

Report 305

# Ground-Water Resources of the Nacatoch Aquifer

April 1988



**Texas Water Development Board**



**TEXAS WATER DEVELOPMENT BOARD**

**REPORT 305**

**GROUND-WATER RESOURCES OF  
THE NACATOKH AQUIFER**

**By**

**John B. Ashworth, Geologist**

**April 1988**

# TEXAS WATER DEVELOPMENT BOARD

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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 Development Board. To minimize delays in producing these publications, references to the Department will not be altered except on their covers and title pages.**

## ABSTRACT

The Nacatoch aquifer occurs along a narrow band in northeast Texas and yields small to moderate quantities of ground water. The formation is comprised of sequences of sand separated by impermeable layers of mudstone. Three areas in Texas have been identified as deltaic complexes and are characterized by a substantial increase in net sand thickness. Faulting along the Mexia-Talco system has a significant effect on the occurrence of ground water. Depth to the water-bearing sand, ground-water movement, quality, and quantity are often controlled by the faults. Annual effective recharge to the Nacatoch aquifer is estimated to be 3,030 acre-feet which is derived from about one-half of one percent of the precipitation falling on the outcrop. Heavy pumpage from the Nacatoch results in water-level declines because of the aquifer's low transmissivity. Regional areas of water-level decline occur around the city of Commerce in Hunt and Delta Counties, and in southern Red River County. Total water pumped from the aquifer has declined in recent years as many users are converting to surface-water sources. The quality of Nacatoch ground water is generally alkaline, high in sodium bicarbonate, and soft. In areas where the Nacatoch occurs as multiple sand layers, the upper layer contains the best quality water. The water quality is generally acceptable for most uses except irrigation due to high SAR and RSC values.

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Hopkins	91	93	95	96	99
Hunt	101	106	108	109	111
Kaufman	113	115	117	118	119
Navarro	121	123	125	126	127
Rains	—	129	—	—	131
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# GROUND-WATER RESOURCES OF THE NACATOCH AQUIFER

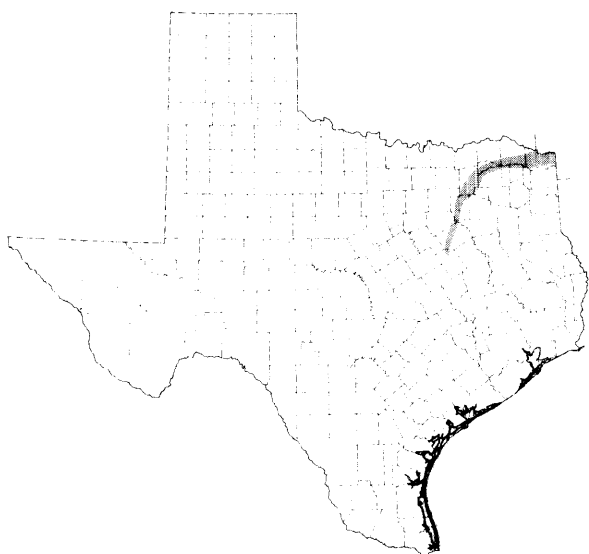
## INTRODUCTION

### Purpose and Scope

The purpose of the study was to describe the hydrologic characteristics of the Nacatoch aquifer in northeast Texas. This included the determination of the occurrence, availability, quality, and quantity of ground water from the Nacatoch Formation of Cretaceous age. The study was initiated in May of 1982.

Principal objectives included: (a) determination of areal extent; (b) determination of quantity and quality of available ground water; (c) collection and evaluation of previously compiled geologic and hydrologic data; (d) determination of areas undergoing continuous ground-water depletion; and (e) determination of average annual recharge to the aquifer.

A secondary objective of the study was to describe the hydrological variances within the framework of the deltaic depositional complex of the Nacatoch Formation.



**Figure 1.—Location of Study Area**

### Location and Extent

The study area, shown in Figure 1, covers a narrow strip in northeast and north-central Texas that subparallels the Mexia-Talco fault zone. It extends westward from the Texas-Arkansas border at Texarkana to approximately the city of Commerce in Hunt County where it then turns south-southwest and extends to approximately the Navarro-Limestone County line. This area represents the Nacatoch Formation outcrop and the downdip extent of the aquifer containing water with a dissolved-solids content of less than 3,000 milligrams per liter.

The areal extent of the study region is approximately 2,500 square miles of which the aquifer's outcrop comprises 835 square miles. The Nacatoch Formation has been delineated on surface geologic maps from the southern extent of the study area northward to approximately

where the outcrop trends eastward at which point the Nacatoch Formation is included as part of the undivided Navarro Group. The study area includes parts of the following counties: Bowie, Delta, Franklin, Henderson, Hopkins, Hunt, Kaufman, Lamar, Navarro, Rains, Red River, Titus, and Van Zandt.

## **Previous Investigations**

The name "Navarro Beds" was first used in 1861 by Shumard (1863) in a description of Cretaceous fossils in the Navarro County area of Texas. "Corsicana Beds" was given to a more sandy basal part of the Navarro in Texas by Hill (1901), which probably included the Nacatoch Formation. Veatch (1906) first used the name Nacatoch Sand in Arkansas to describe a series of sandy beds above the Marlbrook Marl. Nacatoch replaced the less definitive term "Washington Greensand" formerly used by Hill (1888). Dane and Stephenson (1928), Dane (1929), and Sellards and others (1932), further defined the position of the Nacatoch within the Navarro Group in Texas and Arkansas. More recent stratigraphic studies that emphasize the deltaic mode of deposition include McGowen and Lopez (1983) and Knight (1984). Several reports concerned with the structural relationship of the Nacatoch Formation within the East Texas Basin are also listed in the selected references.

A number of ground-water investigations have been published by the Texas Department of Water Resources that deal with the geohydrology of the Nacatoch aquifer in certain areas. Local water availability studies have been conducted for the Commerce and Greenville areas by Broadhurst (1944), Rose (1945) and Baker (1971).

Geologic mapping of the Nacatoch in the study area is best presented on the Dallas, Sherman, Texarkana, and Waco Geologic Atlas Sheets published by the University of Texas, Bureau of Economic Geology. The geologic base map for this report is adapted from these sheets.

## **Acknowledgements**

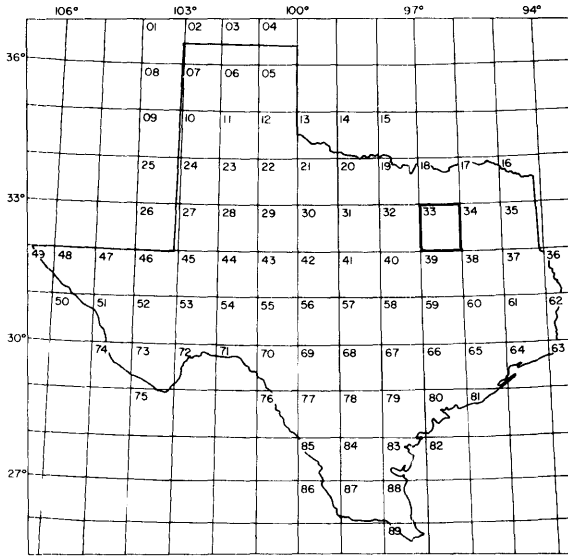
The author wishes to thank the property owners within the study region for their cooperation in providing information concerning their wells and allowing access to their wells to measure water levels and to take samples for chemical quality. Appreciation is also extended to the city officials who furnished information concerning their municipal water-supply systems and allowed access to their wells. Special thanks are given to the State Department of Highways and Public Transportation and to East Texas State University for allowing test holes to be drilled on highway right-of-way and university property. Recognition is extended to Michael T. Knight for his analysis of cores from the test holes and for his aid in interpreting the geologic framework of the Nacatoch Formation. Appreciation is also expressed to Richard Preston and Phillip Nordstrom for reviewing the manuscript and suggesting improvements.

Field work involved in collecting the basic data for this report was performed by the author and assisted by John Derton of the Texas Department of Water Resources. General direction in the preparation of this report was furnished by Tommy R. Knowles, Director of the Department's Data and Engineering Services Division, and Henry Alvarez, Chief of the Data Collection and Evaluation Section.

# Well-Numbering System

The well-numbering system in this report, illustrated on Figure 2, was adopted by the Texas Department of Water Resources for statewide use. It is designed to identify, facilitate the location of, and avoid duplication of well numbers in present and future studies. The system is based upon the division of the State into quadrangles of latitude and longitude and the repeated division of these quadrangles into smaller ones.

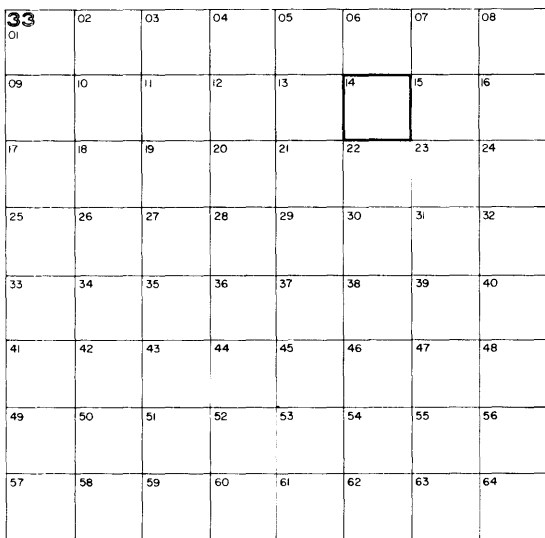
The State is first divided into one-degree quadrangles which are numbered 01 through 89. Each one-degree quadrangle is then subdivided into sixty-four 7½-minute quadrangles. And lastly, each 7½-minute quadrangle is subdivided into nine 2½-minute quadrangles. Within each 2½-minute quadrangle, each well is assigned a two-digit number in the sequence inventoried, beginning with 01; these are the last two digits of the well number.



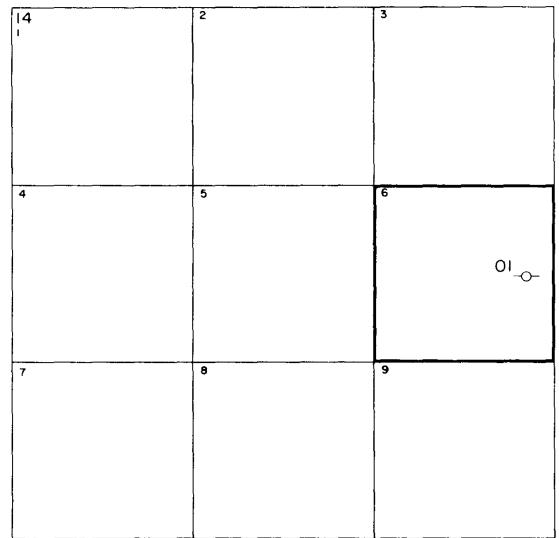
1 - degree Quadrangles

Location of Well RA-33-14-601

- 33** 1 - degree quadrangle
- 14 7 1/2 - minute quadrangle
- 6 2 1/2 - minute quadrangle
- 01 Well number within 2 1/2 - minute quadrangle



7 1/2 - minute Quadrangles



2 1/2 minute Quadrangles

**Figure 2.—Well-Numbering System**

Each well is assigned a seven-digit number. The first two digits of a well number identify the one-degree quadrangle in which the well is located. The second two digits identify the 7½-minute quadrangle. The fifth digit identifies the 2½-minute quadrangle and the sixth and seventh digits identify the particular well within the 2½-minute quadrangle.

In addition to the seven-digit number, a two-letter prefix is used to identify the county. The prefixes for the 12 counties covered by this report are:

<u>Prefix</u>	<u>County</u>	<u>Prefix</u>	<u>County</u>
BD	Bowie	RA	Kaufman
HU	Delta	TY	Navarro
JZ	Franklin	UX	Rains
LT	Henderson	WB	Red River
LZ	Hopkins	YA	Titus
PH	Hunt	YS	Van Zandt

## Metric Conversions

For those readers interested in using the International System (SI) of units, factors for converting inch-pound units to metric equivalents are given in the following table:

<u>From</u>	<u>Multiply by</u>	<u>To obtain</u>
acres	0.4047	square hectometers (hm <sup>2</sup> )
acre-feet (acre-ft)	.001233	cubic hectometers (hm <sup>3</sup> )
feet (ft)	.3048	meters (m)
feet per day (ft/d)	.3048	meters per day (m/d)
feet per mile (ft/mi)	.189	meters per kilometer (m/km)
gallons (gal)	3.785	liters (l)
gallons per minute (gal/min)	.06309	liters per second (l/s)

<u>From</u>	<u>Multiply by</u>	<u>To obtain</u>
gallons per minute per foot [(gal/min)/ft]	.207	liters per second per meter [(1/s)/m]
inches (in)	2.54	centimeters (cm)
miles (mi)	1.609	kilometers (km)
square feet per day (ft <sup>2</sup> /d)	.0929	square meters per day (m <sup>2</sup> /d)
square miles (mi <sup>2</sup> )	2.590	square kilometers (km <sup>2</sup> )

To convert degrees Fahrenheit to degrees Celsius use the following formula:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) (0.556)$$

### **Definitions of Terms**

For convenience and clarification, certain technical terms used in this report are defined as follows:

***Aquifer***—A geologic formation, group of formations, or part of a formation that is water bearing.

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

***Artesian aquifer, confined aquifer***—Artesian (confined) water occurs where an aquifer is overlain by rock of lower permeability (such as clay) that confines the water under pressure greater than atmospheric. The water level in an artesian well will rise above the top of the aquifer even without pumping.

***Bioturbation***—The churning and stirring of a sediment by organisms.

***Clastic***—Rock composed of fragmental material derived from pre-existing rocks or from the dispersed consolidation products of magmas or lavas. The most common clastics are sandstones and shales.

***Coefficient of storage***—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.

**Cone of depression-** Depression of the water table or potentiometric surface surrounding a discharging well, more or less the shape of an inverted cone.

**Confining bed-**One which, because of its position and its impermeability or low permeability relative to that of the aquifer, keeps the water in the aquifer under artesian pressure.

**Contact-**The place or surface where two different kinds of rock or geologic units come together, shown on both maps and cross sections.

**Deltaic deposits-**Sediments deposited at the mouth of a river.

**Dip of rocks or attitude of beds-**The angle or amount of slope at which a bed is inclined from the horizontal; direction is also expressed (for example, one degree west or 90 feet per mile west).

**Dissolved solids-**A measure of the total concentration of dissolved material in water. Widely used in evaluating water quality and comparing waters with one another.

**Effective recharge-**The amount of water that enters an aquifer and is available for development.

**Electric log-**A graph log showing the relation of 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.

**Fault-**A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture.

**Formation-**A body of rock that is sufficiently homogeneous or distinctive to be regarded as a mappable unit, usually named from a locality where the formation is typical.

**Ground water-**Refers to water in that area below land surface in which all pore spaces and voids are filled with water (called the zone of saturation) and from which wells, springs, and seeps are supplied.

**Hydraulic conductivity-**The volume of water that will flow in 1 day through a cross sectional area of 1 square foot under unit hydraulic gradient (1 foot of fall for each foot of lateral movement). It is measured in feet, or meters, per day. Also called the coefficient of permeability which is measured in gallons per day per square foot. Multiply hydraulic conductivity values by 7.48 to convert to coefficient of permeability values.

**Hydraulic gradient-**The slope of the water table or potentiometric surface, usually given in feet per mile.

**Hydrograph-**A graph or line plot showing the fluctuation of the water level in a well over a period of time.

**Outcrop-**That part of a rock layer which appears at the land surface.



**Perched ground water**-Ground water separated from an underlying body of ground water by unsaturated rock. Its water table is a perched water table.

**Percolation**-The movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as caves.

**Permeable**-Pervious or having a texture that permits water to move through it perceptibly under the head differences ordinarily found in subsurface water. A permeable rock has communicating interstices of capillary or supercapillary size.

**Potentiometric surface**-The imaginary surface to which water will rise in artesian wells, or the surface formed by the water table in the outcrop areas. The terms "water table" and "potentiometric surface" are synonymous in the outcrop area, but potentiometric surface alone is applicable in artesian areas. Also called piezometric surface, a term which has been used by many in the past.

**Recharge of ground water**-The process by which water is absorbed and is added to the zone of saturation. Also used to designate the quantity of water that is added to the zone of saturation, usually given in acre-feet per year or in million gallons per day.

**Recoverable storage**-That portion of underground reservoir capacity estimated as capable of being economically and physically withdrawn from an aquifer.

**Specific capacity**-The discharge of a well expressed as the rate of yield per unit of drawdown, generally in gallons per minute per foot of drawdown. If the yield is 250 gallons per minute and the drawdown is 10 feet, the specific capacity is 25 gallons per minute per foot.

**Structural feature, geologic**-The result of the deformation or dislocation (such as faulting) of the rocks in the earth's crust. In a structural basin, the rock layers dip toward the center or axis of the basin. The structural basin may or may not coincide with a topographic basin.

**Transmissivity**-The rate at which water will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity. It is the product of the hydraulic conductivity and the saturated thickness of the aquifer. It is also called the coefficient of transmissibility which is measured in gallons per day per foot. Multiply transmissivity values by 7.48 to convert to coefficient of transmissibility values.

**Water level**-Depth to water, in feet below the land surface, where the water occurs under water table conditions (or depth to the top of the zone of saturation). Under artesian conditions the water level is a measure of the pressure in the aquifer, and the water level may be at, below, or above the land surface.

**Water-table aquifer (unconfined aquifer)**-An aquifer in which the water is unconfined; the upper surface of the zone of saturation is under atmospheric pressure only and the water is free to rise or fall in response to the changes in the volume of water in storage. A well penetrating an aquifer under water table conditions becomes filled with water to the level of the water table.

**Yield of a well**-The rate of discharge, commonly expressed as gallons per minute, gallons per day, or gallons per hour.

## **GEOGRAPHIC SETTING**

### **Physiography**

The study area extends over three physiographic subdivisions based on soil type and vegetation (Dallas Morning News, 1981). The eastern portion of Bowie County falls within the East Texas Timberlands or "Piney Woods" Belt. This area is heavily forested primarily with pine. From mid-Bowie to mid-Red River County occurs the Claypan-Post Oak Belt characterized by gently rolling woodlands. The remainder of the study area falls within the Blackland Prairies. Treeless rolling prairies dissected by wooded streams characterize this belt.

Four major drainage basins occupy the study area. The Red and Sulphur River basins drain eastward, while the Sabine and Trinity River basins drain toward the southeast. Drainageways typically have shallow valleys and broad floodplains. At the time of the study no major lakes exist on the Nacatoch Formation outcrop, although proposed reservoirs are under consideration in the northern portion of the study area.

The majority of the long narrow strip of Nacatoch outcrop was originally covered by hardwood forests, but have been cleared for cultivation. Much of this cultivated land is now used only for pasture because of the rapidly deteriorating productivity of the soil.

### **Climate**

The Nacatoch study area has a subhumid climate that becomes humid in the far eastern section. Average evaporation exceeds average precipitation over most of the area. The average annual gross lake surface evaporation for the period 1940 through 1965 ranged from approximately 60 inches in the south and west to 47 inches in the east. Normal annual precipitation ranges from 36 inches in the south to 47 inches in the east.

The average annual low temperature ranges from 54°F in the south to 50°F in the east while average annual high temperature ranges from 77°F in the south to 75°F in the east.

The above figures, except evaporation, are based on data collected by the National Oceanic and Atmospheric Administration for the period 1951 through 1980. Evaporation values are based on data collected by the Texas Department of Water Resources. The above ranges in values are illustrated on Figure 3.

## **GEOLOGIC SETTING**

### **Stratigraphy**

The Nacatoch Formation is a unit of the Navarro Group of upper Cretaceous age (Table 1) and, in Texas, crops out along the north and west edge of the East Texas Basin (Figure 4). Units of the Navarro Group are recognized throughout the East Texas Basin and extend eastward into Arkansas and Louisiana where they can be correlated with the Arkadelphia Marl, Nacatoch Sand,

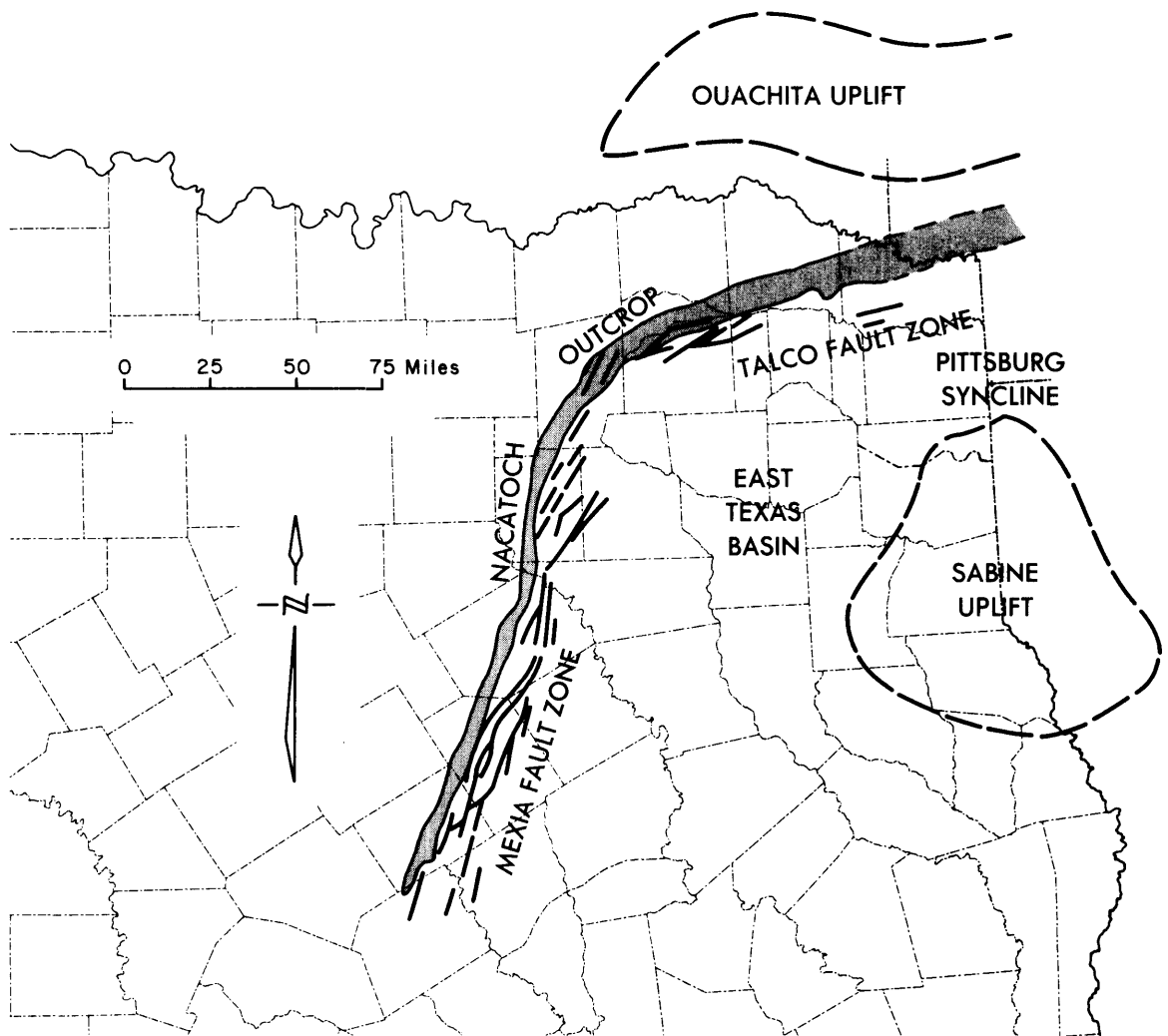
**Table 1.—Stratigraphic Units and Their Water-Bearing Properties**

System	Series	Group	Stratigraphic unit	Approximate maximum thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Recent		Alluvium	80	Sand, silt, clay, and gravel.	Yields small to moderate quantities of fresh to slightly saline water.
Cretaceous	Gulf	Navarro	*Upper Navarro Clay **(Kemp Clay)	400	Clay, calcareous, silty, medium-dark gray.	Not known to yield water.
			*Upper Navarro Marl **(Corsicana Marl)	20	Mudstone, sandy and hard calcareous sandstone and siltstone.	Not known to yield water.
			Nacatoch Formation **(Nacatoch Sand)	450	Alternating sequences of fine-grained quartz sand and mudstone.	Yields small to moderate quantities of fresh to slightly saline water near the outcrop.
			*Lower Navarro Formation **(Neylandville Marl)	125	Clay, calcareous, silty, sandy, medium-gray.	Not known to yield water.
		Taylor	Marlbrook Pecan Gap Wolf City	1,500	Clay, marl, mudstone, and chalk.	Not known to yield water.

\* Stratigraphic nomenclature from Wood and Guevara (1981).

\*\* Surface stratigraphic nomenclature.

Yield of wells: small, less than 100 gal/min (gallons per minute) and moderate, 100-1,000 gal/min.



**Figure 4.—Regional Structure and Generalized Geologic Outcrop**

and Saratoga Chalk. The Nacatoch Sand in Arkansas is also a fresh-water aquifer (Counts and others, 1955).

The Upper Navarro Marl is a relatively thin layer, less than 20 feet thick, which overlies the Nacatoch Formation in most of the study area. It consists of sandy mudstone or hard, calcareous sandstone and siltstone (McGowen and Lopez, 1983). This unit is often included with the Nacatoch Formation for subsurface mapping purposes because of similar traits displayed on geophysical logs.

The Nacatoch Formation in Texas is comprised of sequences of sandstone and mudstone. Sandstone layers consist predominantly of rounded, moderately sorted to well sorted, fine-grained sand and silt which is moderately consolidated to unconsolidated with occasional thin, calcite-cemented layers. Original sedimentary structures are rare as a result of post depositional disturbance by burrowing marine fauna. The sands are various shades of gray in the subsurface but, when exposed at the surface, are more commonly light-brown to yellow and often streaked with purple and orange. The mineralogical composition of cores taken from test holes drilled by

the Department showed mostly quartz grains with lesser amounts of feldspar, chert particles, and glauconite (Knight, 1984).

Knight (1984) identified five major sequences coarsening upward that can be correlated laterally, though discontinuously, along strike for up to 162 miles (See Figures 16 through 18). Grain-size analysis of the cores taken in the sandy layers showed a distinct coarsening upward (Figures 25 through 29). This trend may be due more to a decrease in percentage of silt and clay upward than to an actual increase in maximum sand particle size. The top of each sand section generally represents an erosional surface and forms a sharp contact with the overlying mudstone. The mudstone, in turn, coarsens gradationally upward into the next sand layer. Average grain size and net-sand thickness decrease in the southern part of the study area. Figure 5 shows the approximate altitude of and depth to the top of the Upper Navarro Marl, or if not present, the Nacatoch Formation. The approximate altitude of and depth to the base of the lowest Nacatoch sand interval, but not the formation, is shown on Figure 6.

Mudstone layers separating the sand intervals are generally dark gray, fossiliferous, and very bioturbated with thicknesses often in excess of 100 feet. The mudstones act as confining beds which prevent subsurface mixing of water from the various sand layers. Each sand layer thus represents a separate hydrologic unit. Geophysical logs and grain-size analysis results from five test holes drilled through the Nacatoch Formation are displayed in Figures 25 through 29 and illustrate the alternating sequences of sandstone and mudstone.

A mantle of alluvium often covers the Nacatoch along drainageways that cross the outcrop (Figure 4). The alluvium is generally floodplain and terrace deposits consisting of sand, silt, and clay. Alluvial deposits that are in contact with Nacatoch sand layers in the subsurface often form excellent recharge sites because of their high permeability. A large portion of northern Bowie County is covered by up to 80 feet of alluvium which contains moderate quantities of usable ground water.

## **Depositional System**

The Navarro Group represents the final deposition of Cretaceous sediments into the East Texas Basin. The Nacatoch Formation, which was deposited during a minor influx of terrigenous clastics, is sandwiched between the marine clays of the Upper and Lower Navarro Formations. Nacatoch sediments occurring along the north and west margin of the basin were derived from the northwest, north, and northeast. The Ouachita Mountains of southeast Oklahoma and southwest Arkansas were the most probable primary source area (Knight, 1984).

Knight (1984) identifies five major facies in the Nacatoch in Texas based on geometry, lithology, sedimentary structures, and fossil content which describe a deltaic depositional system characterized by moderate sediment input and influenced by wave action and longshore currents. The five facies include shoreface, delta-abandonment, reworked delta front, channel-fill, and shelf. Back-bay facies and fluvial feeder systems that would geographically occur updip of the existing sands have been eroded away.

An increase in net sand thickness as shown on the net sand thickness map (Figure 7) and geologic sections A-A', A'-A'', and A''-A''' (Figures 16, 17, and 18) indicates the presence of three

areas of sediment input in Texas. The locations of the geologic sections are shown on Figure 15. The three areas of increased net sand thickness occur in: (1) southern Red River County; (2) eastern Hunt-southwestern Delta-western Hopkins Counties; and (3) southern Hunt County. Reworked delta front and shoreface deposits are the prominent facies represented in these areas. Because of greater sand thickness and porosity, these areas contain as much as 80 percent of the usable-quality water in the aquifer. A fourth area of input and subsequent accumulation occurs in southern Bowie and Cass Counties where sand was transported through the Pittsburg syncline (Figure 4) from sources to the east and deposited in an area of greater subsidence (McGowen and Lopez, 1983). Ground water from the Nacatoch in this area is of poor quality.

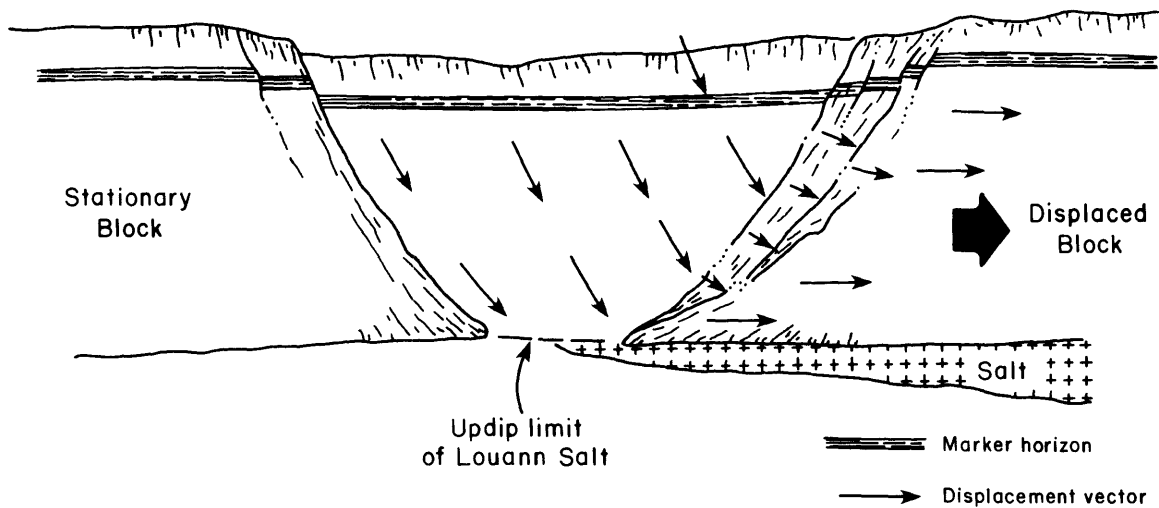
Between the deltas, the Nacatoch consists predominantly of bioturbated sandy muds and thin sand layers characteristic of strandplain and barrier island sandstones (Knight, 1984). In Kaufman and Navarro Counties and downdip from the delta complexes, the Nacatoch is recognized as a fossiliferous shelf sand. The Nacatoch aquifer is very limited in these areas.

Near the central axis of the East Texas Basin, which is outside of the study area, net sand thicknesses of as much as 280 feet have accumulated in depressions, or synclines, formed around the periphery of salt domes. Elongate, laterally discontinuous, offshore sand bars have net sand thicknesses in excess of 100 feet (McGowen and Lopez, 1983). These features can be identified in Figure 7 and contain highly saline water.

## Structure

Geologic structures affecting ground water in the Nacatoch aquifer include the East Texas Basin and the Mexia-Talco fault zone (Figure 4). The Nacatoch Formation crops out in Texas along the north and west margin of the East Texas Basin and dips toward the central axis of the basin. The basin has been a negative structural feature since late Triassic time and is filled with alternating sequences of transgressive marine deposits and regressivefluvial-deltaic sandstones and shales.

The basinward dip of the Nacatoch Formation is interrupted by the Mexia-Talco fault zone, which occurs near the north and west boundary of the basin. Faulting within the zone consists of strike oriented normal faults which often form grabens. According to Jackson (1982), the geometry of the faults is likely the result of basinward creep of overlying strata as the underlying Louann Salt was being displaced (Figure 8). Although movement along the faults occurred intermittently during the Mesozoic and early Tertiary, little movement occurred during the deposition of the Navarro Group (Hager and Burnett, 1960). Faults shown in Figure 5 are mapped surface fault traces. Numerous additional faults are recognized in the subsurface (GEOMAP Company, 1980). The faulting usually causes the normal downdip flow of ground water to be halted or diverted. Chemical quality of ground water is often different on opposing sides of fault planes. The fault system also resulted in the formation of hydrocarbon traps in sand units that terminate updip against the faults.



**Figure 8.—Conceptual Model of the Origin of the Mexia-Talco Fault Zone  
(From Jackson, 1982)**

## GENERAL CHEMICAL QUALITY OF GROUND WATER

All ground water contains minerals carried in solution, the type and concentration of which depend upon the environment, movement, and source of the ground water. Rainfall is relatively free of minerals until it comes in contact with the various constituents which make up the soil and component rocks of the aquifer; then, as a result of the solvent power of water, minerals are dissolved and carried into solution as the water passes through the aquifer. The concentration depends upon the solubility of the minerals present, the length of time the water is in contact with the rocks, and the amount of dissolved carbon dioxide in the water. In addition, concentration of dissolved minerals in ground water generally increases with depth and especially increases where circulation has been restricted due to faulting or zones of lower permeability. Restricted circulation retards the flushing action of fresh water moving through the aquifers, causing the water to become highly mineralized. The source, significance, and range in concentration of dissolved carbon dioxide in the water. In addition, concentration of dissolved mineral constituents and properties of natural waters are given in Table 2.

The degree and type of mineralization of ground water determines its suitability for municipal, industrial, irrigation, and other uses. Several criteria for water-quality requirements have been developed through the years which serve as guidelines in determining the suitability of water for various uses. Subjects covered by the guidelines are bacterial content; physical characteristics, including color, taste, odor, turbidity, and temperature; and chemical constituents. Water-quality problems associated with the first two subjects can usually be alleviated economically. The neutralization or removal of most of the unwanted chemical constituents is usually difficult and often very costly.

Total dissolved-solids content is usually the main factor which limits or determines the use of ground water. Winslow and Kister (1956) used an applicable, general classification of waters

**Table 2.—Source, Significance, and Range in Concentration of Dissolved-Mineral Constituents and Properties of Water**

(Adapted from Doll and others, 1963, p. 39-43)

Only analyses which were representative of native ground water were used. Analyses are in milligrams per liter except percent sodium, specific conductance, pH, and SAR.

Constituent or property	Source or cause	Significance	Range in concentration of Nacatoch water
Silica (SiO <sub>2</sub> )	Dissolved from practically all rocks and soils, commonly less than 30 mg/l. High concentrations, as much as 100 mg/l, generally occur in highly alkaline waters.	Forms hard scale in pipes and boilers. Carried over in steam of high pressure boilers to form deposits on blades of turbines. Inhibits deterioration of zeolite-type water softeners.	5 — 91
Iron (Fe)	Dissolved from practically all rocks and soils. May also be derived from iron pipes, pumps, and other equipment.	On exposure to air, iron in ground water oxidizes to reddish-brown precipitate. More than about 0.3 mg/l stain laundry and utensils reddish-brown. Objectionable for food processing, textile processing, beverages, ice manufacture, brewing, and other processes. Texas Department of Health (1977) drinking water standards state that iron should not exceed 0.3 mg/l. Larger quantities cause unpleasant taste and favor growth of iron bacteria.	—
Calcium (Ca) and Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum. Calcium and magnesium are found in large quantities in some brines. Magnesium is present in large quantities in sea water.	Cause most of the hardness and scale-forming properties of water; soap consuming (see hardness). Waters low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing.	1 — 382 0 — 40
Sodium (Na) and Potassium (K)	Dissolved from practically all rocks and soils. Found also in oil-field brines, sea water, industrial brines, and sewage.	Large amounts, in combination with chloride, give a salty taste. Moderate quantities have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers and a high sodium content may limit the use of water for irrigation.	9 — 1,076 0.1 — 31.0
Bicarbonate (HCO <sub>3</sub> ) and Carbonate (CO <sub>3</sub> )	Action of carbon dioxide in water on carbonate rocks such as limestone and dolomite.	Bicarbonate and carbonate produce alkalinity. Bicarbonates of calcium and magnesium decompose in steam boilers and hot water facilities to form scale and release corrosive carbon-dioxide gas. In combination with calcium and magnesium, cause carbonate hardness.	17 — 886 0 — 60
Sulfate (SO <sub>4</sub> )	Dissolved from rocks and soils containing gypsum, iron sulfides, and other sulfur compounds. Commonly present in some industrial wastes.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Texas Department of Health (1977) drinking water standards recommend that the sulfate content should not exceed 300 mg/l.	0 — 1,422
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and found in large amounts in oil-field brines, sea water, and industrial brines.	In large amounts in combination with sodium, gives salty taste to drinking water. In large quantities, increases the corrosiveness of water. Texas Department of Health (1977) drinking water standards recommend that the chloride content should not exceed 300 mg/l.	6 — 1,330
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of municipal supplies.	Fluoride in drinking water reduces the incidence of tooth decay when the water is consumed during the period of enamel calcification. However, it may cause mottling of the teeth, depending on the concentration of fluoride, the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132).	0 — 9.8
Nitrate (NO <sub>3</sub> ) or Nitrate (as N)	Decaying organic matter, sewage, fertilizers, and nitrates in soil.	Concentration much greater than the local average may suggest Texas Department of Health (1977) drinking water standards suggest a limit of 44 mg/l (as NO <sub>3</sub> ) or 10 mg/l (as N). Waters of high nitrate content have been reported to be the cause of methemoglobinemia (an often fatal disease in infants) and therefore should not be used in infant feeding (Maxcy, 1950, p. 271). Nitrate shown to be helpful in reducing inter-crystalline cracking of boiler steel. It encourages growth of algae and other organisms which produce undesirable tastes and odors.	0 — 556.7



**Table 2.—Source, Significance, and Range in Concentration of Dissolved-Mineral Constituents and Properties of Water—Continued**

Constituent or property	Source or cause	Significance	Range in concentration of Nacatoch water
Boron (B)	A minor constituent of rocks and of natural waters.	An excessive boron content will make water unsuitable for irrigation. Wilcox (1955, p. 11) indicated that a boron concentration of as much as 1.0 mg/l is permissible for irrigating sensitive crops; as much as 2.0 mg/l for semitolerant crops; and as much as 3.0 mg/l for tolerant crops. Crops sensitive to boron include most deciduous fruit and nut trees and navy beans; semitolerant crops include most small grains, potatoes and some other vegetables, and cotton; and tolerant crops include alfalfa, most root vegetables, and the date palm.	—
Dissolved solids	Chiefly mineral constituents dissolved from rocks and soils.	Texas Department of Health (1977) drinking water standards recommend that waters containing more than 1,000 mg/l dissolved solids not be used if other less mineralized supplies are available. For many purposes the dissolved-solids content is a major limitation on the use of water. A general classification of water based on dissolved-solids content, in mg/l, is as follows (Winslow and Kister, 1956, p. 5): Waters containing less than 1,000 mg/l of dissolved solids are considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine.	77 — 2,703
Hardness as CaCO <sub>3</sub>	In most waters nearly all the hardness is due to calcium and magnesium. All of the metallic cations other than the alkali metals also cause hardness.	Consumes soap before a lather will form. Deposits soap curd on bathtubs. Hard water forms scale in boilers, water heaters, and pipes. Hardness equivalent to the bicarbonate and carbonate is called carbonate hardness. Any hardness in excess of this is called non-carbonate hardness. Waters of hardness up to 60 mg/l are considered soft; 61 to 120 mg/l, moderately hard; 121 to 180 mg/l, hard; more than 180 mg/l, very hard.	2 — 1,008
Percent Sodium (% Na)	Sodium in water.	A ratio (using milliequivalents per liter) of the Sodium ions to the total sodium, calcium, and magnesium ions. A sodium percentage exceeding 60 percent is a warning of a sodium hazard. Continued irrigation with this type of water will impair the tilth and permeability of the soil.	15 — 99
Sodium-adsorption ratio (SAR)	Sodium in water.	A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil (U.S. Salinity Laboratory Staff, 1954, p. 72, 156). Defined by the following equation:	.6 — 102.7
		$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$	
		where Na <sup>+</sup> , Ca <sup>++</sup> , and Mg <sup>++</sup> represent the concentrations in milliequivalents per liter (me/l) of the respective ions.	
Residual sodium carbonate (RSC)	Sodium and carbonate or bicarbonate in water.	As calcium and magnesium precipitate as carbonates in the soil, the relative proportion of sodium in the water is increased (Eaton, 1950, p. 123-133). Defined by the following equation:	0 — 14.2
		$RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++})$	
		where CO <sub>3</sub> <sup>--</sup> , HCO <sub>3</sub> <sup>-</sup> , Ca <sup>++</sup> , and Mg <sup>++</sup> represent the concentrations in milliequivalents per liter (me/l) of the respective ions.	
Specific conductance (micromhos at 25°C)	Mineral content of the water.	Indicates degree of mineralization. Specific conductance is a measure of the capacity of the water to conduct an electric current. Varies with concentration and degree of ionization of the constituents.	115 — 5,576
Hydrogen ion concentration (pH)	Acids, acid-generating salts, and free carbon dioxide lower the pH. Carbonates, bicarbonates, hydroxides, phosphates, silicates, and borates raise the pH.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increasing alkalinity; values lower than 7.0 indicate increasing acidity. pH is a measure of the activity of the hydrogen ions. Corrosiveness of water generally increases with decreasing pH. However, excessively alkaline waters may also attack metals. The Texas Department of Health (1977) recommends a pH greater than 7.	6.2 — 9.2

based on the dissolved-solids concentration in parts per million (ppm). The classification is as follows:

<u>Description</u>	<u>Dissolved-solids content (ppm)</u>
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

In recent years, most laboratories have begun reporting analyses in milligrams per liter (mg/l) instead of ppm. These two units, for practical purposes, are identical until the dissolved-solids concentration of water reaches or exceeds 7,000 units (ppm or mg/l). The concentrations of chemical constituents reported in this report are in mg/l, and since all of the chemical concentrations are below 7,000 mg/l, the units are interchangeable. For more highly mineralized waters, a density correction should be made using the following formula:

$$\text{parts per million} = \frac{\text{milligrams per liter}}{\text{specific gravity of the water}}$$

The property of water known as hardness is associated primarily with reactions of water to soap. As hardness increases so does the soap-consuming ability of water. Since most of these effects result from the presence of calcium and magnesium, hardness is defined quantitatively as the summation of milliequivalents per liter of calcium and magnesium times 50 (Hem, 1970, p. 224), and reported as an equivalent concentration of calcium carbonate (CaCO<sub>3</sub>). This method was used to determine the values listed in Table 8 under the column labeled "Total Hardness as CaCO<sub>3</sub>". The following classification using range of hardness concentration was devised by the U.S. Geological Survey:

<u>Hardness range (mg/l as CaCO<sub>3</sub>)</u>	<u>Description</u>
0 to 60	Soft
61 to 120	Moderately hard
121 to 180	Hard
More than 180	Very hard

For general domestic use, hardness of water is not particularly objectionable until it reaches about 100 mg/l.

When ground water does not meet specific requirements for usage, various methods of treatment can be implemented to alter the chemical composition. Such treatments include softening, aeration, filtration, cooling, dilution, and the addition of chemicals. The type of treatment is dependent on the particular problem; however, the primary limiting factor is economics.

## Public Supply

As the first step in setting national standards for drinking water quality under the provisions of the Safe Drinking Water Act of 1974, the U.S. Environmental Protection Agency (EPA) issued drinking water regulations on December 10, 1975. These standards apply to all of the public water systems of Texas and became effective July 1, 1977. The responsibility for enforcement of these standards was assumed by the Texas Department of Health. Minor revisions of the standards have occurred, the last one becoming effective on November 29, 1980.

As defined by the Texas Department of Health, municipal systems are classified as follows:

1. A "public water system" is any system for the provision to the public of piped water for human consumption, if such a system has at least 15 service connections or regularly serves an average of at least 25 individuals daily at least 60 days out of the year.
2. A "community water system" is a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.
3. A "non-community water system" is any public water system which is not a community water system.

Standards which relate to municipal supplies are of two types: (1) primary and (2) secondary. Primary standards are devoted to constituents and regulations affecting the health of consumers. Secondary standards are those which deal with the esthetic qualities of drinking water. Contaminants for which secondary maximum contaminant levels are set in these standards do not have a direct impact on the health of the consumers, but their presence in excessive quantities may discourage the use of the water.

### Primary Standards

Primary standards for dissolved minerals apply to community water systems and are as follows:

<u>Contaminant</u>	<u>Maximum concentration (mg/l)</u>
Arsenic (As)	0.05
Barium (Ba)	1.0

<u>Contaminant</u>	<u>Maximum concentration (mg/l)</u>
Cadmium (Cd)	.010
Chromium (Cr <sup>6</sup> )	.05
Lead (Pb)	.05
Mercury (Hg)	.002
Selenium (Se)	.01
Silver (Ag)	.05
Nitrate (as N)	10

Except for nitrate content, none of the above contaminant levels for toxic minerals applies to non-community water systems. The maximum of 10 mg/l nitrate as nitrogen (44.3 mg/l nitrate as NO<sub>3</sub>) applies to community and non-community systems alike. Water having an excess concentration of nitrate poses a potential health hazard. A high concentration of nitrate is an indication of organic decomposition, usually within the source well. Steps should be taken to identify and rectify the source of contamination.

Maximum fluoride concentrations are applicable to community water systems and vary with the annual average of the maximum daily air temperature at the location of the system. These are shown in the following tabulation:

<u>Temperature (°F)</u>	<u>Temperature (°C)</u>	<u>Maximum concentration (mg/l)</u>
63.9 to 70.6	17.7 to 21.4	1.8
70.7 to 79.2	21.5 to 26.2	1.6
79.3 to 90.5	26.3 to 32.5	1.4

Maximum contaminant limits for organic chemicals, as specified, apply to community water systems and are as follows:

<u>Constituent</u>	<u>Maximum concentration (mg/l)</u>
1. Chlorinated hydrocarbons: Endrin (1, 2, 3, 4, 10, 10-hexachloro-6, 7-epoxy-1, 4, 4a, 5, 6,	

<u>Constituent</u>	<u>Maximum concentration (mg/l)</u>
7, 8, 8a-octahydro-1, 4-endo, endo-5, 8-dimethano naphthalene).	0.0002
Lindane (1, 2, 3, 4, 5, 6-hexachloro-cyclohexane, gamma isomer).	.004
Methoxychlor (1, 1, 1-Trichloro-2, 2-bis [p-methoxyphenyl] ethane).	.1
Toxaphene (C <sub>10</sub> H <sub>10</sub> Cl <sub>8</sub> -Technical chlorinated camphene, 67-69 percent chlorine).	.005
<b>2. Chlorophenoxys:</b>	
2, 4-D (2, 4-Dichlorophenoxyacetic acid).	.1
2, 4, 5-TP Silvex (2, 4, 5-Trichloro-phenoxypropionic acid).	.01

Maximum levels for coliform bacteria, as specified by the Texas Department of Health, apply to community and non-community water systems. The limits specified are basically the same as in the 1962 U.S. Public Health Service Standards which have been widely adopted in most states.

In addition to the previously stated requirements, there are also stringent rules regarding general sampling and the frequency of sampling which apply to all public water systems. Additionally, community water systems are subject to rigid radiological sampling and analytical requirements.

### Secondary Standards

Recommended secondary standards applicable to all public water systems are given in the following table:

<u>Constituent</u>	<u>Maximum level</u>
Chloride (Cl)	300 mg/l
Color	15 color units

<b>Constituent</b>	<b>Maximum level</b>
Copper (Cu)	1.0 mg/l
Corrosivity	non-corrosive
Foaming agents	.5 mg/l
Hydrogen sulfide (H <sub>2</sub> S)	.05 mg/l
Iron (Fe)	.3 mg/l
Manganese (Mn)	.05 mg/l
Odor	3 Threshold Odor Number
pH	>7.0
Sulfate (SO <sub>4</sub> )	300 mg/l
Dissolved solids	1,000 mg/l
Zinc (Zn)	5.0 mg/l

The above secondary standards are recommended limits, except for water systems which are not in existence as of the effective date of these standards. For water systems which are constructed after the effective date, no source of supply which does not meet the recommended secondary standards may be used without written approval by the Texas Department of Health. The determining factor will be whether or not there is an alternate source of supply of acceptable chemical quality available to the area to be served.

After July 1, 1977, for all instances in which drinking water does not meet the recommended limits and is accepted for use by the Texas Department of Health, such acceptance is valid only until such time as water of acceptable chemical quality can be made available at reasonable cost to the area in question from an alternate source. At such time, either the water which was previously accepted would have to be treated to lower the constituents to acceptable levels, or water would have to be secured from the alternate source.

### **Domestic and Livestock**

Ideally, water used for domestic purposes should be as free of contaminants as those used for municipal purposes; however, this is not always economically possible. At present, there are no controls placed on private domestic or livestock wells. In general, the chemical constituents of waters used for domestic purposes should not exceed the concentrations shown in the following

table, except in those areas where more suitable supplies are not available (the primary standard for nitrate should still be adhered to):

<u>Constituent</u>	<u>Concentration (mg/l)</u>
Chloride (Cl)	300
Fluoride (F)	1.4*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (as N)	10
Nitrate (NO <sub>3</sub> )	45
Sulfate (SO <sub>4</sub> )	300
Dissolved solids	1,000

\*Maximum fluoride limit based on annual average of maximum daily air temperature range of 79.3—90.5°F. (After Texas Department of Health, 1977.)

Supplies which do not meet these standards have been used for long periods of time without any apparent ill effects to the user. It is generally recommended that water used for drinking purposes contain less than 2,000 mg/l dissolved solids; however, water containing somewhat higher mineral concentrations has been used where water of better quality was not available.

Generally, water used for livestock purposes is subject to similar quality limitations as those relating to drinking water for humans; however, the tolerance limits of the various chemical constituents as well as the dissolved-solids concentration may be considerably higher for livestock than that which is considered satisfactory for human consumption. The type of animal, the kind of soluble salts, and the respective amount of soluble salts determine the tolerance limits (Heller, 1933, p. 22). In the western United States, cattle may tolerate drinking water containing nearly 10,000 mg/l of dissolved solids providing these waters contain mostly sodium and chloride (Hem, 1970, p. 324). Waters containing high concentrations of sulfate are usually considered undesirable for livestock use. Many investigators recommend an upper limit of dissolved solids near 5,000 mg/l as necessary for maximum growth and reproduction. Hem (1970, p. 324) cited a publication of the Department of Agriculture of the state of Western Australia as recommending the following maximum upper limits for dissolved-solids concentration in livestock water:

<u>Animal</u>	<u>Dissolved solids (mg/l)</u>
Poultry	2,860
Hogs	4,290

<u>Animal</u>	<u>Dissolved solids (mg/l)</u>
Horses	6,435
Cattle (dairy)	7,150
Cattle (beef)	10,100
Sheep (adult)	12,900

Water having concentrations of chemical constituents in excess of the Texas Department of Health's standards may be objectionable for many reasons. Brief explanations for these objections, as well as the significance of each constituent, are given in Table 2.

### Irrigation

The suitability of ground water for irrigation purposes is largely dependent on the chemical composition of the water. The extent to which the chemical quality will affect the growth of crops is in part determined by the climate, soil, management practices, crops grown, drainage, and quantity of water applied.

Primary characteristics that determine the suitability of ground water for irrigation, according to the U.S. Salinity Laboratory Staff (1954), are: (1) total concentration of soluble salts; (2) relative proportion of sodium to other cations (magnesium, calcium, and potassium); (3) concentration of boron or other toxic elements; and (4) under some conditions, the carbonate and bicarbonate concentrations as related to the concentration of calcium and magnesium. These have been termed, respectively, the salinity hazard, the sodium (alkali) hazard, the boron hazard, and the bicarbonate ion hazard (U.S. Salinity Laboratory Staff, 1954, p. 69-82; Wilcox, 1955, p. 11-12; and Lyerly and Longenecker, 1957, p.13-15).

A high concentration of soluble salts in irrigation water may cause a buildup of salts in the soil. Saline soils decrease the ability of plants to take up moisture and nutrients from the soil resulting in decreased yields. This salinity hazard is expressed in terms of specific conductance, measured in micromhos at 25°C. In general, water having a conductance below 750 micromhos at 25°C is satisfactory for irrigation; however, salt-sensitive crops such as strawberries and green beans, may be adversely affected by irrigation water having a specific conductance in the range of 250 to 750 micromhos at 25°C.

The physical condition of soil can be adversely affected by a high concentration of sodium relative to the concentration of calcium and magnesium in irrigation water. The sodium hazard is expressed as the sodium-adsorption ratio(SAR) which is the measurement of the relative activity of sodium ions in exchange reactions with soil. A high SAR in irrigation water affects the soil by forming a hard impermeable crust that results in cultivation and drainage problems. Under most conditions, irrigation waters having a percent sodium less than 60 and a low bicarbonate content are probably satisfactory. The sodium hazard becomes progressively greater as the sodium percentage increases above 60.



Boron is necessary for good plant growth, but rapidly becomes highly toxic at concentrations above acceptable levels. Maximum tolerable levels for various crops range from 1.0 to 3.0 mg/l (Scofield, 1936). Consult Table 2 for specific crops and their tolerance ranges.

A concentration of bicarbonate in irrigation water often causes calcium and magnesium carbonate to precipitate from solution upon drying, which results in an increase in the proportion of sodium in solution. The effect of higher proportions of sodium has been previously discussed. Waters containing 1.24 to 2.5 me/l (milliequivalents per liter) of residual sodium carbonate (RSC) are considered marginal and those containing greater than 2.5 me/l probably are not suited for irrigation use (Wilcox, 1955).

## **Industrial**

Chemical quality standards for ground water used for industrial purposes vary greatly with the type of industry utilizing the water. The primary concern with many industries is that the water does not have constituents that are corrosive or scale-forming. Also of concern are those minerals that affect color, odor, and taste; therefore, water with a high content of dissolved solids is usually avoided. Table 2 lists the effect that most of the minerals have on industrial usage.

# **GROUND-WATER CHARACTERISTICS OF THE NACATOCH AQUIFER**

## **The Hydrologic Cycle**

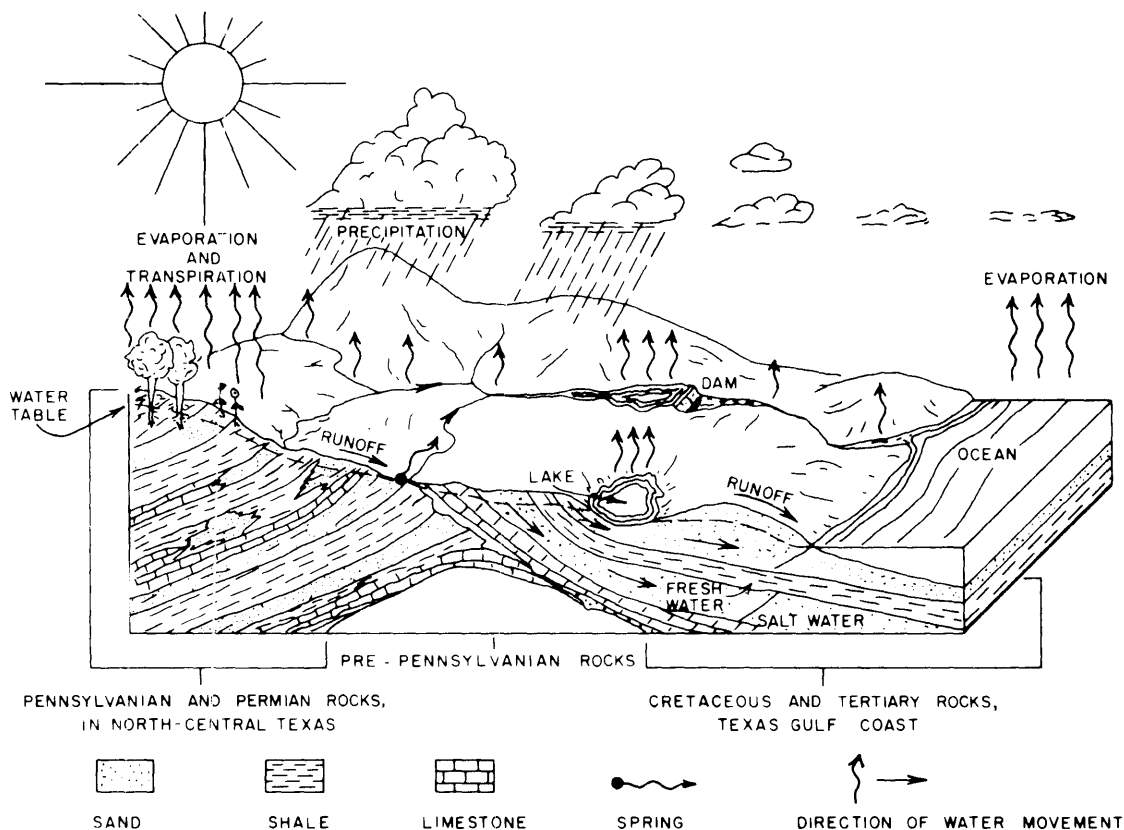
The hydrologic cycle is the sum total of the processes through which water passes. Many courses that water may take to complete the cycle are illustrated on Figure 9.

## **Source and Occurrence**

The original source of ground water in the Nacatoch aquifer is the infiltration of precipitation either directly in the outcrop or indirectly through seepage from streams and lakes. That small portion of the total precipitation which seeps down through the soil mantle and reaches the water table is called ground water.

Ground water is said to occur under either water-table or artesian conditions. Ground water in the outcrop of many formations is unconfined and under water-table conditions. Water under these conditions is under atmospheric pressure and will rise or fall in response to changes in the volume of water stored. In most places, the configuration of the water table approximates the topography of the land surface. In a well penetrating an unconfined aquifer, water will rise to the level of the water table.

Down dip from the outcrop, ground water in the aquifer may occur beneath a relatively impermeable bed. The water is under artesian or confined condition and the impermeable bed confines the water under a pressure greater than atmospheric. In a well penetrating an artesian aquifer, water will rise above the confining bed and, if the pressure head is large enough to cause the water in the well to rise above the land surface, the well will flow.



**Figure 9.—Hydrologic Cycle**

## Recharge, Movement, and Discharge

The replenishment of water, or recharge, to the Nacatoch aquifer is primarily accomplished by the downward percolation of precipitation on the formation outcrop. The amount of recharge is controlled by the ability of the formation to receive and transmit water, topographic features, areal extent of the outcrop, and the amount and frequency of precipitation on the outcrop.

The type of soil and its physical characteristics primarily determine the rate at which water initially percolates downward from the surface. Soils associated with the Nacatoch outcrop are described by the Soil Conservation Service as generally being a loose, acidic, sandy to silty loam at the surface and underlain by dense clay subsoils. These soils are moderate to poorly drained and very slowly permeable. Following is a typical soil profile, using the Axtell soil of Hunt County as an example, which lists the physical and chemical properties of the soil (U.S. Soil Conserv. Serv., 1981):

Depth inches	Percent clay	Permeability inches/hour	Reaction pH
0-8	7-18	0.6-2.0	5.1-6.5
8-15	40-55	.06	4.5-7.3
15-34	40-55	.06	5.1-7.1
34-80	25-50	.2-0.6	5.6-8.4

A higher rate of recharge generally occurs where alluvium is in contact with Nacatoch sand layers. Figure 5 shows that parts of the Nacatoch outcrop primarily along river courses are covered by alluvial deposits. The alluvium is generally coarser grained, less cemented, and topographically flatter than the Nacatoch outcrop, and therefore is more capable of receiving water as recharge. Where alluvial deposits overlie Nacatoch sands, a hydrologic connection exists. As water percolates down the alluvium, it enters the Nacatoch Formation and becomes a part of the Nacatoch aquifer.

The areal extent of the Nacatoch Formation outcrop is approximately 835 square miles. Of this total, only 275 square miles of the outcrop contain rechargeable sandy material. This estimate is based on a percentage of sand to the total formation thickness as calculated from electric logs. Therefore, only about one-third of the Nacatoch outcrop is reasonably capable of accepting water.

Effective recharge differs from total recharge in that it does not include water that may be trapped in perched layers, lost by leakage to other formations, or remains as non-drainable moisture attached to sand grains (specific retention). Annual effective recharge is equivalent to sustainable annual yield. The trough method, which is an application of Darcy's Law, provides an index to the aquifer's maximum effective recharge capability and is computed by using the formula

$$Q = TIL,$$

where **Q** is the quantity of water in cubic feet per day moving through the aquifer; **T** is the transmissivity in square feet per day; **I** is the hydraulic gradient of the static water level in feet per mile; and **L** is the length of the aquifer in miles normal to the gradient. Because of changing characteristics along the Nacatoch outcrop, the length was divided into segments with similar characteristics. "**Q**" was calculated for each segment and totaled. The annual effective recharge to the Nacatoch aquifer is estimated to be approximately 3,030 acre-feet.

The effective recharge of the Nacatoch equates to about one-half of one percent of the average annual rainfall falling on the rechargeable outcrop area. Therefore, the limiting factors appear to be the low hydraulic conductivity of the soil cover and the poor transmitting ability of the formation.

Upon reaching the saturated zone, ground water in the Nacatoch generally moves in response to the hydraulic gradient. Movement is in a direction normally at right angles to the contours of the potentiometric surface (Figure 10) and in the direction of decreasing elevation. The rate of flow is very slow due to low hydraulic conductivity and hydraulic gradient.

In the Nacatoch aquifer, this downdip movement is often interrupted by the numerous faults which traverse the formation. Faulting in the Nacatoch usually results in the misalignment of sand layers, thus creating a barrier to the normal downdip flow (see sections B-B' through G-G', Figures 19 through 24). When this occurs, the ground-water flow usually is diverted. Pumpage of ground water for the city of Commerce is withdrawn from a downfaulted block, or graben, which has the effect of isolating that portion of the Nacatoch from the downdip portion of the formation. According to the potentiometric surface within this block, ground-water movement appears to be from west to east, parallel to the fault trend.

Locally, ground water will be diverted toward areas of discharge. Discharge by heavy pumpage in the Nacatoch results in extensive cones of depression. These cones form a mechanically altered potentiometric surface which dips from all directions toward the center of pumpage. Thus the flow of ground water within the effective range of the cone is toward the center of pumpage.

Discharge from the Nacatoch aquifer occurs primarily as pumpage from wells with municipalities representing the largest users. The estimated amount of ground water pumped from the Nacatoch for municipal and industrial use from 1963 through 1982 is shown in Table 3.

Spring flow once represented a significant amount of discharge. Due to the overall lowering of the potentiometric surface, most springs and some flowing wells have ceased to flow. A few flowing wells still occur in southern Red River County.

## **Water Levels**

Ground water in the Nacatoch aquifer is predominantly under artesian conditions except in shallow wells on the outcrop where water-table conditions occur. Figure 10 shows the 1982 altitude of water levels in selected wells completed in the uppermost sand layer. According to test hole observations, wells completed in lower sands have slightly lower water-level altitudes. Water levels in numerous wells are listed in Tables 5 and 7.

Figure 10 illustrates the effect faulting has on water levels. Wells PH-17-49-306 and PH-17-49-315 in Hunt County are separated by a prominent fault. A difference of over 200 feet occurs in the water-level altitude between these wells.

In general, water levels in the Nacatoch aquifer fluctuate minimally with climatic changes. In order to measure the fluctuations in the water level, two test holes were completed in Hunt County and continuous recording equipment was installed in each. One well was completed in the upper of three sand intervals and the other was completed in the lower sand interval. After one year of monitoring, during which several periods of heavy rainfall occurred, the water levels were observed to change by a magnitude of only 2 feet (Figure 11).

Long term water-level declines appear to be the result of pumpage exceeding effective recharge. Figure 12 is a hydrograph of two closely spaced public supply wells in the city of Commerce. The hydrograph shows a continuous water-level decline of 195 feet in the 57 years since the first well was drilled. Similar water-level declines, due to heavy pumpage and unchecked flowing wells, have been observed in southwestern Red River County.

## **Hydraulic Characteristics**

The hydraulic characteristics of an aquifer that express its value as a ground-water source are generally described in terms of transmissivity and storage. The transmissivity expresses the ability of the aquifer to transmit water. Pump tests on five city of Commerce wells in Hunt and Delta Counties indicate an average transmissivity of 335 square feet per day ( $\text{ft}^2/\text{d}$ ). These wells are located in a deltaic sand where the aquifer is most productive. Therefore, significantly higher

**Table 3.—Estimated Use of Ground Water For Public Supply and Industrial Purposes, 1963-82**

Use: PS public supply; Ind, industrial. Values are in acre-feet.

	Bowie		Hunt		Hopkins		Navarro		Red River		Titus		Totals
	PS	Ind	PS <sup>1</sup>	Ind	PS	Ind	PS	Ind	PS	Ind	PS <sup>2</sup>	Ind	
1963	175.4	—	1,320.0	—	46.0	—	17.7	1.6	81.4	410.8	69.8	—	2,122.7
1964	263.4	—	1,155.2	—	33.6	—	17.7	1.6	84.4	407.8	67.9	—	2,031.6
1965	257.5	—	1,124.3	—	88.4	—	16.3	1.6	97.6	407.3	65.7	—	2,058.7
1966	374.7	—	1,223.3	—	90.8	—	19.5	1.6	125.8	405.8	67.7	—	2,309.2
1967	339.7	—	1,272.2	—	112.0	—	22.8	1.6	123.1	408.4	66.8	—	2,346.6
1968	394.6	—	1,445.1 <sup>3</sup>	—	41.8	—	19.7	1.6	106.5	408.3	65.6	—	2,483.2 <sup>3</sup>
1969	477.9	—	1,503.3	—	74.5	—	16.1	1.6	127.5	407.3	74.7	—	2,682.9
1970	409.9	—	1,559.0	—	124.3	—	17.5	1.6	132.0	412.6	70.9	—	2,727.8
1971	110.9	—	1,529.1	—	160.1	—	16.7	1.6	175.7	552.5	74.0	—	2,620.6
1972	117.9	—	1,642.8	—	178.9	—	10.8	1.6	153.2	416.5	114.2	—	2,635.9
1973	128.2	—	1,334.3	—	184.0	—	13.4	1.6	153.6	414.0	65.9	—	2,295.0
1974	144.0	—	1,339.9 <sup>3</sup>	—	155.7	—	12.8	1.6	162.0	428.8	63.9	—	2,308.7 <sup>3</sup>
1975	159.7	—	1,299.5	—	142.5 <sup>3</sup>	—	16.3	1.6	167.9	415.1	66.0	—	2,268.6 <sup>3</sup>
1976	158.5	—	1,379.9 <sup>3</sup>	—	133.0	—	15.1	1.6	176.7	418.0	66.9	—	2,349.7 <sup>3</sup>
1977	182.7 <sup>3</sup>	—	1,574.4 <sup>3</sup>	—	127.0	—	10.5	.4	201.4	418.0	69.8	—	2,584.2 <sup>3</sup>
1978	218.1	—	1,508.9 <sup>3</sup>	—	135.0	—	9.3	.4	202.5	393.5	80.9	—	2,548.6 <sup>3</sup>
1979	186.6	—	1,385.7 <sup>3</sup>	—	189.7	—	9.0	.4	188.3	393.5	70.3	—	2,423.5 <sup>3</sup>
1980	49.4	—	1,229.6 <sup>3</sup>	—	215.2	—	7.9	.4	207.1	187.0	67.1	—	1,963.7 <sup>3</sup>
1981	5.1 <sup>3</sup>	—	999.7 <sup>3</sup>	—	305.5	—	16.0	.2	179.7	174.8	67.1	—	1,748.1 <sup>3</sup>
1982	5.1 <sup>3</sup>	—	1,121.2 <sup>3</sup>	—	206.4	—	10.8	.4	202.3	168.8	72.1	—	1,786.7 <sup>3</sup>

<sup>1</sup>Portions pumped from Delta County.

<sup>2</sup>Pumped from Red River County.

<sup>3</sup>Portions estimated by Texas Department of Water Resources.

transmissivities are not to be expected. Pump tests conducted on test holes and specific capacities determined from well tests reported on drillers' reports indicate much lower transmissivities in areas outside of the major delta sand complexes.

The coefficient of storage is a measure of an aquifer's ability to store or release ground water from storage. The term specific yield is used when water-table conditions exist. Coefficients of storage in artesian aquifers are very small in comparison to specific yields of water-table aquifers since artesian storage is dependent upon the elastic properties of the aquifer. Artesian wells will have a storage coefficient generally ranging from  $10^{-5}$  to  $10^{-3}$ , which is usually about  $10^{-6}$  per foot of aquifer thickness. Wells under water-table conditions will have specific yields ranging from approximately 0.1 to 0.3.

The specific capacity of a well, expressed as its yield per foot of drawdown, is another indication of the hydraulic characteristic of an aquifer, but must be used with caution. The measure is affected by methods of well completion, and change with the rate and length of pumping. Specific capacities obtained from 15 wells in which pump tests of 24 hours or more in duration were made ranged from 0.2 to 13.8 gallons per minute per foot [gal/min)/ft]. Table 4 lists transmissivities and specific capacities determined from pump tests conducted on wells in the study region.

## Chemical Quality

Nacatoch ground water, like all other aquifer waters, contains minerals carried in solution. The concentration of dissolved minerals determines the usefulness of the water and generally increases with depth. Chemical analyses of water from 190 wells in the study region are given in Table 8. Sampled wells are indicated on the county well location maps by a bar over the well number. The source, significance, and range in concentration of the dissolved-mineral constituents are given in Table 2. Concentrations of sodium, chloride, hardness as calcium carbonate ( $\text{CaCO}_3$ ), and dissolved solids from samples taken from selected wells in the study region are also shown on Figure 13.

Fresh to slightly saline water occurs in the Nacatoch aquifer in the area designated on Figure 13. The downdip limit of usable water (less than 3,000 mg/l), especially in the northern half of the study region, is controlled by the Mexia-Talco fault system. The faults interrupt the normal downdip flow of ground water, thus preventing the flushing action by fresh water.

The chemistry of ground water generally changes in a predictable manner along a specific flow path and can be shown on a trilinear diagram. Figure 14 is a trilinear diagram which illustrates how the chemical composition of water from the Nacatoch aquifer changes with increasing distances downdip. The seven analyses used in this illustration were chosen because of chemical compositions representative of water in their respective locations. Well number one is located furthest updip while subsequently numbered wells are located at increasing depths downdip. The trilinear diagram shows that relative concentrations of calcium decrease in a downdip flow direction while relative concentrations of sodium, chloride, and bicarbonates increase. This indicates that the geochemical evolution of Nacatoch ground water is from a calcium rich recharge type water to a sodium bicarbonate and sodium chloride marine type. This example illustrates an ideal condition of chemical change in Nacatoch ground water and should

**Table 4.—Results of Pumping Tests**

<u>Well</u>	<u>Date test began</u>	<u>Screened interval (ft)</u>	<u>Yield (gal/min)</u>	<u>Transmissivity (ft<sup>2</sup>/d)</u>	<u>Specific capacity [(gal/min)/ft]</u>	<u>Hydraulic conductivity (ft/d)</u>
<b>BOWIE COUNTY</b>						
BD 16-28-703	Jan. 20, 1945	—	63.5	1,755	13.8	—
	Jan. 21, 1945		(Recovery)	2,224	—	—
40-102	July 28, 1960	485-585	107	295	1.3	2.95
	July 28, 1960		(Recovery)	295	—	—
<b>DELTA COUNTY</b>						
HU 17-42-806	Oct. 16, 1965	422-525	200	308	1.0	2.95
807	Nov. 15, 1985	507-620	254	343	1.2	3.08
808	Dec. 8, 1965	425-525	183	288	1.0	2.95
<b>HUNT COUNTY</b>						
PH 17-41-901	Nov. 9, 1943	374-412	285	358	5.1	9.38
902	Nov. 7, 1943	375-435	185	356	9.3	5.90
49-304	Sept. 27, 1950	327-419	225	188	—	2.01
	Nov. 7, 1950		252	268	1.4	2.95

Chemical quality of the water in each producing sand layer in the Nacatoch varies because thick mudstone layers separating the sand beds prevent mixing of the water. In general, the quality of water decreases with each producing sand interval in descending order. The situation often exists where the upper sand produces good, usable water while lower sands produce poorer, unusable water. If this lower water producing layer is not sealed off, it can possibly contaminate the upper sand layer. Few water wells have been drilled and completed through all producing zones of the Nacatoch, therefore, this contamination problem rarely occurs. Dissolved solids in water from individual sand layers in Nacatoch test holes are as follows:

Well	Sand interval	Dissolved solids (mg/l)
LZ-17-45-301	90- 120	725
	340-365	6,915
PH-18-64-802	105-130	806
	218-238	828
	340-375	1,468
WB-16-34-509	285-325	679
	558-624	1,551

### Production and Disposal of Oil-Field Brine

Oil and gas production has been associated with the Mexia-Talco fault system for many years. Corsicana was the site of the first large oil discovery west of the Mississippi in 1894, and gas was found in Nacatoch sand near Mexia in 1912. Production was at a peak in the 1920s in Limestone, Navarro, and Kaufman Counties. The hydrocarbons usually accumulated in traps formed in the Nacatoch, Wolf City, and Woodbine sands that terminated updip against the faults.

Along with oil and gas, large quantities of salt water, or "brine" were brought to the surface and subsequently disposed of. Prior to a ruling concerning oil-field brine disposal by the Texas Railroad Commission in 1969, the majority of salt water produced in the area was disposed of in open surface pits and surface-water courses. No chemical-quality data collected during this investigation indicated contamination by salt-water seepage from open surface pits, although it is possible that in some places salt water may have penetrated the surface and caused the local ground water to become saline.



## UTILIZATION AND DEVELOPMENT OF THE NACATOCH AQUIFER

Ground water from the Nacatoch aquifer has been used for public supply, industrial, irrigation, domestic, and livestock purposes. Public supply and industrial use represents the largest percent of ground-water pumpage and has decreased from a high of 2,728 acre-feet in 1970 to 1,787 acre-feet in 1982 (Table 3). Decreased use of ground water since 1980 is due to the increasing use of surface water. Several towns have completely converted to surface-water use. The only major industrial user is a power company in Red River county. Public supply and industrial wells are usually 12 inches or more in diameter and penetrate all water-bearing layers in the formation in order to obtain the highest possible yield.

The city of Commerce is the single largest user of Nacatoch groundwater. The first municipal well for the city was drilled in 1914 followed by 10 more by 1970, five of which are located east of town in the Horton well field. Water levels were at or below the top of the aquifer at Commerce by 1961, indicating a dewatering of the sand in that area. Water levels have also declined in the area of the Horton well field. In 1982, the city used water from five wells in the Horton well field and from two wells within the city limits. The city is no longer able to meet its water consumption demand with ground water alone and has therefore obtained an additional supply from Lake Tawakoni. Heavy municipal and industrial pumpage, resulting in declining water levels, also occurs in southwestern Red River County.

In 1959, eighteen flowing wells in southeastern Red River County and eastern Bowie County discharged about 0.13 million gallons per day, most of which was wasted (Baker, Long, Reeves, and Wood, 1963). A few of these wells continue to flow today but at a much reduced rate. This uncontrolled discharge has caused most of the springs in the area to cease flowing.

Irrigation use of ground water from the Nacatoch is limited primarily to Bowie and Red River Counties. Ground water used for irrigating rice fields in northern Bowie County is pumped mostly from wells in the alluvium that overlies the Nacatoch. A small amount of pasture land is irrigated with Nacatoch ground water in Red River County.

Domestic pumpage mostly occurs in the more populated rural areas. The wells are generally shallow, only penetrating enough sand to give an adequate supply. Rural homes are often served by private water companies in areas where ground-water quality or quantity are inadequate. Ground-water use by livestock is centered in the eastern portion of the study area where dairy farming prevails.

## AVAILABILITY OF GROUND WATER IN THE NACATOCH AQUIFER

The amount of fresh to slightly saline ground water available annually for development from the Nacatoch aquifer is approximately 3,030 acre-feet, which is the approximate average annual effective recharge to the aquifer. The method used to compute this quantity was discussed previously. Theoretically, this amount can be developed without reducing the quantity of ground water in storage, although it should be recognized that a single well, or well field, cannot recover the total sustainable annual yield of the aquifer.

Hydrologic factors that govern the amount of ground water available for development from the Nacatoch aquifer differ from one location to the next. Therefore, local hydrologic characteristics must be evaluated to determine expected availability at a selected well site. Hydrologic factors include volume of water in storage and the ability of the aquifer to transmit water. To obtain the maximum supply possible at a well site, every layer of sand containing acceptable quality water must be developed.

Areas with the greatest saturated sand thickness usually will have the greatest potential yield. The three deltaic areas described previously contain approximately 80 percent of the usable-quality water in the Nacatoch aquifer because of their greater net sand thickness. Ground-water availability diminishes rapidly in Kaufman and Navarro Counties, and in the areas between the delta complexes due to thin net sand. Figure 7 shows net sand thickness and can be used as a general guide for locating areas of greatest potential yield. Other factors such as faulting and chemical quality must also be considered when investigating potential well sites.

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## BOWIE COUNTY

### Table 6.—Selected Oil and Gas Tests

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
BD-16-31-8A	Harry Wirick	Sanders No. 1	Dec. 7, 1966	5,812	282
36-7A	W. M. Coats	S. H. Hall No. 1	Feb. 12, 1948	8,085	366
9A	Renwar Oil Corp.	McCoy No. 1	Dec. 24, 1952	3,548	285
37-4A	Bass Drilling Co.	McGee No. 1	Feb. 10, 1953	3,405	357
7A	W. M. Coats	A. L. Simms No. 1	Dec. 29, 1948	3,853	290
40-2A	Murray Petroleum Co.	Gregory No. 1	May 12, 1953	4,112	270
2B	Hawkins and Wadley, et al.	P. S. Cork No. 1	June 30, 1945	6,540	341
43-2A	American Petrofina	Edward—No. 1	—	3,910	306
5A	Tide Water Assoc., Company of Texas, et al. Seaboard	Daley and Joiner No. 1	June 7, 1947	4,826	280
44-1A	Permac Oil and Gas Co. Inc.	Tidewell No. 1	Aug. 19, 1943	4,225	293
2A	Delta Drilling Co.	J. N. Gauntt No. 1-A	1940	4,173	314
45-3A	Shell Oil Co.	W. D. Wall No. 1	July 23, 1940	6,220	275
46-3A	A. L. Willis	H. L. Taylor No. 1	Feb. 14, 1941	3,903	284
48-1A	Barnsdale and Sohio	J. R. Greenwood No. 1	Mar. 16, 1947	8,188	297

## DELTA COUNTY

### Table 6.—Selected Oil and Gas Tests—Continued

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
HU-17-42-701	Bond Oil Corp.	N. Albowitch No. 1	May 21, 1960	5,893	483
8A	Hickey and Randall	E. R. Petty No. 1	Feb. 4, 1956	6,005	476
901	Talco Asphalt and Refining Co.	W. T. Peek No. 1	Oct. 20, 1941	4,699	433
43-6A	A. V. Erwin and Peek Oil Co.	C.O. Thomas No. 1	Nov. 2, 1963	4,106	400
50-102	Morty Freedman	M. L. Pritchard No. 1	Nov. 14, 1949	6,225	473
201	W. C. Perryman and George J. Greer, et al.	W. T. Peek Estate No. 1	July 25, 1958	4,738	477



# FRANKLIN COUNTY

## Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
JZ-17-39-903	Max Hightower	Harvey No. A-1	June 21, 1961	3,870	307
46-301	D. L. Parker	Troy Fite No. 1	Sept. 24, 1956	4,910	399
5A	Marshall Exploration, Inc.	A. J. Laws No. 2	Oct. 1, 1970	5,441	395
602	D. R. Snider	Eric Bagwell, et al. No. 1	Jan. 5, 1959	4,626	388
6A	Peveto, Byars, et al.	Loy Clifton No. 1	Sept. 26, 1948	4,505	372
47-104	L. D. Lowry, Jr. and R. V. Parker	Kate Terry Brown No. 1	Aug. 25, 1959	3,955	320
2A	Humble Oil and Refining Co.	T. G. Gemon, et al. No. 1	1945	5,495	321
4A	V. A. Hughes	Hayden No. 1	Aug. 2, 1938	4,343	367
502	W. B. Hinton	M. and P. National Bank of Mt. Vernon No. 1	Nov. 2, 1949	4,419	355
701	John B. Stephens, Jr. and American Liberty Oil Co.	D. Hale No. 1	Oct. 21, 1956	6,711	358

## HENDERSON COUNTY

**Table 6.—Selected Oil and Gas Tests—Continued**

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
LT-33-46-901	Pan American Petroleum Corp.	E. P. Harwill Trust No. 1	Jan. 12, 1966	9,868	288
9A	D. J. Crawford, et al.	J. E. Reese No. 1	May 11, 1944	3,247	353
47-101	F. R. Jackson	Todd Estate No. 1	Dec. 31, 1954	3,516	362
601	Harry Hines	Russell Mallory No. 1	Nov. 24, 1939	3,508	294
7A	H. W. McGee	Mickeal No. 1	June 21, 1938	3,224	359
55-2A	Stephen W. Schneider and Rex Corey and Bruce Smith	Bruce Smith No. 1	Aug. 26, 1970	5,180	287

# HOPKINS COUNTY

## Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
LZ-17-42-9A	L. H. Armer	C. B. Wallace No. 1	Mar. 5, 1956	4,807	487
43-7A	W. B. Hinton	Lindley No. 1	May 16, 1955	4,610	480
7B	Humble Oil and Refining Co.	Sallie Dunham No. 1	Jan. 1, 1964	9,600	423
8A	Vaughn Petroleum Co.	Chance Heirs No. 1	June 9, 1974	4,810	533
9A	H. F. Williams	McKinney, et al. No. 1	May 13, 1963	4,120	422
44-6A	Wiggins Brothers, Inc.	Roy Herman No. 1	Jan. 27, 1961	5,417	492
7A	W. B. Hinton and Talco Asphalt Co.	J. D. Crisp No. 1	April 16, 1942	4,832	496
9A	F. R. Jackson	Pearl Spencer No. 2	Aug. 8, 1954	4,764	495
45-5A	Ridley and Locklin	Modena Flippin No. 1	July 29, 1960	5,286	446
6A	Grelling Estate	Bassham No. 1	Mar. 19, 1958	9,463	462
7A	White and A. O. Phillips	Davis No. 1	Dec. 10, 1948	4,857	466
46-4A	Sun Oil Co.	Glaze Brothers No. 1	Aug. 9, 1968	4,752	395
5A	Shell Oil Co.	C. M. Mayes No. 1	Mar. 6, 1960	9,442	391
7A	E. C. Johnston Co.	Ada Cain No. 1	Feb. 12, 1961	4,727	398
50-9A	Wil-Mc Oil Corp.	Morris Brasher No. 1	Nov. 16, 1974	4,809	543
51-7A	Pitcock, Inc.	Prime Estate No. 1	Mar. 29, 1977	5,860	536
8A	Ardis, Legget and Long	McMullan No. 1	Aug. 23, 1950	6,003	517
52-2A	Crown Central Petroleum Corp.	V. O. Wells	May 27, 1953	7,299	457
2B	Bamoil, Inc.	J. R. Beckham No. A-1	Feb. 25, 1958	5,116	472
53-1A	E. L. Howard	Elbert Yoss No. 1	Jan. 8, 1953	5,300	430
4A	LaCoastal Petroleum Corp.	V. O. Wells	Feb. 21, 1973	7,100	419
6A	Wil-Mc Oil Corp.	Jasper Payne No. 1	Aug. 16, 1975	3,975	415
58-2A	Campbell and Hill	J. W. Warren No. 1	Jan. 9, 1944	5,974	560
4A	T. G. Shaw-Trustee	Hattie Lee No. 1	July 25, 1947	5,860	552
8A	Hunt Oil Co.	G. H. Marable No. 1	Apr. 1944	6,123	531

## HOPKINS COUNTY—Continued

### Table 6.—Selected Oil and Gas Tests—Continued

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
LZ-17-59-9A	B. G. Byars, Power Drilling Co.	D. B. White No. 1	Dec. 18, 1949	6,441	514
9B	Sonac Texas Oil and Gas Corp.	R. S. Stubbs No. 1	Mar. 4, 1946	6,510	493

# HUNT COUNTY

## Table 6.—Selected Oil and Gas Tests—Continued

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
PH-17-41-9A	Nicklos Oil and Gas Co.	William Agnew Swindell No. 1	July 28, 1963	5,460	554
49-302	Stanolind Oil and Gas Co.	W. M. Bickley No. 1	Oct. 16, 1943	4,520	515
501	Hollandsworth Drilling Co.	C. H. Kimball No. 2	Nov. 18, 1944	4,507	587
503	R. L. Peveto, et al.	Adams No. 1	Sept. 4, 1953	3,407	490
701	Peveto and Hager	Cannon No. 1	July 15, 1952	3,306	570
702	Hager and Peveto	J. M. Andrews, Jr. No. 1	Aug. 26, 1953	2,952	550
7A	Stanolind Oil and Gas Co.	Tilson Heirs No. 1	Apr. 1, 1943	4,451	619
8A	Ira L. McMahan, et al.	Mrs. May Winniford No. 1	Sept. 13, 1942	3,140	543
57-1A	National Steel Erection Co.	Lester Money No. 1	Dec. 4, 1962	4,597	500
3A	O. W. Killam	E. L. Waid No. 1	May 18, 1943	3,652	581
4A	Hunt Oil Co.	Naud Burnett No. 1	Nov. 22, 1947	4,669	493
18-64-601	A. O. Phillips	W. E. Burnett No. 1	Oct. 30, 1953	3,316	465
6A	Prince and Germany	C. L. Miller No. 1	July 11, 1942	3,002	490
8A	Vincent and Welch, Inc.	F. R. Hill No. 1	Dec. 15, 1963	4,350	500
901	Curry and Thomas	Greenville Lake and Water Co., Wise Unit No. 3	Jan. 12, 1949	2,863	487
902	Byars, Peveto and Stephens	Charles Nevill, Jr. No. 1	May 20, 1955	4,875	480
9A	Morris Palmer	Pritchard No. 1	Dec. 5, 1949	2,888	484
33-07-6A	Paul B. Scott and C. D. Gray	Fannie B. Ervin No. 1	Dec. 8, 1945	4,373	476
901	A. O. Phillips, et al.	J. W. Green No. 1	July 6, 1950	4,571	496
08-101	Floyd C. Ramsey	P. B. Paul No. 4	Feb. 20, 1953	3,251	489
402	Empire Oil and Refining Co.	Walter Graner No. 1	May 8, 1953	3,173	441
501	W. M. Coats	J. O. Adams No. 1	June 8, 1956	4,746	418

**HUNT COUNTY—Continued**

**Table 6.—Selected Oil and Gas Tests—Continued**

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
PH-33-08-901	Bert Fields	H. Meridith No. 1	Dec. 7, 1948	4,783	451
9A	Gene Heape Oil Co., Berry and Berry Holding Co.	Naud Burnett No. 1	Sept. 23, 1974	10,014	453
16-101	American Liberty Oil Co.	J. W. Barrow No. 1	Feb. 6, 1952	5,406	427
105	Omni Exploration, Inc.	F. W. Barrow Estate No. 1	July 11, 1981	4,255	490
1A	Sunray Mid-Continent Oil Co.	G. W. Barrow No. 1	Feb. 3, 1960	9,926	452
34-01-101	W. H. Bryant	W. H. Hunt No. 1	June 13, 1953	3,518	524

## KAUFMAN COUNTY

### Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
RA-33-15-601	T. D. Humphrey and Sons, LTD.	Whitesides No. 1	June 24, 1954	4,986	542
902	L. O. McMillan	T. O. Rutledge No. 1	Dec. 1, 1956	2,836	540
16-401	J. K. Hughes	Lee Eubanks No. 1	Jan. 13, 1954	5,005	468
22-501	J. W. Bibb	Smith No. 1	Sept. 7, 1952	3,516	482
23-601	T. D. Humphrey and Sons	B. H. Doves No. 1	Aug. 2, 1955	5,433	458
7A	Vernon Whitely Drilling Co.	A. D. Gardner No. 1	Oct. 29, 1951	4,946	497
8A	El Tigre Oil Co.	Paul Tankersly No. 1	Jan. 29, 1959	3,604	530
31-2A	Jno. B. Stephens Jr. and R. S. Peveto	J. R. Floyd No. 1	Dec. 11, 1955	4,842	505
3A	Tulsa Iron and Metal	Ollie B. Jackson No. 1	Apr. 4, 1949	5,014	487
3B	Delphi Oil Co.	Miller High No. 1	Dec. 5, 1956	5,141	439
901	John B. Stephens, Jr.	Henry McKinney No. 1	July 11, 1954	5,298	375
902	L. A. Grelling	Geo. Booker No. 1	Jan. 16, 1955	5,373	366
32-101	Superior Oil Co.	G. L. Phillips No. 1	Jan. 15, 1954	5,381	409
7A	Coulston Drilling Co.	R. L. Warren No. 1	Nov. 20, 1954	3,505	418
38-301	American Liberty Oil Co.	Hall No. 1	Mar. 1, 1954	4,430	351
6A	Heimen Brothers	Will and Etta Freeman No. 1	Dec. 24, 1958	4,589	367
39-1A	Humble Oil and Refining Co.	Lon Hale	Aug. 7, 1946	4,513	395
2A	E. B. Germany and Sons	Mrs. Florence Becker No. 1	June 29, 1956	4,288	350
4A	Humble Oil and Refining Co.	H. L. Guy No. 1	May 14, 1947	8,013	411
5A	Maxwell Herring Drilling Corp. and R.S. Peveto	R. R. Watkins No. 1	Feb. 27, 1956	3,511	319
7A	Elbert Williams, et al.	Hood Berryman No. 1	Jan. 13, 1943	3,026	315
7B	Four W. Oil Co.	Fitzgerald No. 1	Nov. 11, 1954	3,525	314

**KAUFMAN COUNTY—Continued**

**Table 6.—Selected Oil and Gas Tests—Continued**

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
RA-33-39-7C	Martin and Milton, et al.	Rutland Savings Bank No. 1	Oct. 31, 1942	3,178	305
9A	Humble Oil and Refining Co.	Ed Legg No. 5	Dec. 31, 1952	6,415	367
40-4A	Evans Producing Corp.	Howard Jones No. 1	Jan. 2, 1955	4,244	351



## NAVARRO COUNTY

### Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
TY-33-53-301	Oakland Corp.	L. P. Hodge Estate No. 1	Nov. 10, 1954	2,788	417
3A	Youngblood and Youngblood	Witherspoon No. 1	Oct. 15, 1963	2,730	439
7A	Terry Moore	Hall No. 1	Sept. 25, 1979	945	355
8A	Can-Tex Energy Corp.	Glasgow No. 6	June 11, 1980	1,118	375
54-2A	E. J. Moran, et al.	First National Bank No. 1	Oct. 31, 1945	3,225	343
3A	Jack C. Staley	Lloyd B. Sands No. 1	Jan. 31, 1975	3,521	291
6A	John W. Hooser	Watt-Tramel, et al. No. 1	May 19, 1945	3,353	402
7A	Amity Oil Co., Inc.	Rutherford No. 1	Feb. 25, 1974	3,315	399
7B	Woodbine Oil Co.	J. H. Burke No. 1	June 1, 1946	2,082	373
805	L.T. Davis	R. Waller No. 1	Sept. 22, 1942	3,260	368
55-1A	Topaz Oil Co.	W. J. Tramel No. 1	Sept. 3, 1939	2,908	298
1B	Ted Weiner	W. G. Holleman No. 1	Oct. 27, 1949	3,287	370
61-2A	R. J. Paschal	Chewning No. 8-R	July 21, 1967	1,170	370
3A	Southwestern Hydrocarbon Co.	Worthy "A" No. 1-R	Apr. 20, 1960	1,362	365
4A	Talbert, Clark and Walker	J. D. McManus	Aug. 3, 1956	2,529	436
8A	W. H. Clement	Eden No. 14	May 7, 1958	810	430
901	J. Olson	Hill No. A-1	Sept. 24, 1954	3,242	431
62-2A	John F. Dill	J. A. Jackson No. 1	May 12, 1950	1,036	462
6A	Oil Well Drilling Co. and Brandor Petroleum Co.	Lela Mae Hight No. 1	June 17, 1956	3,287	347
801	Fullwood and Thornton	A. M. Boyd No. 1	Oct. 6, 1948	1,714	365
63-4A	Harry S. Phillips	Luther Johnson No. 1	Dec. 29, 1967	10,848	287
7A	J. L. Collins and Co.	R. R. Greenlee No. 1	Aug. 25, 1945	7,507	339
8A	Brown and Wheeler	Henderson No. 1	Aug. 1, 1951	7,233	299
39-05-2A	Dick Boyd	A. P. Mays No. 1	July 20, 1979	1,103	350
2B	Tex-Harvey Oil Co.	J. L. Jackson No. 3	Dec. 1, 1946	1,506	427

**NAVARRO COUNTY—Continued**

**Table 6.—Selected Oil and Gas Tests—Continued**

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
TY-39-05-301	Sohio Petroleum and John R. Bunn	Cheney Estate No. 1	Apr. 21, 1944	3,141	360
302	Coffield and Guthrie, Inc.	A. M. Kelly No. 3	June 1, 1950	3,361	364
5A	General Crude Oil Co.	Elkins Estate No. 1	Oct. 19, 1959	9,590	360
06-101	Baldrige and Clayton	R. D. Fleming No. 1	Apr. 9, 1956	3,254	375
6A	W. S. Guthrie	Baum Core Hole No. 1	Apr. 13, 1956	1,235	346
07-4A	Carter-Gragg Oil Co.	J. E. Edens No. 2	Aug. 21, 1954	6,952	366
12-6A	Bond Oil Corp.	Miller No. 1	Sept. 19, 1960	2,935	465
13-1A	Billy J. Blacklidge	C. L. and Evie Keeling No. 1	Nov. 28, 1972	634	493
1B	Four W. Oil Co.	Tucker No. 1	June 16, 1955	3,865	415
4A	W. M. Coats and Danciger Oil and Refining Co.	Livingston No. 1	May 5, 1949	3,753	472

# RAINS COUNTY

## Table 6.—Selected Oil and Gas Tests—Continued

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
UX-34-02-4A	M. H. Kassard	J. D. Whittle No. 1	Mar. 18, 1946	3,934	505
7A	Hunt Oil Co.	J. H. Sparks No. 1	Jan. 10, 1945	6,211	541
802	Person and Andree	Glass No. 1	Aug. 9, 1938	3,881	520

## RED RIVER COUNTY

**Table 6.—Selected Oil and Gas Tests—Continued**

<u>Well</u>	<u>Operator</u>	<u>Lease and well</u>	<u>Date drilled</u>	<u>Depth (ft)</u>	<u>Approximate land surface elevation (ft)</u>
WB-16-33-1A	Hemphill and Irwin	Dr. J. C. Calabria No. 3	Sept. 15, 1959	3,197	329
6A	W. M. Coats and R. E. Moore	Albert Simmons No. 1	June 11, 1950	3,098	320
34-6A	Tex-Harvey Oil Co.	T. H. York No. 1	Aug. 24, 1945	8,191	316
17-40-9A	General American Oil Co.	Coline Oil Co. No. 1	Sept. 14, 1959	5,581	287

## TITUS COUNTY

### Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
YA-16-41-1A	R.E. Moore and W. M. Coats	Bud Lewis No. 2	May 17, 1960	3,826	289
2A	B. G. Byars, et al.	L. C. Taylor No. 1	Apr. 24, 1961	4,002	305
2B	Stephens and Phillips	McGee No. 1	July 4, 1952	4,474	320
3A	Sunray Mid-Continent Oil Co.	Paul H. Pewitt No. 3	Dec. 2, 1960	4,001	337
3B	Charles R. Halstead	Mary J. Chamness No. 1	Jan. 28, 1965	4,635	312
42-101	Paul H. Pewitt	P. H. Pewitt Fee No. 1	May 7, 1956	7,104	310
2A	Sunray Mid-Continent Oil Co. and British American	Pewitt No. 2	June 12, 1960	5,595	307
403	Stephens and Phillips	Pewitt No. D-12	Feb. 27, 1951	4,562	278
501	John B. Stephens and A.O. Phillips	P. H. Pewitt No. 1	Dec. 17, 1954	4,697	302
17-40-7A	Humble Oil and Refining Co.	Maggie Barnard No. B-1	May 14, 1961	5,501	320
802	Humble Oil and Refining Co.	Maggie Barnard No. 1	June 13, 1956	4,761	304
9A	American Petrofina Co. of Texas	Lilienstern-Hoffman No. 1	Jan. 11, 1959	7,212	311
48-1A	W. B. Hinton	Harper No. 4-R	Oct. 2, 1973	4,378	363
1B	Humble Oil and Refining Co.	Talco Ind. School Dist. No. 1	Jan. 1, 1964	4,400	370
203	Magnolia Petroleum Co.	C. W. Belcher No. 7	July 24, 1949	4,241	335

## VAN ZANDT COUNTY

### Table 6.—Selected Oil and Gas Tests—Continued

Well	Operator	Lease and well	Date drilled	Depth (ft)	Approximate land surface elevation (ft)
YS-33-16-5A	L. A. Greiling	Minnie Teel, et al. No. 1	Nov. 2, 1954	5,099	499
24-601	B. G. Byars	Manning No. 1	Oct. 10, 1957	5,763	481
801	W. C. Perryman	Mollie Curtis No. 1	—	5,600	439
32-202	R. E. Barbre, et al.	Bobbitt No. 1	Aug. 26, 1955	4,406	400
3A	J. M. Deu Pree Jr.	B. W. Bruce, Jr. No. 2	Nov. 16, 1947	4,608	444
601	Fadler and Brightwell	Dewey Priest	May 21, 1954	5,641	473
40-5A	R. J. Caraway and Lloyd M. Smith	Joe M. Howell No. 1	May 17, 1963	12,015	430
601	Cooper-Herring Drilling Co.	J. C. Gibbs No 1	Oct. 9, 1952	4,235	498
48-3A	Jerrell Garonzik	Clara McLaughlin No. 1	Dec. 1, 1946	4,507	439
34-09-4A	Texlan Oil Co., Inc.	R. D. Deen No. 1	Feb. 8, 1977	1,600	481
7A	Robert Lake	Ike Alfred No. 1	1941	—	475
17-4A	Royal Petroleum Corp.	Mrs. E. Key Sr. No. 1	—	—	496
701	F. R. Jackson	B. W. Bruce Estate No. 1	Sept. 29, 1948	4,327	464
25-2A	O. W. Killam	Coy Giddens No. 1	May 29, 1944	4,375	528
8A	Pan American Petroleum Corp. and Skelly Oil Co.	C. M. Gage No. 1	Dec. 17, 1963	13,440	490
41-101	E. B. La Rue, Jr.	E. E. Smith No. 1	June 19, 1955	4,368	415