 due to the solution of carbon dioxide from the atmosphere. The pH range of most natural surface and ground waters is about 6.0 to 8.5. Many natural waters are slightly basic (pH >7.0) because of the prevalence of carbonates and bicarbonates, which tend to increase the pH. | The pH of a domestic or industrial water supply is significant because it may affect taste, corrosion potential, and water-treatment processes. Acidic waters may have a sour taste and cause corrosion of metals and concrete. The National Secondary Drinking Water Regulations (U.S. Environmental Protection Agency, 1977b) set a pH range of 6.5 to 8.5 as the secondary maximum contaminant level for public water systems. |

1/ Most of the material in this table has been summarized from several references. For a more thorough discussion of the source and significance of these and other water-quality properties and constituents, the reader is referred to the following additional references: American Public Health Association and others (1975); Hem (1970); McKee and Wolf (1963); National Academy of Science, National Academy of Engineering (1973); National Technical Advisory Committee to the Secretary of the Interior (1968); and U.S. Environmental Protection Agency (1977a).

## Water-Quality Criteria and Standards

The Federal Water Pollution Control Act Amendment of 1972 requires that the U.S. Environmental Protection Agency (EPA) publish criteria accurately reflecting the latest scientific knowledge. The law requires that these criteria consider the kind and extent of all identifiable effects upon health and welfare that may result from the presence of any pollutants. Moreover, these criteria should be set forth for all bodies of water including ground water. During 1973, the Environmental Protection Agency published criteria relating to the protection of human health and desired species of aquatic plants (National Academy of Sciences, National Academy of Engineering, 1973). During 1976, the Environmental Protection Agency revised the earlier rules (U.S. Environmental Protection Agency, 1977a).

The Environmental Protection Agency's "Quality Criteria for Water, 1976," discusses more than 50 constituents commonly occurring in water. It sets the recommended limits, presents the reason for selecting a given criteria, and cites references relating to these standards. Rules for the primary drinking water regulations were published in the Federal Register (U.S. Environmental Protection Agency, 1976) and became effective July 3, 1979. Rules for the National secondary drinking water regulations were published in the Federal Register (U.S. Environmental Protection Agency, 1979) and became effective January 19, 1981. Although concentrations of chemical constituents exceeding the recommended limits are objectionable, these limits may sometimes be changed in areas where suitable water is not otherwise available, provided that health and public welfare are adequately protected (U.S. Environmental Protection Agency, 1979).

## Aquifers and Geologic Units

Chemical analyses showing the concentrations of dissolved constituents in water from 158 wells and 2 springs are listed in Table 11. About 68 percent of these wells tap the Wilcox aquifer, 18 percent the Carrizo aquifer, and 1 percent the combined Carrizo and Wilcox aquifers. Another 13 percent tap the basal sands of the Reklaw Formation, which are hydraulically connected to the underlying Carrizo Electric logs are available for many additional wells and are useful in delineating variation in water salinity.

The dissolved-solids concentrations of water from representative wells from the various units are shown in Figure 18. Some of the wells inventoried in previous investigations could be relocated only approximately.

Chemical quality of ground water based on electric logs indicates that sand containing slightly saline water sometimes overlies freshwater sands. In places, even the shallow sands yield slightly mineralized water. Water from 28 shallow wells, less than 75 feet deep, had concentrations of more than 1,000 mg/L (milligrams per liter) dissolved solids according to Lyle (1937, p. 72-86). Water from nine of these wells had dissolved-solids concentrations exceeding 3,000 mg/L. Partial analyses of water from two of these wells, WR-35-57-803 and WR-35-60-701, are listed in Table 11.

### Midway Group

Some electric logs indicate that slightly saline water occasionally is present in a sand about 100 feet below the top of the Midway. Where this occurs, the base of slightly saline water is picked at the base of this unit. The presence of this sand also is noted by the Texas Department of Water Resources, which may require use of surface casing to protect the sand from contamination by oil and gas production. The Midway, however, does not yield water to wells in Rusk County.

### Wilcox Aquifer

Water from 107 wells tapping the Wilcox generally was of a sodium bicarbonate type. A calcium magnesium chloride sulfate type of water occurs in several shallow wells (generally less than 300 feet deep), such as WR-35-51-903 and WR-35-52-701. Both types of water in the Wilcox are described in Rusk County by Henry, Basciano, and Duex (1980).

Concentrations of dissolved solids in the 107 samples analyzed ranged from 49 mg/L (in a 200-foot deep well) to 3,430 mg/L in one well tapping a basal Wilcox sand. Only eight samples exceeded concentrations of 1,000 mg/L dissolved solids. The electric logs shown in the cross sections (Figures 25-27) also indicate that some of the sand beds in the lower part of the Wilcox aquifer contain better quality water than the overlying beds. One example of water-quality zonation in the Wilcox aquifer is illustrated at WR-35-50-804, a test hole drilled for the city of Henderson in 1942. Analyses of water from the well show:

| Interval sampled (feet) | Dissolved-solids concentration (milligrams per liter) |
| --- | --- |
| 246-257 | 292 |
| 493-504 | 1,116 |
| 600-611 | 945 |
| 683-694 | 795 |

Analyses of water samples collected from well WR-35-50-801, owned by the city of Henderson, show that dissolved-solids concentrations increased from 249 to 328 mg/L between 1941 and 1983. This well is located between the cone of depression at Henderson and Henderson Oil Field. It is also only half a mile due east of well WR-35-50-804.

### Carrizo Aquifer

Water from each of 31 wells and springs in the Carrizo was analyzed. Most of the wells were less than 100 feet deep. The water usually was of a calcium magnesium chloride sulfate type, although sodium and bicarbonate ions were predominant in a few analyses. Only three samples exceeded 1,000 mg/L dissolved-solids concentration.

Spring WR-35-57-406 (Big Springs), once used for public supply, issues from the Carrizo Sand. Water from the spring contained 60 $\mu$g/L (micrograms per liter) of chromium and 28 $\mu$g/L of lead (see Table 12). The concentration of chromium exceeds the recommended limit of 50 $\mu$g/L for public supply use. In 1983, water from Big Springs was reported to be used by some local residents for washing automobiles.

Analyses of water from well WR-35-41-703, tapping the Carrizo-Wilcox, show that the concentration of dissolved solids has increased from 140 to 493 $\mu$g/L between 1941 and 1983. This city of Overton well is located along the west side of East Texas Oil Field near the source of Bowles Creek.

### Other Aquifers and Geologic Units

Only one analysis of water from a well tapping the Queen City is listed in Table 11, and the analysis may or may not be representative of water in the aquifer. No analyses of water from the Sparta Sand are included in this report.

Results of analyses of water from 15 wells tapping the Reklaw Formation are listed. Water from two of these wells contained more than 1,000 mg/L dissolved solids. Two of these wells yielded water with relatively high sulfate concentrations. Analyses also are included in Table 11 for two samples collected from wells tapping unknown water-bearing sands.

## Contamination and Protection of Ground Water

Rusk County is a substantial, but declining oil-producing county. During 1980, it produced 14,900,000 barrels of oil, down from about 21,164,311 barrels of oil during 1973. Much of this crude was withdrawn from East Texas Oil Field, which had a cumulative production of 4.622 billion barrels of oil through 1980. The number of producing wells peaked at 25,987 during November 1939 according to the Railroad Commission of Texas. According to the East Texas Salt Water Disposal Company (1958), by January 1, 1958, 29,806 wells had been drilled in the field. At that time there were 19,684 producing wells.

During 1981, pressure-maintenance programs used fresh and slightly saline water from the Wilcox aquifer for oilfield water flooding at a number of oil fields in the area. These include the following fields as shown in Figure 5 (and pay zones): East Texas (Woodbine), Pone (basal Pettit), Shiloh (upper Pettit), Tatum (Pettit and lower Pettit), Henderson (Pettit and Travis Peak), and East Henderson (Travis Peak).

### Surface Casing

An act of the Texas Legislature, passed in 1899, requires that oil and gas wells be cased to prevent ground water above the producing zone from entering oil and gas wells. Later, acts of 1919, 1931, 1932 and 1935, gave broad powers to the Railroad Commission to prevent oil, gas, and water from escaping from the original strata in which they are confined into another strata.

Originally, the Railroad Commission determined where surface casing should be set. Later, the Texas Department of Water Resources and its predecessors were given the authority to make recommendations concerning the protection of usable water. Water containing dissolved-solids

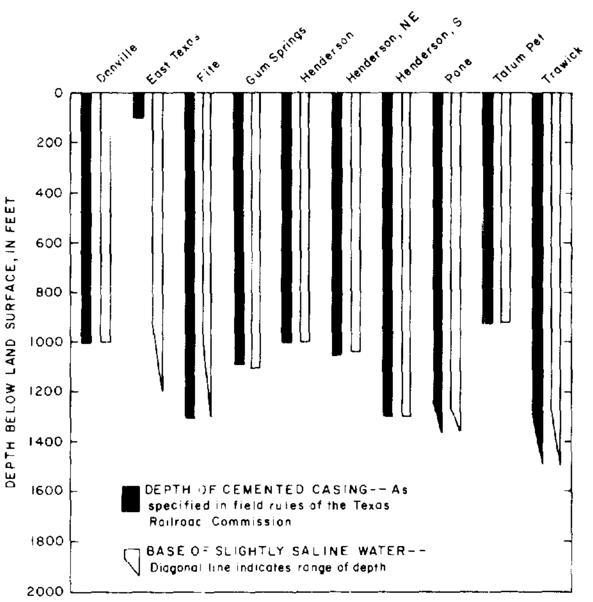


**Figure 19.—Relationship Between Surface-Casing Requirements and the Base of Fresh to Slightly Saline Water, Rusk County**

concentrations of less than 3,000 mg/L is recommended for protection by use of surface casing or cement. Recommendation for protection of more highly mineralized water may be made if the water is being used for beneficial purposes.

The depth to the base of sands containing fresh to slightly saline water (in those fields for which field rules exist) and the amount of required cemented surface casing, according to published rules of the Railroad Commission of Texas are shown in Figure 19. A recent statewide regulation of the Railroad Commission of Texas (1979) relating to the drilling, producing, and plugging of any oil, gas, or geothermal well requires the protection of usable water both above and below the surface. Also, the Texas Department of Water Resources requires that all fresh and slightly saline water sands be protected. However, according to the original field rules in 1932 for East Texas (Woodbine) Oil Field, the base of usable water is not adequately protected.

## Disposal of Saltwater

Considerable amounts of brine are produced in Rusk County in connection with the production of oil. If mishandled in improperly cased or plugged oil wells or tests holes, these brines can move upward from the underlying higher pressured saltwater-bearing formations into zones of fresh and slightly saline water. To prevent this, the Railroad Commission requires that brine be disposed of in ways that will not contaminate freshwater.

Between January 1, 1969, (when the Railroad Commission established a rule prohibiting the use of open pits for disposal of oilfield brine) and 1981, nearly all of the brine produced in Rusk County was disposed of through injection wells. Currently (1982), this is particularly true in the area around East Texas Oil Field where the additional water is needed to maintain reservoir pressure for secondary recovery.

Large quantities of saltwater have been produced from East Texas Oil Field. During some years, the production of saltwater almost equaled the production of oil. The amounts (daily average) of saltwater that were produced, injected, and otherwise diverted for selected years are shown in Table 5.

## Table 5.--Saltwater Production and Disposal, East Texas Oil Field

(Figures modified from East Texas Salt Water Disposal Co., 1958, and Texas Water Commission and Texas Water Pollution Control Board, 1963)

| Year | Saltwater produced (daily average) | | Saltwater injected (daily average) | | Saltwater otherwise diverted (daily average) | |
|---|---|---|---|---|---|---|
| | Barrels | Million gallons | Barrels | Million gallons | Barrels | Million gallons |
| 1935 | 15,000 | 0.63 | 0 | 0 | 15,000 | 0.63 |
| 1938 | 100,000 | 4.20 | 610 | .03 | 100,000 | 4.17 |
| 1942 | 439,000 | 18.44 | 81,000 | 3.40 | 358,000 | 15.04 |
| 1950 | 643,000 | 27.00 | 466,000 | 19.57 | 177,000 | 7.43 |
| 1961 | 433,000 | 18.19 | 429,000 | 18.02 | 4,000 | 0.17 |

NOTE: Figures may vary slightly due to rounding procedures.

A study of saltwater disposal (Railroad Commission of Texas, 1952, p. 91) showed that during October 1935, East Texas Oil Field had been producing about 15,000 barrels of saltwater per day. By 1938, water production had increased to about 100,000 barrels per day. During this period, saltwater was pumped into natural drainage systems. Saltwater was first reinjected into the subsurface during June 1938. By 1942, saltwater production had increased to 439,000 barrels per day. This was equivalent to about 18.44 million gal/d, of which 18.4 percent was being reinjected into the producing Woodbine sands. About 15 million gal/d was being otherwise diverted, probably into surface pits and into the natural drainage system.

During 1961, the total brine production for East Texas Oil Field was estimated to be 155,193,391 barrels. About 99 percent was disposed of through injection wells. About 0.2 percent, 0.4 million gal/d was disposed of through open surface pits, while another 0.7 percent, 0.12 million gal/d was disposed of by unknown methods. (See Texas Water Commission and the Texas Water Pollution Control Board, 1963.)

**Contamination**

One case of oilfield brine contamination has been documented at Henderson Field in Rusk County by Burnitt (1963). Contamination was found in an 85-foot deep water well (WR-35-50-204) and at three stream sites along the Beaver Run and Cherokee Bayou drainage areas. Leakage occurred from unlined surface pits, formerly used for storing oilfield brines. Analyses of water collected from the contaminated well show relatively high amounts of calcium, sodium, chloride, and total dissolved solids, and a relatively low pH. The first sample was collected after 1 minute of pumping; the second sample after 5 hours of pumping. During this period, the total dissolved solids increased from 1,870 to 2,475 mg/L; the pH declined from 6.5 to 5.6. Water collected from one stream site contained 50 mg/L of dissolved solids. Water collected from the three contaminated stream sites had dissolved-solids concentrations of 116,880, 6,684, and 6,609 mg/L.

Hughes and Leifeste (1967) completed a reconnaissance of water quality of surface water in the Neches River basin. Their study includes data on Striker Creek Lake and the Striker Creek drainage basin, which also includes the Bowles Creek watershed. Water samples were collected during low flows from 24 sites in the Striker Creek basin during March and June 1964. Hughes and Leifeste (1967, p. A21) reported that some earthen pits were still used to store oil-field brine. They also observed oil wastes along the banks of water courses, which indicated that there had been brine spills. "In addition to deliberate dumping," reported Hughes and Leifeste, "brine also reaches streams as a result of leaks in collection systems, breaks in pipelines, overflow of storage tanks, and other accidents incidental to the handling of large volumes of waste water." The following are conclusions they reached:

1. Bowles Creek and its tributaries are the source of most of the salinity;

2. Many streams carry acid water with the pH as low as 3.2;

3. Sodium and chloride are the principal dissolved constituents;

4. Sulfate concentrations generally are low throughout the area;

5. Where acid water occurs outside the oilfield area, sulfate is the principal anion; and

6. High chloride water was not found outside the oilfield area.

# DEVELOPMENT AND USE OF GROUND WATER

## History of Development

Prior to about 1920, nearly all the water used in Rusk County came from shallow wells du into the Wilcox and Carrizo aquifers. Numerous springs (there may be as many as severa hundred) also provide water throughout much of the area. Brune (1981, p. 390-394) in "Spring of Texas" lists 43 springs of historical interest. Many of these are located along the Moun Enterprise Fault Zone. Stockman Springs (WR-37-03-403), west of Mount Enterprise, is locate along the East Fork of the Angelina River. Brune reports that in 1833, Henry Stockman received land grant which included the springs now named after him. He also relates that Stockman, alon with a yoke of oxen, drowned in the springs. Other springs such as Sulphur Springs (WR-37-02 904) are of similar extent.

The discovery of East Texas Oil Field in 1930 created an immediate demand for water to be used for industrial purposes. Almost all of this withdrawal was from the Carrizo and Wilco aquifers. Turner (1932, p. 6) estimated that about 16.2 million gal/d was being withdrawn fo oilfield operations in Rusk and Gregg Counties. The cities of Kilgore (Gregg and Rusk Counties and Longview (Gregg County) at first used water from the Sabine River. By 1934, concentrations of oilfield brines and industrial wastes became so high during low flow in the Sabine River tha these cities located other sources of drinking water. For a while Longview diverted creek water fo drinking, but now (1982) uses water from Lake Cherokee (Rusk and Gregg Counties). Kilgore withdraws ground water from well fields in Smith County.

When Lyle (1937) inventoried 406 wells in Rusk County, only 15 were classified as industrial, 8 as public supply, and 16 as "oilfield" use. Most of the larger-capacity wells were concentrated around East Texas Oil Field and the city of Henderson. Elsewhere, shallow-dug wells were used for domestic and livestock purposes.

Much of the industrial use of ground water is related to the production of oil and gas with most of the withdrawals concentrated in East Texas Oil Field. Follett (1943) inventoried those industrial wells in the northwestern part of the county. During 1981, water levels were measured in some of the same wells he visited.

Shallow wells continued to be used rather extensively in the area until the late 1960's and early 1970's. By then, a number of rural water-supply corporations were organized under the auspices of the Farmers Home Administration. During 1981, there were 24 active water-supply corporations serving residents of Rusk County. These systems, together with the municipalities of Henderson, Overton, New London, and Tatum, supply about 90 percent of the water used for domestic and livestock purposes.

# Use of Water

Withdrawals of ground water during 1960, 1970, and 1980 are summarized by use in Table 6. During 1980, all significant withdrawals of ground water, about 4.6 million gal/d, were from the Wilcox aquifer. Of this amount, about 94 percent was freshwater. Numerous springs, creeks, and ponds supply the water needs for livestock. Surface water is used for some public supply and industrial purposes. The Elderville Water-Supply Corporation obtains water from Lake Cherokee through the city of Longview; Texas Utilities Generating Company uses Martin Lake as a source of cooling water at their generating plant.

## Municipal Use

Estimates of municipal use of ground water are listed in Table 7. Of the 4.20 million gal/d of ground water used for public supply, 3.23 million gal/d of water was used by the five municipalities listed in Table 7. The city of Henderson, the largest single user, pumped 2.05 million gal/d of ground water from the Wilcox during 1980. The average per capita consumption of ground water from the five largest communities was 190 gal/d. The 24 rural water-supply corporations serving the smaller communities furnished about 0.97 million gal/d or about 23 percent of the water used for public supply during 1980. The approximate area served by all 29 public water-supply systems in Rusk County is shown in Figure 20. Elderville Water Supply Corporation, which uses surface water from Lake Cherokee, is the only public supply system that does not use ground water.

## Industrial Use

Industrial use during 1980 was estimated to be about 0.50 million gal/d, a decline of more than 50 percent from 1970. Nearly all of the industrial use is for cooling at gasoline plants and refineries. Increased energy costs have caused some operators to replace ground water with more economical sources of cooling, such as air and liquid hydrocarbons. Other industrial users have abandoned their wells and now obtain water from public-supply sources.

## Mining Use

Withdrawals of water for mining (fuels) are reported to the Railroad Commission of Texas. During 1980, about 0.550 million gal/d of water was withdrawn from the Wilcox aquifer for pressure maintenance. One example of such a project, Mobil's T.O. Mason lease, is pictured in Figure 21. Here, slightly saline water from the Wilcox is treated and mixed with produced brine from the Woodbine. This fluid is then injected underground in secondary recovery of oil at East Texas Oil Field. Pressure maintenance operations (water flooding) are or have been underway at eight oil-field sites in East Texas, two in Tatum, one in Henderson, one in South Henderson, one in Pone, and one in Shiloh.

## Table 6.--Approximate Withdrawals of Ground Water During 1960, 1970, and 1980 in Rusk County

(Mgal/d, million gallons per day; acre-ft, acre-feet)

| Use | 1960 | | 1970 | | 1980 | |
|---|---|---|---|---|---|---|
| | Mgal/d | Acre-ft | Mgal/d | Acre-ft | Mgal/d | Acre-ft |
| Industrial | 1.20 | 1,344 | 1.15 | 1,288 | 0.50 | 504 |
| Mining 1/ | -- | -- | .04 | 45 | .55 | 616 |
| Public supply | 1.40 | 1,568 | 2.25 | 2,520 | 4.20 | 4,705 |
| Rural domestic | .50 | 560 | .08 | 90 | .15 | 224 |
| Totals | 3.10 | 3,472 | 3.52 | 3,943 | 5.40 | 6,049 |

1/ Includes slightly saline water.

## Table 7.--Municipal Use of Ground Water in Rusk County

| Municipality | 1980 Population | 1980 Per capita consumption (gallons) | 1942 | 1943 | 1970 | 1980 |
|---|---|---|---|---|---|---|
| | | | (million gallons per day) | | | |
| Henderson | 11,473 | 178 | 0.36 | 1/0.38 | 1.27 | 2.05 |
| Mount Enterprise | 485 | 365 | -- | -- | .07 | .18 |
| New London | 942 | 400 | -- | -- | .22 | .38 |
| Overton | 2,430 | 178 | 1/.20 | 2/.20 | .29 | .43 |
| Tatum | 1,614 | 120 | -- | .01 | -- | .19 |
| Totals | 16,944 | 3/190 | 0.56 | 0.59 | 1.85 | 3.23 |

1/ November and December estimated on 1941 basis.
2/ Estimated.
3/ Average per capita consumption.

NOTE: Some figures may vary slightly due to rounding.

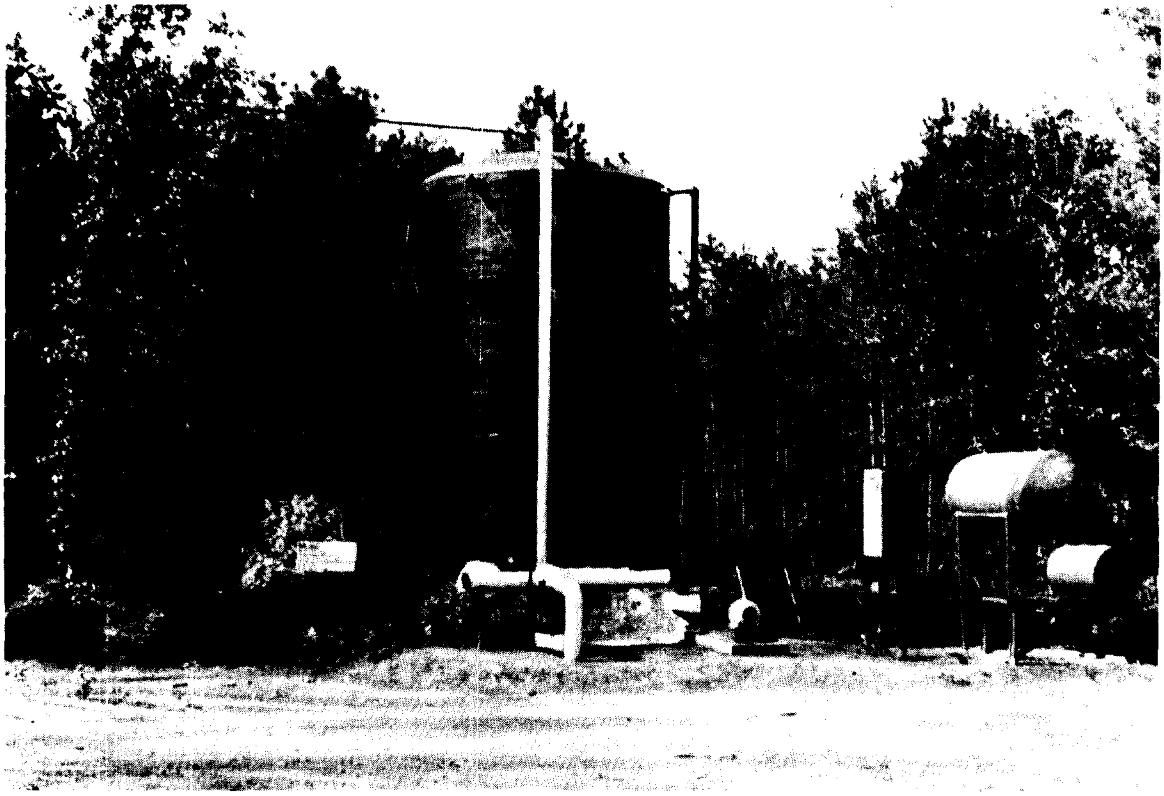

**Figure 21.—Water-Storage Tank at Mobil's T.O. Mason Pressure-Maintenance Project in East Texas Oil Field**

## Changes in Water Levels

Most water levels in Rusk County were measured during three periods: during 1936, between 1937 and 1940, and from about 1972 through 1981. Most of the observation wells before 1972 were concentrated near the city of Henderson. During 1972, the Texas Department of Water Resources initiated a network of observation wells that included the entire county. Practically no water-level data are available prior to the discovery of East Texas Oil Field in 1930.

Water-level measurements (three or less) are listed in the records of wells, springs, and test holes (Table 8). Other measurements (four or more) are tabulated in the list of water levels in wells (Table 10). Hydrographs depicting water-level fluctuations in selected wells are shown in Figure 22.

Many of the water levels measured are in wells that show no particular change. These water levels rise and fall due to changes in season and variations in rainfall. Sustained long-term declines in water levels are evident in two places, near the city of Henderson and in the area of East Texas Oil Field. In both areas there is a concentration of wells producing an average of over a million gallons per day. Most of the wells withdraw water from the middle and lower Wilcox sands.

At the city of Henderson, a moderate cone of depression (Figure 15) has resulted from ground-water withdrawals of about 2.0 million gal/d. The water level in well WR-35-50-901, near Henderson, declined about 134 feet between 1935 and 1981 (Figure 22).

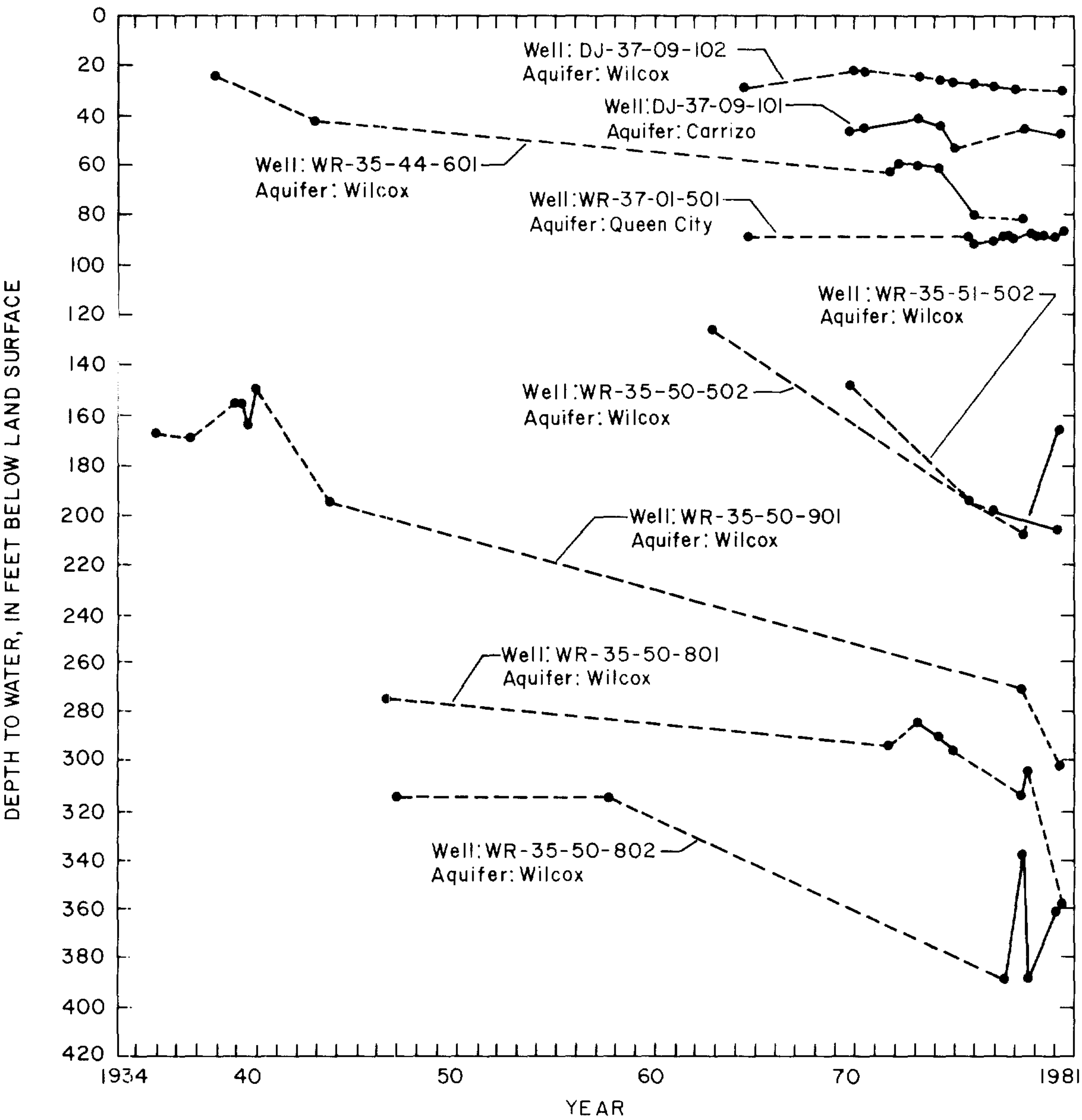


**Figure 22.—Fluctuations of Water Levels in Selected Wells in Rusk and Cherokee Counties**

Water levels in well WR-35-41-703 declined 29 feet between 1941 and 1979; water levels in well WR-35-41-901 declined about 17 feet between 1949 and 1981; and water levels in well WR-35-49-702 declined 67 feet between 1938 and 1979. However, not all water levels in Rusk County declined. The water level in well WR-35-41-501 rose 43 feet between 1947 and 1979. The water level in well WR-35-44-601, tapping the Wilcox, declined about 54 feet between 1938 and 1979. Elsewhere in Rusk County, water levels in most wells have not declined appreciably. For example, the water level in well WR-37-01-501 (Figure 22), tapping the Queen City, shows no long-term change.

## Well Construction

Well construction depends on several factors such as the desired capacity of the well, intended use, allowable cost, methods of drilling, and quality of the water desired. Some information on the well construction used in the county is tabulated in Table 8. Except for shallow-dug wells, wells are cased and have slotted screen opposite water-bearing sands.

Large-capacity wells such as those used for industrial and municipal supply are drilled by hydraulic rotary methods. First, a test hole (usually 6 inches in diameter) is drilled to total depth and logged for thickness of sand intervals. Water samples are collected to determine water quality in the different sands. If the data indicate that sufficient quantities of suitable quality water can be developed, a well is constructed. Test drilling is necessary in much of Rusk County, but particularly in the Mount Enterprise Fault Zone or in areas where the Wilcox sands contain water that varies in quality.

In a typical large-capacity well, the upper part of the test hole usually is reamed to 14 to 20 inches in diameter. A slightly smaller surface casing is set and cemented in place to form the pump pit or housing. The remaining part of the test hole is then reamed to a diameter slightly less than that of the surface casing. The interval to be screened is then underreamed as desired, usually to 30 inches in diameter, and 8- to 12-inch diameter wire-wrapped screens and blank casing are installed. Next, the annular space between the screen or casing and the wall of the hole is filled with sorted gravel. This gravel pack stabilizes the hole and effectively increases the diameter of the well. Large-capacity wells are developed and tested with large-capacity pumps. The wells then are fitted with deep-well turbine pumps, usually powered by electric motors. Properly constructed wells in the Wilcox or Carrizo aquifers yield about 500 gal/min.

Most of the drilled wells used for livestock and domestic purposes in Rusk County have 2- to 4-inch casing. Generally, jet pumps are used for the smaller-diameter wells if the water level is near the surface, and submersible pumps are used in the deeper 4-inch wells. Plastic (PVC) casing is often used due to its lower cost and ability to resist corrosion from water having a low pH or high iron content. Often the 4-inch wells are completed with a smaller-diameter single screen placed at the bottom of the well. Sometimes a wire-wrapped screen is used. More frequently, however, the last joint of pipe is slotted or perforated and possibly gravel packed.

# AVAILABILITY OF GROUND WATER

Some freshwater is available from every formation above the Midway Group. Only the Carrizo and Wilcox aquifers, however, are capable of producing substantial quantities of water. The Sparta and Queen City Sands, as previously mentioned, are limited in thickness and extent and only rarely are tapped by large wells in Rusk County. Although basal sands of the Reklaw furnish some water, they are hydraulically connected with the underlying Carrizo and should not be considered a source of water apart from the Carrizo. Moreover, the Reklaw, Queen City, Weches, and Sparta also overlie the Carrizo and Wilcox aquifers. Consequently, there is almost always a higher-yielding, but deeper, source of ground water available from the Carrizo and Wilcox sands.

It is not known if the current level of freshwater withdrawal will be maintained for the foreseeable future. If it is, a continued but moderate lowering of the potentometric surface is expected. With withdrawal of ground water, the lowering of water levels continues until the area of influence from the well fields becomes large enough so that the recharge equals the discharge. While water levels are lowered, water is taken from storage. The potentiometric surface of the Wilcox aquifer (Figure 15) indicates that the area of influence already extends past the Rusk County line. There are not sufficient withdrawal or water-level data to determine if the general water-level declines shown in Figure 22 will continue permanently because of continued increases in pumpage or only be temporary because of recent increases in pumpage. Data are insufficient to construct a water-level decline map for Rusk County.

In the case of the Wilcox and Carrizo aquifers in Rusk County, the recharge may be effectively increasing as the water levels are drawn down. Additional drawdown causes an increase in the head differences between the water table, which is expected to remain reasonably stable, and the potentiometric surface of the major water-bearing zones. Thus, the vertical hydraulic gradient is increased, thereby proportionally increasing the vertical leakage or movement of water.

One unknown aspect of continuing or increasing the ground-water withdrawals from the Wilcox is the possibility of increasing the water's salinity. As the water levels are lowered, water movement from nearby zones occurs. If these zones contain water of a higher salinity, the dissolved-solids concentrations in the major freshwater zones would be expected to eventually increase.

## Wilcox and Carrizo Aquifers

Fresh to slightly saline water is available from the Wilcox aquifer throughout the entire 939 square miles of Rusk County. The average thickness of sand in the Wilcox containing freshwater in Rusk County is about 245 feet. Based upon a porosity of 30 percent, the Wilcox contains about 40 million acre-feet of water; however, it is economically impractical to recover more than a small percentage of this water. Assuming a specific yield of 0.15, about 20 million acre-feet of water is available from storage. Water in storage is not a good measure of availability in Rusk County because it is not economically practical to recover more than a moderate amount of the total water stored in the aquifer system. Also, because the slightly saline water-bearing sands are interbedded with the freshwater-bearing sands, chemical quality may be a deterrent to development.

Freshwater is available from the Carrizo wherever it is present in Rusk County. Based on an area of 656 square miles, a porosity of 30 percent, and an average sand thickness of 70 feet, the aquifer contains about 8 million acre-feet of water. Assuming a specific yield of 0.15 and an overall average sand thickness of 70 feet, about 4 million acre-feet of water is available from storage in the Carrizo. The Carrizo is in hydraulic continuity with and serves as an avenue of recharge to the Wilcox throughout much of Rusk County.

Moderate amounts of ground water are available for development. The amount that is available perennially is not known, but is greater than that being withdrawn. Assuming a pre-development hydraulic gradient of about 8 ft/mi, a hydraulic conductivity of 14 ft/d and an average freshwater sand thickness of 245 feet, at least 12 million gal/d of fresh ground water is being transmitted through the Wilcox and about 3 million gal/d through the Carrizo.

## Other Aquifers

The Queen City aquifer, present in about 10 percent of the county, is practically undeveloped. Maximum thickness of the Queen City is about 132 feet. The aquifer is capable of producing ample supplies of ground water for livestock and domestic use. The Sparta Sand aquifer, which only occurs locally in the vicinity of the Mount Enterprise Fault system, is practically undeveloped. Because of their limited extent and near-surface occurrence, neither the Sparta nor Queen City is an important aquifer in Rusk County.

## Areas Most Favorable for Future Development

Areas most favorable for future development of ground water are shown in Figure 23. These areas have been designated as follows: I, most favorable; II, favorable; III, moderately favorable; IV, moderately unfavorable; and V, most unfavorable.

Representative criteria useful in classifying the favorability of areas for additional freshwater development include: 1, hydraulic conductivity; 2, average thickness of freshwater-bearing sands; 3, amount of ground water being withdrawn; 4, thickness or amount of slightly saline water-bearing sands interbedded with freshwater sands; 5, possible effects of faulting; and 6, possibility of freshwater sands being mineralized by oilfield brines.

The most favorable region for future development, shown as area I in Figure 23, is located in southwestern Rusk County. The area has one of the thicker sections of freshwater-bearing Wilcox sands, and the Carrizo is present in about 95 percent of the area. Also no significant ground-water withdrawals occur in the area.

Two favorable areas, shown as area II, are present. One lies in the east-central part of the county east of Henderson and another is present south of the Mount Enterprise Fault System. Although some Carrizo crops out on the surface in both areas, the largest ground-water supplies could be developed from the Wilcox aquifer.

Three moderately favorable areas, shown as area III, are present. Two of these areas are located in the southern section of the county and are associated with the Mount Enterprise Fault System. Outliers of both the Queen City and Sparta are preserved in the downdropped blocks of the system. Consequently, these are the places where the most complete geologic section is developed. Although there could be considerable amounts of available freshwater in this area, development of individual wells should be considered carefully because faulting may have interrupted the lateral continuity of a producing zone. The other moderately favorable area is located in the north-central part of the county where the freshwater-bearing Wilcox sands are relatively thin.

The moderately unfavorable area, shown as area IV, extends from about the city of Henderson northwestward to the county line. The area has experienced a substantial decline in water levels and has encountered some brine pollution.

Three most unfavorable areas, shown as area V, are present. One of the areas, about 30 square miles near the city of Henderson, accounts for about 40 percent of all ground water withdrawn in the county and may be considered moderately developed. Two other areas are located between Overton and New London and at Price in the area of East Texas Oil Field. This is an area where there are two cones of depression and considerable interfingering of slightly saline water-bearing sands with freshwater sands.

## NEEDS FOR CONTINUING DATA COLLECTION

Collection of withdrawal, water-level, and water-quality data in Rusk County should be continued and expanded. During about 1972, the Texas Department of Water Resources initiated a program of measuring water levels and collecting water-quality data in the area. The data-collection program should be continued and could be expanded to include a few wells that tap the deeper Wilcox sands outside of the more heavily pumped areas. Water-quality data also could be collected at Henderson to monitor saltwater encroachment.

A ground-water program to investigate contamination of freshwater sands by oilfield brines could be initiated in the East Texas and Henderson Oil Fields. Emphasis of such a program should be placed on investigating the deeper sands of the Wilcox as well as the shallow sands in areas of recharge.

## CONCLUSIONS

The Wilcox aquifer is the major source of ground water in Rusk County. It yields both fresh and slightly saline water. Water can also be obtained from the Carrizo, Queen City,and Sparta aquifers and from the Reklaw Formation. The Carrizo, the most extensive of the other sources, is in hydrologic continuity with the underlying Wilcox.

Numerous facies changes are present within the Wilcox, which consists of thin but sometimes massive beds of fine-to coarse-grained sand, silt, and clay. The aquifer ranges in thickness from about 750 feet to more than 1,200 feet. The Wilcox is the only freshwater-bearing unit that is present throughout all of Rusk County. No freshwater occurs below the base of the Wilcox. In places, however, slightly saline water-bearing beds are interbedded with and sometimes overlie freshwater-bearing sands. Although some of these relationships are natural, others may result from the mineralization of water by oilfield brines.

Daily withdrawal of ground water for all purposes increased from 3.1 million gal/d during 1960 to 5.4 million gal/d during 1980. Daily withdrawal for municipal purposes has increased from 1.4 million gal/d during 1960 to 4.2 million gal/d during 1980. About half of the municipal and about 38 percent of the total ground-water withdrawal (1980) is from a small area around the city of Henderson. Consequently, water levels at Henderson have declined about 135 feet or an average of about 2.9 feet per year between 1935 and 1981.

Additional supplies of fresh ground water can be developed throughout nearly all of Rusk County. About 20 million acre-feet of freshwater is available from storage, and a total of 12 million gal/d is being transmitted through the Wilcox aquifer. Slightly saline water also is available from the Wilcox aquifer. About 4 million acre-feet of freshwater is available from storage, and a total of about 3 million gal/d is being transmitted through the Carrizo aquifer. Wells that are properly constructed should yield about 500 gal/min from the Wilcox and possibly the Carrizo aquifers; a few wells have been constructed that yield as much as 1,000 gal/min.

Much of the variation in the quality of the ground water in the Wilcox aquifer is natural. Three areas in which variations are likely to occur are near the city of Henderson, in the East Texas Oil Field, and along the Mount Enterprise Fault System. Because drastic water-quality changes occur between zones, it is essential that the water from each sand be analyzed during a test-drilling operation to make certain that it is of acceptable quality.

Poorer-quality ground water occurs in the vicinity of the city of Henderson. The withdrawal of 2.05 million gal/d of ground water from the Wilcox during 1980 created a cone of depression into which the poor-quality water could migrate.

Ground water has been contaminated by oilfield brine at Henderson field. In addition, oilfield brine has contaminated Bowles Creek and Beaver Run Creek in two separate instances.

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## Table 9.--Drillers' Logs of Selected Wells in Rusk County

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-41-304**<br>Owner: White Oak Water Supply Corp.<br>Driller: Layne-Texas Co. | | |
| Surface soil | 4 | 4 |
| Clay | 3 | 7 |
| Sand | 15 | 22 |
| Clay | 32 | 54 |
| Shale | 5 | 59 |
| Sand | 8 | 67 |
| Shale | 33 | 100 |
| Rock | 2 | 102 |
| Shale | 16 | 118 |
| Sand | 18 | 136 |
| Shale | 4 | 140 |
| Rock | 1 | 141 |
| Shale | 13 | 154 |
| Sandy shale | 9 | 163 |
| Rock | 2 | 165 |
| Shale and boulders | 25 | 190 |
| Shale and layers of sand | 23 | 213 |
| Hard shale | 20 | 233 |
| Shale and lignite | 29 | 262 |
| Sand | 15 | 277 |
| Sandy shale | 8 | 285 |
| Sand | 16 | 301 |
| Sandy shale | 45 | 346 |
| Sand | 94 | 440 |
| Shale | 4 | 444 |
| **Well WR-35-41-505**<br>Owner: Gulf Pipeline Co.<br>Driller: Benson Drilling Co. | | |
| Surface soil | 20 | 20 |
| Sand | 25 | 45 |
| Shale | 13 | 58 |
| Sandy shale | 17 | 75 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-41-505--Cont.** | | |
| Rock | 1 | 76 |
| Sticky shale | 27 | 103 |
| Rock | 2 | 105 |
| Sand and boulders | 9 | 114 |
| Hard sand rock | 9 | 123 |
| Rock | 2 | 125 |
| Sandy shale | 8 | 133 |
| Rock | 1 | 134 |
| Sandy shale | 7 | 141 |
| Rock | 1 | 142 |
| Sand | 64 | 206 |
| Sandy shale | 14 | 220 |
| Hard shale | 7 | 227 |
| Shale and boulders | 23 | 250 |
| Hard sand rock | 15 | 265 |
| Sand | 15 | 280 |
| Lignite and sand streaks | 10 | 290 |
| Lignite | 23 | 313 |
| Sandy shale | 23 | 336 |
| Lignite | 4 | 340 |
| Sandy shale | 48 | 388 |
| Hard sand rock | 6 | 394 |
| Shale | 14 | 408 |
| Sandy shale | 10 | 418 |
| Sand and shale | 112 | 530 |
| Gumbo | 10 | 540 |
| Shale | 20 | 560 |
| Sticky shale | 20 | 580 |
| Packsand | 8 | 588 |
| Gray sand | 17 | 605 |
| Hard Sand | 25 | 630 |
| Sand | 60 | 690 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-41-505--Cont. | | |
| Rock | 4 | 694 |
| Gumbo | 10 | 704 |
| Sandy shale | 64 | 768 |
| Sand and lignite | 22 | 790 |
| Lignite | 16 | 806 |
| Sand | 12 | 818 |
| Broken sand and lignite | 32 | 850 |
| Gumbo | 5 | 855 |
| Rock | 5 | 860 |
| Sand and lignite | 20 | 880 |
| Rock | 6 | 886 |
| Sand | 144 | 1,030 |
| Gumbo | 3 | 1,033 |
| WR-35-41-708<br>Owner: Missouri Pacific Railroad<br>Driller: Pomeroy Drilling Co. | | |
| Surface clay and sand | 18 | 18 |
| Water sand | 17 | 35 |
| Clay | 15 | 50 |
| Packed sard and boulders | 27 | 77 |
| Clay | 34 | 111 |
| Rock | 2 | 113 |
| Packed sard | 18 | 131 |
| Sand and shale | 7 | 138 |
| Shale | 15 | 153 |
| Rock | 2 | 155 |
| Packed sand | 4 | 159 |
| Hard sandy shale | 10 | 169 |
| Rock | 1 | 170 |
| Sand and boulders | 33 | 203 |
| Sandy shale | 16 | 219 |
| Sand | 30 | 249 |
| Sand and boulders | 51 | 300 |
| Well WR-35-41-708--Cont. | | |
| Fine sand | 10 | 310 |
| Sand and boulders | 17 | 327 |
| Packed sand | 5 | 332 |
| Sand | 13 | 345 |
| Sand and shale | 11 | 356 |
| Sand and boulders | 5 | 361 |
| Hard shale | 10 | 371 |
| Packed sand | 9 | 380 |
| Sand and boulders | 23 | 403 |
| Shale | 14 | 417 |
| Sand and boulders | 23 | 440 |
| Sand and lignite | 20 | 460 |
| Hard shale | 38 | 498 |
| Sand, boulders, and lignite | 32 | 530 |
| Gumbo | 7 | 537 |
| Rock | 1 | 538 |
| Hard shale | 22 | 560 |
| Sand and shale | 20 | 580 |
| Sand and boulders | 20 | 600 |
| Sand and shale | 10 | 610 |
| Sand and boulders | 13 | 623 |
| Shale | 15 | 638 |
| Sand | 5 | 643 |
| Shale | 19 | 662 |
| Hard sand | 22 | 684 |
| Sand | 10 | 694 |
| Packed sand | 11 | 705 |
| Sand | 65 | 770 |
| Gumbo | 1 | 771 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-41-809<br>Owner: City of Overton<br>Driller: Layne-Texas Co. | | |
| Topsoil | 2 | 2 |
| Red clay | 20 | 22 |
| Sand | 3 | 25 |
| Shale | 10 | 35 |
| Sandy shale and sand streaks | 9 | 44 |
| Sand and sandy shale streaks | 10 | 54 |
| Sandy shale with sand and shale streaks | 58 | 112 |
| Rock | 1 | 113 |
| Shale | 6 | 119 |
| Rock | 1 | 120 |
| Shale | 23 | 143 |
| Rock | 1 | 144 |
| Sandy shale | 2 | 146 |
| Rock | 2 | 148 |
| Shale | 6 | 154 |
| Lignite | 1 | 155 |
| Rock | 1 | 156 |
| Sandy shale | 1 | 157 |
| Rock | 1 | 158 |
| Sandy shale | 2 | 160 |
| Rock | 1 | 161 |
| Shale | 3 | 164 |
| Sand | 2 | 166 |
| Rock | 1 | 167 |
| Sand | 9 | 176 |
| Rock and sandy shale | 2 | 178 |
| Sand with lignite streaks | 18 | 196 |
| Shale, sandy shale with lignite streaks | 4 | 200 |
| Sand | 16 | 216 |
| Sand with shale streaks | 7 | 223 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-41-809--Cont. | | |
| Sand | 75 | 298 |
| Shale and sandy shale streaks | 12 | 310 |
| Rock | 1 | 311 |
| Sandy shale with sand and lignite streaks | 24 | 335 |
| Shale, sandy shale with lignite streaks | 26 | 361 |
| Shale with lignite streaks | 63 | 424 |
| Sand | 5 | 429 |
| Shale, sandy shale with lignite streaks | 34 | 463 |
| Sand, sandy shale with shale streaks | 93 | 556 |
| Sandy shale with shale streaks | 44 | 600 |
| Shale | 8 | 608 |
| Sandy with shale streaks | 9 | 617 |
| Rock | 3 | 620 |
| Shale | 12 | 632 |
| Sand | 2 | 634 |
| Sandy shale | 3 | 637 |
| Shale and sandy shale | 29 | 666 |
| Sand with shale streaks | 3 | 669 |
| Sandy shale with shale layers | 20 | 689 |
| Hard shale | 1 | 690 |
| Rock | 1 | 691 |
| Hard shale | 6 | 697 |
| Sand and sandy shale | 105 | 802 |
| Shale with sandy streaks | 6 | 808 |
| Shale with lignite streaks | 24 | 832 |
| Shale with sandy shale | 4 | 836 |
| Shale with sandy shale layers | 50 | 886 |
| Rock | 1 | 887 |
| Shale | 13 | 900 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-42-401<br>Owner: Jacobs Water Supply Corp. No. 2<br>Driller: Layne-Texas Co. | | |
| Surface soil | 2 | 2 |
| Sandy clay | 18 | 20 |
| Sand and sandstone streaks | 8 | 28 |
| Sandy clay | 38 | 66 |
| Sandy clay | 19 | 85 |
| Sand (good) | 90 | 175 |
| Lignite | 3 | 178 |
| Sandy clay and lignite streaks | 58 | 236 |
| Sandy clay and sand streaks | 42 | 278 |
| Clay | 47 | 325 |
| Sand (fair) | 73 | 398 |
| Shale and sandy shale | 34 | 432 |
| Sand (poor) | 10 | 442 |
| Sandy shale and sand streaks | 33 | 475 |
| Sandy shale and sand streaks | 43 | 518 |
| Sand (broken) | 6 | 524 |
| Sand (good) | 27 | 551 |
| Rock | 3 | 554 |
| Sandy clay and rock streaks | 10 | 564 |
| Sand (broken) | 21 | 585 |
| Sand and clay streaks | 14 | 599 |
| Clay | 15 | 614 |
| Well WR-35-43-501<br>Owner: R. C. Walling<br>Driller: Howeth Water Well Service | | |
| Red clay | 12 | 12 |
| White clay | 8 | 20 |
| Gray clay | 12 | 32 |
| Sandy | 8 | 40 |
| Sand | 47 | 87 |
| Clay | 3 | 90 |
| Sand | 3 | 93 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-43-501--Cont. | | |
| Clay | 87 | 180 |
| Sandy | 30 | 210 |
| Clay | 10 | 220 |
| Well WR-35-44-101<br>Owner: Boy Scouts of America, Camp Kennedy<br>Driller: Layne-Texas Co. | | |
| Surface sand | 2 | 2 |
| Clay and sandy clay | 19 | 21 |
| Sand and some gravel | 31 | 52 |
| Fine quicksand | 16 | 68 |
| Gray clay and sand | 27 | 95 |
| Shale and sand | 77 | 172 |
| Sand and shale | 24 | 196 |
| Shale and sand streaks | 23 | 219 |
| Gray sand rock | 2 | 221 |
| Soft gray shale and sandy shale | 19 | 240 |
| Sand rock | 1 | 241 |
| Gray shale, few sand and rock layers | 59 | 300 |
| Shale and sand | 23 | 323 |
| Sand, shale, and sandy shale | 11 | 334 |
| Sand, broken, with shale layers | 12 | 346 |
| Coarse gray sand and few shale breaks | 15 | 361 |
| Sand, soft shale, and lignite breaks | 30 | 391 |
| Sand, soft shale, and lignite breaks | 27 | 418 |
| Hard sand rock | 3 | 421 |
| Well WR-35-44-501<br>Owner: Crystal Farms Water Supply Corp.<br>Driller: Frye Drilling Co. | | |
| Topsoil and white sand | 22 | 22 |
| Rocky shale and lignite | 18 | 40 |
| Shale, thin rocks | 40 | 80 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-44-501--Cont.** | | |
| Gray shale | 21 | 101 |
| Blue shale | 20 | 121 |
| Blue shale, lignite | 41 | 162 |
| shale and sand | 21 | 183 |
| Sand, shale, and rock | 25 | 208 |
| Shale and sand | 16 | 224 |
| Sand and shale | 82 | 306 |
| Rock sand and shale | 20 | 326 |
| Shale and rock | 21 | 347 |
| Sand | 20 | 367 |
| Rock and good sand | 21 | 388 |
| Shale and good sand | 20 | 408 |
| Good sand and rock | 10 | 418 |
| **Well WR-35-44-801**<br>Owner: Texas Utilities Services, Inc., No. 1 Martin Lake Plant<br>Driller: Layne-Texas Co. | | |
| Iron rock and red sandy clay | 7 | 7 |
| Gray sandy clay | 16 | 23 |
| Lignite | 2 | 25 |
| Sandy shale, sand streaks, and lignite streaks | 41 | 66 |
| Lignite | 7 | 73 |
| Sand with lignite and shale | 2 | 75 |
| Sandy shale | 3 | 78 |
| Sand, lignite streaks, and shale | 11 | 89 |
| Shale, sandy shale, and lignite streaks | 34 | 123 |
| Shale with sand streaks | 29 | 152 |
| Sand and shale layers | 25 | 177 |
| Rock | 1 | 178 |
| Sand (cut good) | 16 | 194 |
| Rock | 1 | 195 |
| Sand (cut good) | 35 | 230 |
| **Well WR-35-44-801--Cont.** | | |
| Rock (hard) | 4 | 234 |
| Sand | 8 | 242 |
| Sand and shale streaks | 13 | 255 |
| Rock (hard) | 1 | 256 |
| Sand | 3 | 259 |
| Rock (hard) | 6 | 265 |
| Sand and shale streaks | 56 | 321 |
| Sandy shale, shale streaks, and lignite | 11 | 332 |
| Sand with shale layers | 62 | 394 |
| Sand and shale layers | 66 | 460 |
| Sand, lignite, and shale streaks | 14 | 474 |
| Sand | 114 | 588 |
| Sand and shale (broken) | 12 | 600 |
| Sand with shale streaks | 41 | 641 |
| Sand | 28 | 669 |
| Sand with streaks of shale lignite (cut good) | 31 | 700 |
| Sandy shale | 39 | 739 |
| **Well WR-35-49-206**<br>Owner: Cities Service Co. water supply well No. 1, Wheelis Lease<br>Driller: Layne-Texas Co. | | |
| Top sand | 6 | 6 |
| Red clay and shale | 7 | 13 |
| Sandy shale, shale streaks, and gravel | 35 | 48 |
| Rock (hard) | 1 | 49 |
| Shale | 32 | 81 |
| Sandy shale | 17 | 98 |
| Rock (hard) | 1 | 99 |
| Sand shale and shale | 10 | 109 |
| Rock | 1 | 110 |
| Sandy shale | 3 | 113 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-49-206--Cont. | | |
| Sand, sandy shale streaks, and shale layers | 48 | 161 |
| Sand (cut good, coarse) | 77 | 238 |
| Shale, lignite, and sandy shale | 52 | 290 |
| Fine sand and sandy shale | 11 | 301 |
| Sand shale, lignite | 28 | 329 |
| Rock (hard) | 4 | 333 |
| Sandy shale and sand (broken) | 25 | 358 |
| Sandy shale and shale streaks (cut good) | 25 | 383 |
| Sandy shale and lignite, mixed | 61 | 444 |
| Sand and sandy shale (cut good) | 37 | 481 |
| Sandy shale and sand streaks | 42 | 523 |
| Sand and sandy shale streaks | 16 | 539 |
| Shale and sandy shale (cut hard) | 86 | 625 |
| Sand | 5 | 630 |
| Rock (hard) | 2 | 632 |
| Sand and shale streaks | 19 | 651 |
| Sandy shale | 6 | 657 |
| Sand | 8 | 665 |
| Sandy shale and sand streaks | 9 | 674 |
| Sand and shale streaks | 27 | 701 |
| Sandy shale | 9 | 710 |
| Sand and sandy shale | 19 | 729 |
| Sandy shale and lignite streaks | 8 | 737 |
| Sand | 4 | 741 |
| Sandy shale and lignite streaks | 29 | 770 |
| Sand and sandy shale (broken layers) | 32 | 802 |
| Sandy shale and lignite streaks | 15 | 817 |
| Sand and sandy shale and lignite | 6 | 823 |
| Sand | 8 | 831 |
| Sandy shale, lignite, and sand streaks | 9 | 840 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-49-206--Cont. | | |
| Sand, sandy shale, and lignite (broken) | 21 | 801 |
| Sand and lignite streaks (cut good) | 27 | 888 |
| Sandy shale, sand, and lignite streaks | 29 | 917 |
| Sand | 14 | 931 |
| Shale and sandy shale | 14 | 945 |
| Sand and shale streaks | 11 | 956 |
| Sandy shale and lignite streaks | 7 | 963 |
| Rock | 1 | 964 |
| Sandy shale, shale, and lignite streaks | 24 | 988 |
| Rock | 1 | 989 |
| Sandy shale, sand layers, and lignite streaks | 22 | 1,011 |
| Sand | 5 | 1,016 |
| Sandy shale | 5 | 1,021 |
| Well WR-35-49-601<br>Owner: Gaston Water Supply Corp. No. 1<br>Drilling: Edington Drilling Co. | | |
| Clay | 22 | 22 |
| Shale | 41 | 63 |
| Sand | 20 | 83 |
| Shale | 21 | 104 |
| Sand | 28 | 132 |
| Shale | 34 | 166 |
| Sand, 185 - rock | 20 | 186 |
| Shale rock | 21 | 207 |
| Shale | 102 | 309 |
| Sand shale | 21 | 330 |
| Shale | 21 | 351 |
| Sand | 15 | 366 |
| Shale | 66 | 432 |
| Sand | 20 | 452 |

**Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued**

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-49-601--Cont. | | |
| Sand shale | 21 | 473 |
| Shale | 9 | 482 |
| Rock | 18 | 500 |
| Sand | 18 | 518 |
| Shale | 16 | 534 |
| Shale rock | 21 | 555 |
| Shale | 61 | 616 |
| Shale rock | 21 | 637 |
| Shale | 21 | 1/658 |
| Well WR-35-50-206<br>Owner: Burris Dorsey<br>Driller: White Drilling Co. | | |
| Red, white, and yellow clay | 7 | 7 |
| Tan shale | 20 | 27 |
| White sand, some shale streaks | 37 | 64 |
| Lignite | 12 | 76 |
| Gray sticky shale | 4 | 80 |
| Sandy shale | 4 | 84 |
| Gray sticky shale | 11 | 95 |
| Gray brittle shale | 6 | 101 |
| Gray sticky shale | 15 | 116 |
| Gray sandy shale with heavy lignite | 11 | 127 |
| Gray sticky shale | 10 | 137 |
| Brown shale and lignite | 14 | 151 |
| Gray sand | 2 | 153 |
| Brown and gray shale with some lignite | 5 | 158 |
| Sandy shale | 10 | 168 |
| Brown sticky shale | 8 | 176 |
| Gray sticky shale | 20 | 196 |
| Shale with thin lignite streak | 2 | 198 |
| Sandy shale | 3 | 201 |
| Gray sand | 14 | 215 |

1/ Well is deeper, but driller omitted bottom portion of log.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-50-502<br>Owner: City of Henderson No. 16<br>(formerly White Oak Water Co.)<br>Driller: Layne-Texas Co. | | |
| Surface soil and sand | 10 | 10 |
| Gray clay | 18 | 28 |
| Gray sand and lignite | 9 | 37 |
| Gray shale and lignite streaks | 19 | 56 |
| Gray sand and lignite streaks | 14 | 70 |
| Shale, sand, and limestone streaks | 18 | 88 |
| Sandy shale | 6 | 94 |
| Sand and shale | 3 | 97 |
| Shale, sand streaks, and lignite | 25 | 122 |
| Sand and shale | 12 | 134 |
| Shale and lignite | 30 | 164 |
| Sand and shale layers | 14 | 178 |
| Sand, thin shale layers | 11 | 189 |
| Sand and shale | 9 | 198 |
| Shale | 15 | 213 |
| Sand and shale streaks | 30 | 243 |
| Sand and shale layers (cut good) | 12 | 255 |
| Shale and sand layers | 18 | 273 |
| Shale and sandy shale | 14 | 287 |
| Sand and shale streaks (cut good) | 15 | 302 |
| Sand (cut good) | 62 | 370 |
| Sandy shale and shale layers | 6 | 370 |
| Shale and sand streaks | 22 | 392 |
| Sand and sandy shale | 10 | 402 |
| Shale and sandy shale | 8 | 410 |
| Well WR-35-50-601<br>Owner: Texas Highway R.O.W.<br>Driller: Works Progress Administration | | |
| Surface soil | 3.5 | 3.5 |
| Sand rock | .5 | 4 |
| Yellow and red clay | 2 | 6 |
| Yellow clay | 1 | 7 |

Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-50-601--Cont. | | |
| Red clay | 1 | 8 |
| Yellow sandy clay | 2 | 10 |
| Yellow and red sandy clay | 1 | 11 |
| Yellow sandy clay | 1 | 12 |
| Orange sandy clay | 1 | 13 |
| Yellowish-orange sandy clay | 6 | 19 |
| White clay | 1 | 20 |
| Red and white clay | 1 | 21 |
| White sandy clay | 2 | 23 |
| Red and white sandy clay | 1 | 24 |
| White sandy clay | 1 | 25 |
| Gumbo | 2 | 27 |
| Yellow sandy clay | 1 | 28 |
| White sandy clay | 1 | 29 |
| Yellow and white sandy clay | 1 | 30 |
| White sandy clay | 1 | 31 |
| Well WR-35-50-901<br>Owner: City of Henderson No. 4<br>Driller: Layne-Texas Co. | | |
| Clay | 10 | 10 |
| Yellow sand | 10 | 20 |
| Sandy shale | 80 | 100 |
| Shale and lignite | 45 | 145 |
| Fine-grained sand | 15 | 160 |
| Sandy shale and lignite | 92 | 252 |
| Fine-grained sand | 10 | 262 |
| Shale and lignite | 33 | 295 |
| Sand | 20 | 315 |
| Rock | 1 | 316 |
| Sandy shale | 49 | 365 |
| Shale | 35 | 400 |
| Gray sand | 12 | 412 |
| Shale | 15 | 427 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-50-901--Cont. | | |
| Sand | 52 | 479 |
| Shale | 3 | 482 |
| Sand | 78 | 560 |
| Brown shale and lignite | 23 | 583 |
| Well 35-50-907<br>Owner: City of Henderson No. 13, James Owen well<br>Driller: Layne-Texas Co. | | |
| Sandy soil | 2 | 2 |
| Sandy clay | 10 | 12 |
| Sand | 5 | 17 |
| Clay and lignite | 53 | 70 |
| Sand | 6 | 76 |
| Gray shale, sand and lignite | 111 | 187 |
| Sand and shale layers | 36 | 223 |
| Shale and sand layers | 27 | 250 |
| Brown and gray shale and lignite | 38 | 288 |
| Sand and shale streaks | 8 | 296 |
| Shale and sandy shale | 8 | 304 |
| Sandy shale | 12 | 316 |
| Shale and sand streaks | 58 | 374 |
| Sand and shale | 9 | 383 |
| Rock | 1 | 384 |
| Shale and sandy shale | 17 | 401 |
| Sandy shale | 10 | 411 |
| Shale and sand streaks | 27 | 438 |
| Sand | 6 | 444 |
| Shale and sandy shale | 29 | 473 |
| Sand and shale layers | 22 | 495 |
| Sand, thin shale layers | 20 | 515 |
| Rock | 5 | 520 |
| Sand and hard streaks | 51 | 571 |
| Shale and lignite | 19 | 590 |
| Sand and shale streaks | 91 | 681 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-50-907--Cont.** | | |
| Shale | 11 | 692 |
| Sand and shale streaks | 8 | 700 |
| Shale and sandy shale | 14 | 714 |
| **Well WR-35-51-101<br>Owner: New Prospect Water Supply Corp. No. 2<br>Driller: Layne-Texas Co.** | | |
| Topsoil | 1 | 1 |
| Clay | 15 | 16 |
| Rock | 2 | 18 |
| Clay and sand streaks | 3 | 21 |
| Clay, sandy shale and rock | 12 | 33 |
| Sand and shale streaks | 20 | 53 |
| Rock | 3 | 56 |
| Sand and shale layers | 10 | 66 |
| Rock | 2 | 68 |
| Shale | 4 | 72 |
| Sand, sandy shale and lignite | 15 | 87 |
| Rock | 1 | 88 |
| Sand | 5 | 93 |
| Lignite | 2 | 95 |
| Shale and sandy shale | 17 | 112 |
| Shale and sandy shale | 16 | 128 |
| Shale | 8 | 136 |
| Shale and sandy shale | 17 | 153 |
| Lignite | 6 | 159 |
| Shale and sandy shale | 23 | 182 |
| Sand and shale | 12 | 194 |
| Shale and sandy shale | 40 | 234 |
| Rock | 1 | 235 |
| Sand and shale (hard) | 38 | 273 |
| Rock | 1 | 274 |
| Sand and shale (hard) | 21 | 295 |
| Sand, lignite, and shale | 39 | 334 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-51-101--Cont.** | | |
| Shale | 30 | 364 |
| Sand (fine) | 12 | 376 |
| Sandy shale and sand layers | 4 | 380 |
| Sand, shale, and lignite | 61 | 441 |
| Rock | 1 | 442 |
| Sand, shale, and lignite streaks | 50 | 492 |
| Shale | 2 | 494 |
| Sand and shale streaks (coarse) | 22 | 516 |
| Sandy shale and sand layers | 18 | 534 |
| Sand and shale layers | 10 | 544 |
| Shale, sandy shale, and sand streaks | 29 | 573 |
| Sand, shale, and lignite streaks | 11 | 584 |
| Shale and rock layers (hard) | 34 | 618 |
| Sand (fine) | 7 | 625 |
| Lignite | 3 | 628 |
| Shale and lignite | 6 | 634 |
| **Well WR-35-51-502<br>Owner: Church Hill Water Supply Corp. No. 2<br>Driller: Howeth Water Well Service** | | |
| Red and white clay | 20 | 20 |
| Sand | 20 | 40 |
| Clay | 76 | 116 |
| Sand | 24 | 140 |
| Clay | 40 | 180 |
| Sand | 12 | 192 |
| Clay | 208 | 400 |
| Sand | 40 | 440 |
| Coal, clay, and sand | 24 | 464 |
| Sand, streaked | 44 | 508 |
| Clay | 42 | 550 |
| Sandy | 30 | 580 |
| Clay | 30 | 610 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| **Well WR-35-52-101**<br>Owner: Evel Faulkner<br>Driller: Howeth Water Well Service | | |
| White-yellow clay | 21 | 21 |
| Sand clay | 3 | 24 |
| Clay | 4 | 28 |
| Sand clay | 7 | 35 |
| Dark clay | 13 | 48 |
| Coal | 7 | 55 |
| Clay | 7 | 62 |
| Sand | 6 | 68 |
| Clay | 33 | 101 |
| Coal | 2 | 103 |
| Clay | 7 | 110 |
| Sand | 3 | 113 |
| Clay | 61 | 174 |
| Sand | 14 | 188 |
| Clay | 4 | 192 |
| **Well WR-35-52-701**<br>Owner: H. H. Truelock<br>Driller: Howeth Water Well Service | | |
| Clay | 30 | 30 |
| Sand, streaked | 15 | 45 |
| Clay | 30 | 75 |
| Coal | 9 | 84 |
| Clay | 16 | 100 |
| Sand, streaked | 15 | 115 |
| Clay | 155 | 270 |
| Sand | 26 | 296 |
| Clay | 6 | 302 |
| **Well WR-35-57-203**<br>Owner: Amoco Production Co. No. 3, Siler Lease<br>Driller: Layne-Texas Co. | | |
| Topsoil | 2 | 2 |
| Sand | 22 | 24 |
| **Well-WR-35-57-203--Cont.** | | |
| Sandy shale and lignite | 38 | 62 |
| Sand | 5 | 67 |
| Sand and gravel | 35 | 102 |
| Sand and shale streaks | 18 | 120 |
| Sand | 5 | 125 |
| Sandy shale and sand layers | 35 | 160 |
| Sand | 13 | 173 |
| Shale | 11 | 184 |
| Sand and lignite | 10 | 194 |
| Sandy shale | 74 | 268 |
| Sand, lignite, and shale streaks | 33 | 301 |
| Shale and sandy shale | 25 | 326 |
| Sand and shale streaks | 39 | 365 |
| Rock | 1 | 366 |
| Sandy shale | 19 | 385 |
| Sand | 6 | 391 |
| Shale | 13 | 404 |
| Shale and sandy shale | 26 | 430 |
| Sand and shale streaks | 23 | 453 |
| Shale and sand streaks | 18 | 471 |
| Sand | 8 | 479 |
| Shale and sandy shale | 25 | 504 |
| Sand | 8 | 512 |
| Rock | 1 | 513 |
| Sand with shale streaks | 5 | 518 |
| Sandy shale | 17 | 535 |
| Sand and shale layers | 15 | 550 |
| Rock | 1 | 551 |
| Sand | 34 | 584 |
| Rock | 2 | 586 |
| Shale | 2 | 588 |
| Rock | 2 | 590 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-57-203--Cont. | | |
| Sand | 16 | 606 |
| Shale | 7 | 613 |
| Sand and shale layers | 39 | 652 |
| Shale | 3 | 655 |
| Sand and lignite layers | 23 | 678 |
| Rock | 1 | 679 |
| Shale | 5 | 684 |
| Sand and shale streaks | 15 | 699 |
| Shale | 12 | 711 |
| Sand | 38 | 749 |
| Shale | 11 | 760 |
| Sandy shale with lignite | 60 | 820 |
| Sand and shale layers | 60 | 880 |
| Shale | 19 | 899 |
| Sand | 6 | 905 |
| Rock | 1 | 906 |
| Shale | 2 | 908 |
| Sand | 2 | 910 |
| Shale | 9 | 919 |
| Sand | 19 | 938 |
| Sandy shale | 11 | 949 |
| Shale | 14 | 963 |
| Sand and sandy shale | 22 | 985 |
| Sand | 23 | 1,008 |
| Shale | 5 | 1,013 |
| Rock | 2 | 1,015 |
| Sand and shale streaks | 25 | 1,040 |
| Sandy shale | 12 | 1,052 |
| Sand and shale streaks | 15 | 1,067 |
| Rock | 3 | 1,070 |
| Sand and shale layers | 34 | 1,104 |
| Sandy shale and sand streaks | 21 | 1,125 |
| Shale | 10 | 1,135 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-35-57-901<br>Owner: W. A. Whitehead<br>Driller: White Drilling Co. | | |
| Brown, tan, and yellow clay with gravel | 20 | 20 |
| Brown and gray shale | 35 | 55 |
| Gray sand | 45 | 100 |
| Gray shale and lignite | 50 | 150 |
| Lignite | 15 | 165 |
| Gray sand | 5 | 170 |
| Gray shale with heavy lignite | 40 | 210 |
| Gray sand with heavy lignite | 20 | 230 |
| Gray shale and lignite | 40 | 270 |
| Gray sand | 45 | 315 |
| Well WR-35-58-102<br>Owner: Goodsprings Water Supply Corp.<br>Driller: Edington Drilling Co. | | |
| Clay | 22 | 22 |
| Sand | 48 | 70 |
| Shale | 70 | 140 |
| Sandy shale | 41 | 186 |
| Shale | 9 | 195 |
| Sand | 11 | 206 |
| Shale | 61 | 267 |
| Sand | 8 | 275 |
| Shale | 54 | 329 |
| Sand | 20 | 349 |
| Shale | 41 | 390 |
| Shale and rock layers | 20 | 410 |
| Shale | 82 | 492 |
| Sand | 82 | 574 |
| Shale | 20 | 594 |
| Shale | 14 | 608 |
| Sand | 7 | 615 |
| Shale and sandy shale | 20 | 635 |
| Shale | 7 | 642 |

## Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

Well WR-35-58-102--Cont.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sand | 8 | 650 |
| Shale | 6 | 656 |

Well WR-35-59-803
Owner: Mobil Oil Corp. No. 3
Driller: Edington Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Surface clay and sand | 25 | 25 |
| Gray shale | 108 | 133 |
| Rock | 1 | 134 |
| Gray shale | 13 | 147 |
| Gray sand | 43 | 190 |
| Gray shale | 161 | 351 |
| Gray sand | 41 | 392 |
| Gray shale | 263 | 655 |
| Fine white sand | 65 | 720 |
| Gray sandy shale | 44 | 764 |
| Gray shale | 11 | 775 |

Well WR-35-59-902
Owner: J. G. Spradlin
Driller: Howeth Water Well Service

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Red and yellow clay | 20 | 20 |
| Clay | 20 | 40 |
| Sandy | 19 | 59 |
| Clay | 47 | 106 |
| Sand | 14 | 120 |
| Clay | 178 | 298 |
| Sandy bed | 77 | 375 |
| Clay | 73 | 448 |
| Sand streaks | 32 | 480 |

Well WR-37-01-501
Owner: New Salem Water Supply Corp.
Driller: Triangle Pump & Supply Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay and sand | 5 | 5 |
| Clay and rock, red | 25 | 30 |
| Sand, fine, white | 50 | 80 |

Well WR-37-01-501--Cont.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sandy shale and shale | 100 | 180 |
| Sand, brown and yellow | 28 | 208 |
| Shale, blue, hard | 22 | 230 |
| Sandy shale and sand, fine | 16 | 246 |
| Sand, white and gray, coarse | 24 | 270 |
| Sandy shale and sand | 30 | 300 |
| Sand streaks and sandy shale | 100 | 400 |
| Sand, fine | 20 | 420 |
| Shale | 10 | 430 |
| Shale, blue and black | 83 | 513 |

Well WR-37-02-301
Owner: Pine Springs Baptist Camp
Driller: Key Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Clay | 30 | 30 |
| Sand | 41 | 71 |
| Shale | 14 | 85 |
| Sand | 25 | 110 |
| Shale | 5 | 115 |
| Sand | 25 | 140 |
| Shale | 20 | 160 |
| Sand | 35 | 195 |
| Sandy shale | 35 | 230 |
| Sand | 50 | 280 |

Well WR-37-02-701
Owner: South Rusk County Water Supply Corp.
Driller: Frye Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Topsoil, sandy clay, shale | 60 | 60 |
| Blue shale | 320 | 380 |
| Broken shale, blue | 24 | 404 |
| Sand | 34 | 438 |
| Tight shale, blue | 68 | 506 |
| Sand and rocky sand | 4 | 510 |
| Hard shale, some rock | 88 | 598 |

**Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued**

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-37-02-701--Cont. | | |
| Hardpacked sand | 12 | 610 |
| Sand, shale, ha~dpackec | 74 | 684 |
| Sand | 70 | 754 |
| Shale | 86 | 840 |
| Hardpacked sand | 30 | 870 |
| Streaky sand and shale | 90 | 960 |
| Good sand | 110 | 1,070 |
| Shale | 5 | 1,075 |

Well WR-37-03-202
Owner: Mount Enterprise Water Supply Corp. No. 3
Driller: Key Drilling Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sand | 126 | 126 |
| Shale | 18 | 144 |
| Sand | 10 | 154 |
| Sandy shale | 48 | 202 |
| Sand | 36 | 238 |
| Shale | 72 | 310 |
| Sand | 50 | 360 |
| Sandy shale | 54 | 414 |
| Sand | 60 | 474 |
| Sandy shale | 10 | 484 |

Well WR-37-04-401
Owner: Arlam-Concord Water Supply Corp. "A"
Driller: Triangle Pump & Supply Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sand and clay | 20 | 20 |
| Sandy shale, clay | 26 | 46 |
| Rock, red | 3 | 49 |
| Rock | 54 | 103 |
| Lignite | 25 | 128 |
| Sand | 32 | 160 |
| Shale | 38 | 198 |
| Rock | 1 | 199 |
| Shale and sand streaks | 101 | 300 |

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-37-04-401--Cont. | | |
| Sand, fine, white, gray | 170 | 470 |
| Shale | 30 | 500 |
| Sand | 20 | 520 |
| Shale | 20 | 540 |
| Sand, fine, white | 20 | 560 |
| Shale, black and dark blue | 65 | 625 |

Well WR-37-04-601
Owner: Fred Anderson
Driller: Allen Lumber Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Red clay | 3 | 3 |
| Gray clay | 4 | 7 |
| Brown shale | 13 | 20 |
| Gray shale | 37 | 57 |
| Dark sand | 3 | 60 |
| Shale | 3 | 63 |
| Dark sand | 7 | 70 |
| Shale | 13 | 83 |
| White sand | 17 | 100 |
| Shale | 80 | 180 |
| Sand | 9 | 189 |
| Shale | 29 | 218 |
| Sand stringers | 44 | 262 |
| Sand | 23 | 285 |
| Sand stringers | 25 | 310 |
| Shale | 5 | 315 |

Well WR-37-11-103
Owner: Atlantic Pipeline Co.
Driller: Layne-Texas Co.

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Sand | 3 | 3 |
| Clay | 22 | 25 |
| Blue shale | 45 | 70 |
| Rock | 1 | 71 |
| Shale | 23 | 94 |

# Table 9.--Drillers' Logs of Selected Wells in Rusk County--Continued

| | Thickness (feet) | Depth (feet) |
|---|---|---|
| Well WR-37-11-103--Cont. | | |
| Rock | 3 | 97 |
| Blue shale, hard streaks, sand and ligrite | 100 | 197 |
| Hard shale | 73 | 270 |
| Shale | 54 | 324 |
| Rock | 1 | 325 |
| Shale | 47 | 372 |
| Sand | 23 | 395 |
| Well WR-37-12-302<br>Owner: Arlam-Concord Water Supply Corp.<br>Driller: Triangle Pump & Supply Co. | | |
| Clay and sand | 7 | 7 |
| Sand, white, fine | 63 | 70 |
| Sandy shale | 40 | 110 |
| Shale | 20 | 130 |
| Sand, real fine, white | 90 | 220 |
| Sand streaks and sandy shale | 50 | 270 |
| Sand, coarse gray and white | 60 | 330 |
| Shale | 40 | 370 |
| Sand | 60 | 430 |
| Sand and shale streaks | 178 | 608 |

## Table 12.--Concentrations of Metals and Trace Elements in Water From Wells and Springs in Rusk County

(in micrograms per liter)

| Well | Depth or producing interval (feet) | Date | Dis-solved arsenic (As) | Dis-solved barium (Ba) | Dis-solved cadmium (Cd) | Dis-solved chromium (Cr) | Dis-solved copper (Cu) | Dis-solved lead (Pb) | Dis-solved lithium (Li) | Dis-solved mercury (Hg) | Dis-solved selenium (Se) | Dis-solved silver (Ag) | Dis-solved zinc (Zn) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WR-35-41-703 | 240-330 | 8-23-83 | 1 | 5 | <1 | <10 | 10 | 2 | 24 | 0.7 | <1 | <1 | 8 |
| 807 | 745-800 | 8-23-83 | 1 | 16 | <1 | <10 | 1 | 2 | 24 | .7 | <1 | <1 | 5 |
| 808 | 436-583 | 8-23-83 | -- | -- | -- | -- | -- | -- | 19 | -- | -- | -- | -- |
| 44-701 | 555 | 8-24-83 | -- | -- | -- | -- | -- | -- | 34 | -- | -- | -- | -- |
| 50-502 | 292-364 | 8-22-83 | -- | -- | -- | -- | -- | -- | 19 | -- | -- | -- | -- |
| 801 | 531-611 | 8-22-83 | -- | -- | -- | -- | -- | -- | 20 | -- | -- | -- | -- |
| 57-406 | Spring | 8-23-83 | <1 | 67 | 8 | 60 | 40 | 28 | 19 | <.1 | <1 | <1 | 300 |
| 37-02-904 | Spring | 8-25-83 | 1 | 38 | 3 | <10 | 1 | 13 | -- | .1 | <1 | <1 | 17 |
| 03-202 | 484 | 8-26-83 | <1 | 170 | <1 | <10 | <1 | 1 | 21 | .01 | <1 | <1 | 9 |