Ground-Water Geology of Grayson County Texas

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GROUND-WATER GEOLOGY OF GRAYSON COUNTY, TEXAS

By E. T. Baker, Jr.

ABSTRACT

Grayson County in north-central Texas is near the north edge of the West Gulf Coastal Plain. The county has an area of 927 square miles and had an estimated population of 79,500 in 1957. The major town is Sherman, which has an estimated population of 31,000. The northern two-thirds of the county is drained by tributaries of the Red River; the southern one-third is drained by tributaries of the Trinity River.

Sedimentary rocks exposed at the surface in Grayson County are of Cretaceous and Quaternary age. Sand, clay, marl, and limestone of Cretaceous age, having a maximum thickness of about 3,600 feet, underlie the county; the beds dip regionally to the southeast. Quaternary alluvium mantles part of the surface along the Red River and occurs in scattered patches elsewhere in the county.

The Trinity group and Woodbine formation of Cretaceous age are the principal water-bearing formations. Other stratigraphic units that yield water to wells are, in order of importance, the Quaternary alluvium and the Pawpaw formation, Eagle Ford shale, and Austin chalk of Cretaceous age.

Ground water in Grayson County generally moves eastward and southward from areas of recharge to areas of discharge. Average rates of water movement in the Trinity group and Woodbine formation are estimated to be about 1.5 and 15 feet per year, respectively. The chief source of recharge to these aquifers is precipitation on the outcrop, although Lake Texoma contributed some recharge to the Trinity where it crops out in the lake. Ground water discharges naturally by evapotranspiration, by vertical leakage, through springs, artificially through wells, and by underflow out of the county to the southeast.

The withdrawal of ground water in Grayson County in 1957 was about 5 mgd. Of this amount, about 61 percent came from the Woodbine formation, about 36 percent from the Trinity group, and about 3 percent from the other water-bearing formations. About 65 percent of the ground water pumped in Grayson County is withdrawn in the Sherman area.

Increased withdrawal of water since World War II has resulted in a rapid decline of the water levels in parts of Grayson County. The maximum decline in the Trinity group at Sherman from 1945 to 1958 was 113 feet, or about 8 feet per year. During the same period, water levels in the Woodbine formation at Sherman declined as much as 156 feet, an average of 12 feet per year. Total declines since the early part of the 20th century were at least 180 feet in the Trinity group and about 240 feet in the Woodbine formation. Water levels in the area of outcrop of the principal aquifers, fluctuating chiefly in response to rainfall or changes in the natural rate of recharge, showed no appreciable decline from 1957 to 1959.

Coefficients of transmissibility, determined from pumping tests in Grayson County, averaged 2,800 gpd per ft for the Trinity group and 3,200 gpd per ft for the Woodbine formation.

Results of chemical analyses of water samples indicate that the ground water in Grayson County is suitable for most purposes. The Trinity group generally yields soft water that has a high sodium bicarbonate content and is of questionable quality for irrigation. The water from the Woodbine formation ranges more widely in chemical composition than the water from the Trinity. It generally is soft but has a high iron content; it is usually suitable for irrigation in the outcrop area but unsuitable in the downdip area. Water from the other water-bearing formation, though generally hard, is suitable for most purposes, judging from the few analyses available.

The ground-water resources of Grayson County have been only partly developed. The volume of fresh water in transient storage in the Trinity group and Woodbine formation is estimated to be about 60 and 25 million acre-feet, respectively. Most of this water is not practicably recoverable because of the depth at which it occurs, but relatively high artesian heads and large available drawdowns in much of the county are favorable to future development within economic limits of pumping lift. In the Sherman area, however, concentrated pumping has caused large declines in the water levels, resulting in some dewatering of the Woodbine. Because of the large margin of safety before dewatering of the Trinity group begins, the Trinity is the most favorable source of additional ground water for Sherman. However, the higher lifting costs should be considered.

Large to moderate amounts of additional ground water can be obtained from the Trinity group and Woodbine formation in most presently undeveloped areas in the county. Water suitable for irrigation is available in moderate to large amounts from the Woodbine formation in places on its outcrop. A limiting factor to any large ground-water development, however, is the extent and thickness of saturated fresh-water sand available in the area. The thickness of saturated fresh-water sand in the Trinity decreases northward; the thickness of the sand in the Woodbine is more erratic and has little definite pattern.

Moderate to large supplies of water may be available from the alluvium near the Red River, but more information is needed before definite conclusions can be reached.

INTRODUCTION

LOCATION AND EXTENT OF AREA

Grayson County is in north-central Texas between latitudes 33°25′ and 33°55′ N., and longitudes 96°25′ and 96°55′ W. The Red River and Lake Texoma (impounded by Denison Dam on the Red River) form the northern county boundary and the boundary between Texas and Oklahoma. The Texas-Oklahoma State line has been determined as the south bank of the former course of the Red River. Grayson County is bordered on the east by Fannin County, on the south by Denton and Collin Counties, and on the west by Cooke County (fig. 1). Sherman, the county seat, is about 65 miles north of Dallas and about 15 miles south of Lake Texoma. The area of the county is 927 square miles. Lake Texoma covers approximately 143,000 acres, about 26,000 of which is in Texas.

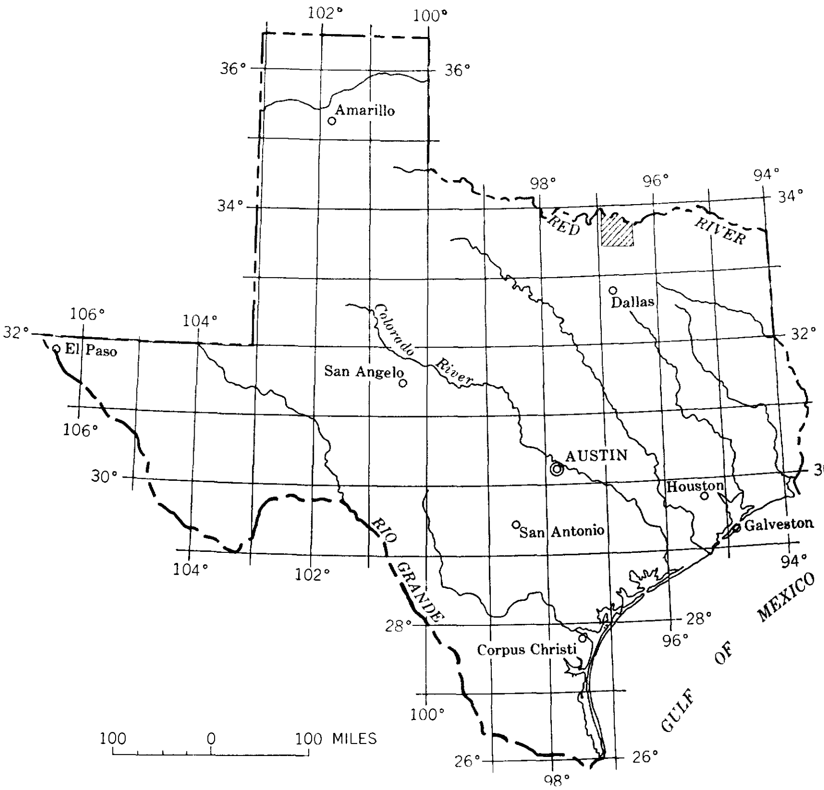

Figure 1.—Map of Texas showing location of Grayson County.

PURPOSE AND SCOPE OF THE INVESTIGATION

Since 1945 the increase of population, expansion of industry, and modernization of both urban and rural homes have greatly increased the use of water in Grayson County. In the Sherman area, the accelerated withdrawals of ground water have emphasized the need for developing additional supplies, as the city of Sherman and several small towns use only ground water for public supply.

Consequently, the current investigation was started as a cooperative project of the city of Sherman, the U.S. Geological Survey, and the Texas Board of Water Engineers. Its purpose was to obtain data on the geology, hydrology, and quality of ground water in Grayson County by which to appraise the county's ground-water resources. Specifically, it was planned to (1) study the geology of Grayson County with special emphasis on the Woodbine formation and the Trinity group, (2) determine the quantity of water in storage in the principal aquifers, (3) study the effect of ground-water withdrawals on water levels in the aquifers, (4) determine the source and areas of recharge, (5) determine the chemical character of the ground water, and (6) estimate the overall potential of the aquifers.

METHODS OF INVESTIGATION

The fieldwork, begun in the spring of 1957 and completed in the fall of 1959, included mapping the geology of the county and collecting hydrologic records pertaining to the occurrence of ground water. The geology was mapped on aerial photographs and the data transferred to a base map. Geologic sections, structure-contour maps showing altitudes of the top of the Woodbine formation and Trinity group, and maps showing thickness of fresh water in the Woodbine and Trinity were prepared from well logs.

The hydrologic records, which are available for inspection in the offices of the Geological Survey in Austin, Tex., include an inventory of 333 wells, drillers' logs of 54 wells, electric logs of many wells, and chemical analyses of water from 219 wells and 2 springs. The location of the wells is shown on plate 1 and figure 2. For purposes of numbering the wells the county has been divided into 10-minute quadrangles, which are lettered alphabetically from the northwest corner of the county in a west-to-east, north-to-south progression. The wells are then numbered consecutively within each quadrangle. A line above the well number on plate 1 and in figure 2 indicates that a chemical analysis of water from the well is available. Analyses of water samples from Lakes Texoma and Randell also are available. The chemical analyses, unless otherwise indicated, were made in the laboratory of the Geological Survey in Austin, Tex.

Periodic water-level measurements were made in 18 wells, and hydrographs of selected wells were prepared to show the fluctuations of the water level. A continuous water-level record of well B–2 was obtained with a recording gage, showing the fluctuations of water level caused by the rise and fall of Lake Texoma.

Pumping tests were made on 16 wells in Grayson County to determine the hydrologic characteristics of the principal aquifers. Pumpage was estimated according to the several uses of the water: public supply, for cities, towns, and communities for which a record of water consumption was available; industrial, by plants having their own wells; domestic; and stock. No estimate was made of pumpage for irrigation, as only about 150 acres was irrigated in Grayson County in 1959.

ECONOMIC DEVELOPMENT

The cities of Sherman and Denison are the industrial centers of Grayson County. Industrial plants in Sherman manufacture textiles, garments, milk products, cottonseed oil, cotton-oil refined products,

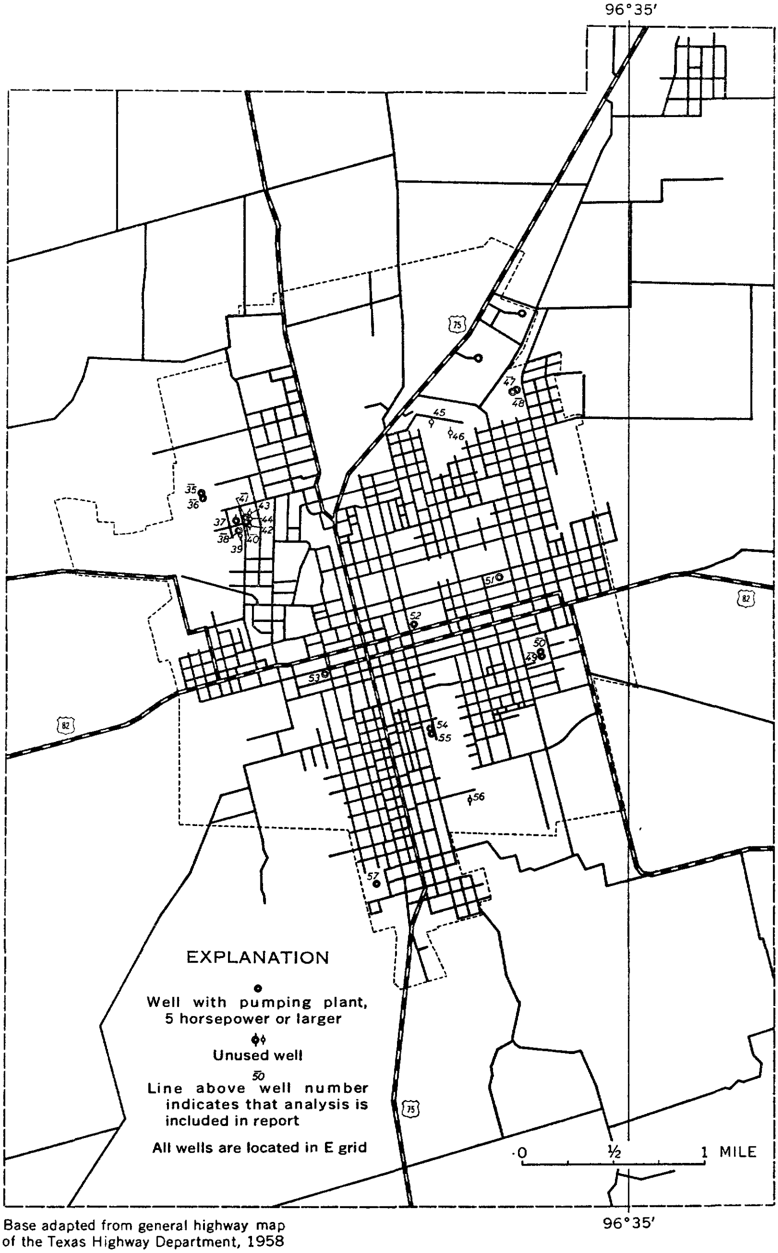

FIGURE 2.—Location of wells in Sherman, Tex.

iron and foundry products, steel and wire products, cotton-gin machinery, building materials, boats, pipes, and oil-well supplies. There are also meatpacking plants, railroad shops, and oil refineries. Denison has diversified industry, including the manufacture of textiles, garments, furniture, mattresses, air-conditioning equipment, dairy products, oleomargine, salad dressing, peanut butter, and livestock feed.

Farming, livestock raising, and dairying are successful in Grayson County because of good soil and favorable climate. The total farm income in 1954 was about $8,500,000 of which 59 percent was received from crops, 30 percent from dairy products, and 11 percent from livestock. Wheat, cotton, corn, oats, grain sorghums, and hay are the principal crops in the southern part of the county; peanuts and truck crops are grown extensively on the sandy soils in the western and northern parts.

The production of oil and gas from fields near Sherman and in the western part of the county is an important source of income. The total oil production in the county from the discovery date through 1958 was about 58,000,000 barrels. The production in 1958 was 6,790,201 barrels, according to records of the Texas Railroad Commission.

The county population, estimated to be 79,500 in 1957, is concentrated in urban areas, about 73 percent being in Sherman and Denison. The population of Sherman increased from 20,150 in 1950 to about 31,000 in 1957; the population of Denison increased from 17,500 to 27,800 in the same period. Ground water supplies the municipal and nearly all the industrial, domestic, and stock needs of the Sherman area, but Denison obtains its municipal supplies from Lakes Randell and Texoma. The following towns use ground water for their public supplies: Whitesboro, population 1,850; Van Alstyne, 1,649; Whitewright, 1,372; Bells, 614; Howe, 572; Collinsville, 561; Tioga, 529; Gunter, 463; Pottsboro, 383 and Tom Bean, 286.

Perrin Air Force Base, between Sherman and Denison, obtains its water supply from two sources; part of it is ground water obtained from 3 wells at their base, and part is surface water purchased from the city of Denison.

The tourist trade is an important factor in the economy of Grayson County. Millions of tourists visit Lake Texoma every year. Many of the motels and fishing and trailer camps in the area obtain their water supply from wells.

PREVIOUS INVESTIGATIONS

Before this investigation very little study had been made of the ground-water resources of Grayson County. Hill (1901, p. 614–627) noted briefly the occurrence of artesian water in Grayson County in his report on the Black and Grand Prairies of Texas. Bullard (1931) mapped and described in detail the geology of Grayson County; however, his report contained very little on the occurrence of ground water. Livingston (1945) reported in detail on the ground-water supplies in the immediate vicinity of Sherman. Sundstrom, Hastings, and Broadhurst (1948, p. 109–116) described the public-water supplies of Sherman, Denison, Whitesboro, Whitewright, Van Alstyne, Bells, Collinsville, Howe, Gunter, and Tom Bean. Bergquist (1949) mapped and reported the geology of the Woodbine formation in Cooke, Grayson, and Fannin Counties.

ACKNOWLEDGMENTS

Appreciation is expressed to the landowners in Grayson County and the surrounding area who furnished information about their wells and gave permission for the periodic measurement of water levels in their wells. Well-drilling contractors, especially Messrs. E. C. Freeman and J. L. McClure of Denison, J. L. Meyers & Sons of Denton, and the Layne-Texas Co., Ltd., of Dallas, supplied drillers' logs and electric logs. The collection of data on the use of water was greatly facilitated by the cooperation of well drillers, well owners, and city and company officials. The U.S. Army Corps of Engineers furnished logs of many test holes and topographic maps of the Lake Texoma area. The Standard Oil Co. of Texas aided the investigation by discussing subsurface correlation problems.

PHYSIOGRAPHY AND DRAINAGE

Grayson County, near the north border of the West Gulf Coastal Plain, is part of a dissected region whose topography is determined chiefly by the type of rock outcrops. On the basis of the outcrops, northern Texas has been divided into physiographic belts which generally coincide with geologic units. The various belts in Grayson County are shown in figure 3.

In the northwestern part of the county the narrow belt known as the Western Cross Timbers occupies the outcrop area of the Trinity group. The belt parallels the shore of Lake Texoma and is characterized by rugged topography marked by deep, steep-walled ravines. The sandy soil supports a growth of post oak and blackjack oak.

The Grand Prairie forms a rolling upland underlain by resistant limestone and softer marl of the Washita and Fredericksburg groups and extends in a narrow belt across the northernmost part of the county. The limestone forms the nearly flat upper surface of the prairie; the marl is exposed in the slopes.

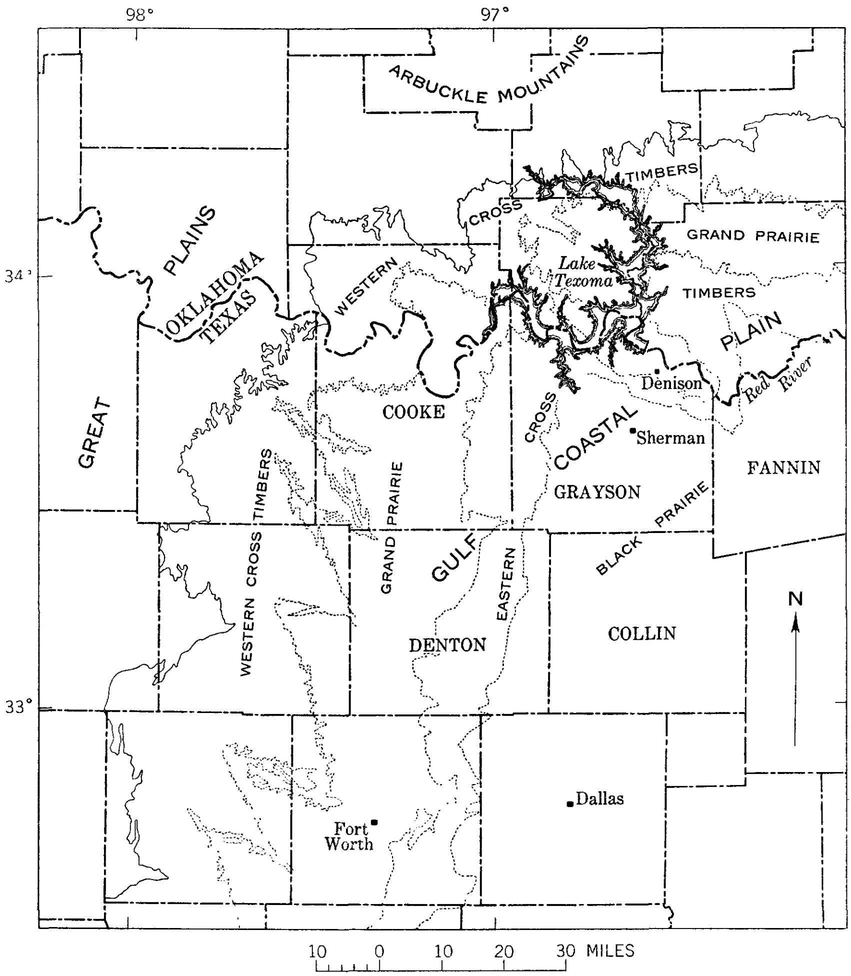

FIGURE 3.—Map of north-central Texas and south-central Oklahoma showing physiographic provinces.

The Eastern Cross Timbers forms a gently rolling sandy belt, about 2 miles wide, that generally coincides with the outcrop of the Woodbine formation. The belt extends from the southwest corner of the county northward through the entire length of the county; thence it swings eastward across the extreme north-central and northeastern parts. The western part of the belt is devoted to farming; the northern part is forested with post oak and blackjack oak.

The Black Prairie occupies the outcrop area of the Eagle Ford shale and the Austin chalk. It forms a gently undulating to moderately rolling surface covering the southeastern three-fourths of Grayson County.

The altitude of Grayson County ranges from about 900 feet above sea level in an area about 5 miles west of Denison to about 500 feet along the Red River at the northeast edge of the county; the maximum relief, therefore, is about 400 feet. The area of greatest relief is in the vicinity of Lake Texoma, where the erosion of the Trinity group (overlain by limestones and marls having greater resistance) has created a rugged topography.

The southern third of Grayson County is drained by the Trinity River, the central and northern parts are drained by the Red River. The divide separating the two drainage systems passes near the towns of Whitesboro, Howe, Tom Bean, and Whitewright. Choctaw Creek, which heads about 6 miles southwest of Sherman, drains the northeastern part of the county, joining the Red River near the Grayson-Fannin County line. Mineral Creek and other intermittent tributaries of the Red River drain the northwestern part of the county and empty into Lake Texoma. Pilot Grove and Sister Grove Creeks and the East Fork of the Trinity River, which drain the southeastern part of the county and the area west of Gunter, empty into Lake Lavon in Collin County. The southwestern part of Grayson County is drained by Range, Buck, and Little Elm Creeks, which empty into Lake Dallas in Denton County.

CLIMATE

Grayson County has a moist subhumid climate—hot summers and mild winters. The mean annual temperature is 64.1°F, the mean July temperature is about 84°F, and the mean January temperature is about 43°F (fig. 4). Occasionally during the summer the temperature reaches 100°F. Freezing weather is not uncommon and generally does not last long. Several light snows fall during the winter, but the snow remains on the ground only a short time. The average dates for the last killing frost in spring and the first killing frost in fall are March 21 and November 17. The long growing season averages 238 days; the rich soils and adequate precipitation make Grayson County a productive agricultural area.

Figures 4 and 5 show graphically the annual and monthly precipitation for the period 1912–58. Precipitation averages 38.89 inches annually and is fairly well distributed throughout the year; the greatest is from April to June and the least from November to February. Droughts sometimes occur in the late summer, but generally they are not prolonged. Extended droughts, although infrequent, may result in loss of crops on many farms, as only a small part of the farm acreage is irrigated.

The average monthly evaporation from a free-water surface, as determined by multiplying evaporation from a class A land pan at the Denison Dam weather station by a factor of 0.80, is shown in figure 4. The average annual evaporation, about 74 inches, is about twice the average annual precipitation. Evaporation is greatest during the hot summer months when soil-moisture demand to sustain plantlife also is large.

GEOLOGY

GEOLOGIC HISTORY

During most of Paleozoic time the area of Grayson County was part of a large sedimentary basin which was receiving a thick accumulation of marine deposits. Near the end of Mississippian time and during the early part of the Pennsylvanian period, structural deformation formed subsidiary troughs and arches within the basin. Parts of the basin subsequently were deepened and faulted, and the basin received several thousand feet of Early Pennsylvanian sediments. By Middle Pennsylvanian time the deeper parts of the basin were filling with sediments and the seas were expanding. A maximum of about 10,000 feet of Middle and Late Pennsylvanian sediments was deposited in the basin. An orogeny during Middle Pennsylvanian time caused a general westward tilting of the land, and the seas moved westward.

Uplift and erosion during the Mesozoic time reduced the area to a nearly flat surface, or peneplain. Because of subsidence in the Gulf

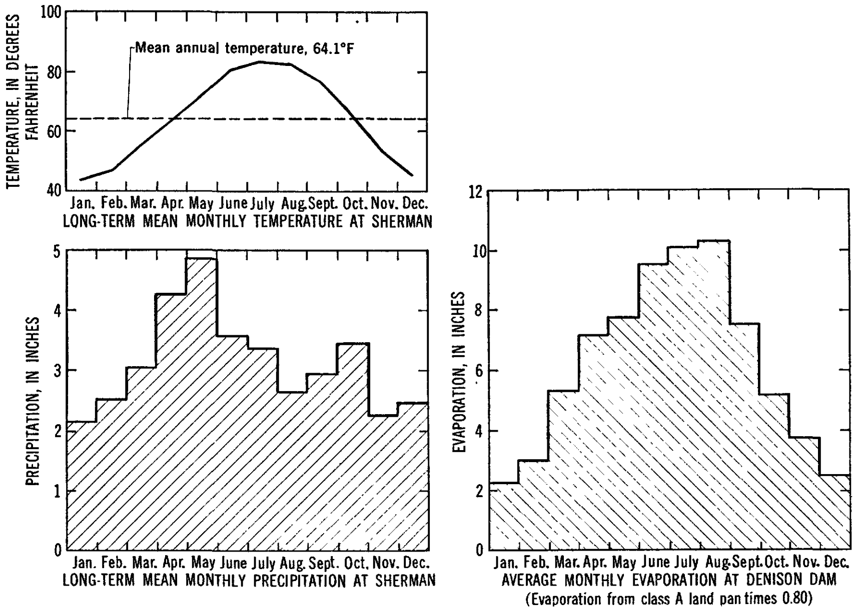

FIGURE 4.—Monthly precipitation and temperature at Sherman, 1912–58, and evaporation at Denison Dam, 1940–58. From records of U.S. Weather Bureau.

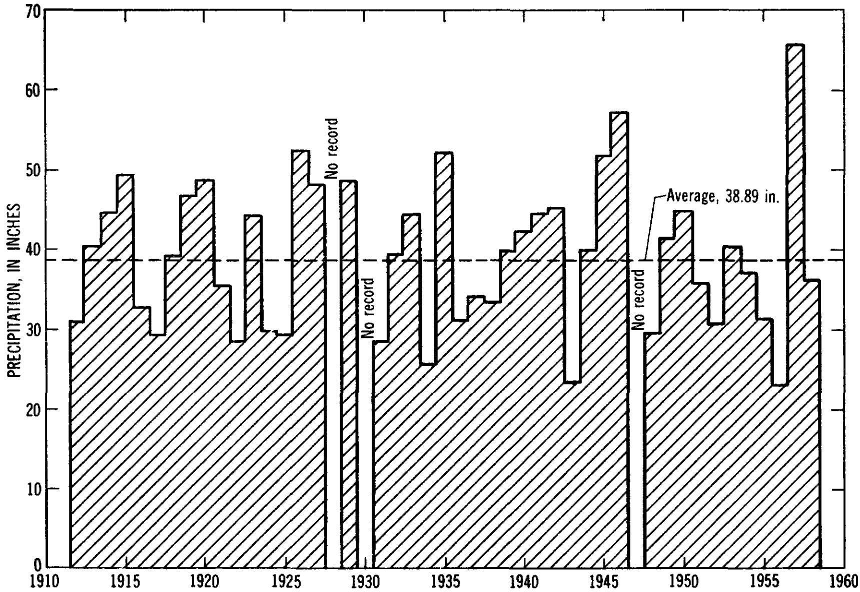

FIGURE 5.—*Annual precipitation at Sherman, Tex. From records of U.S. Weather Bureau.*

Coast geosyncline during middle and late Mesozoic time, Cretaceous seas invaded the area from the southeast and deposited hundreds of feet of sediment in Grayson County, now represented by about 3,600 feet of sand, shale, marl, chalk, and limestone of the Gulf and Comanche series. The seas withdrew at the close of Cretaceous time. Later structural deformation formed the Preston anticline, Sherman syncline, and associated flexures now evident on the surface. Erosion began and probably continued during Quaternary and Tertiary time. Subsidence in the Gulf Coast geosyncline during Quaternary and Tertiary time caused tilting toward the southeast, as represented by the existing regional dip of the Cretaceous strata (pl. 2). Many of the present topographic features, including stream terraces now high above the valley flood plains, were formed during Pleistocene time.

GENERAL STRATIGRAPHY AND STRUCTURE

The consolidated rocks exposed in Grayson County consist of sand, clay, marl, and limestone of Cretaceous age and have an estimated maximum thickness of about 3,600 feet. Near the Red River, the northern boundary of the county, Pleistocene and Recent alluvium, consisting of sand, gravel, clay, and silt, mantle parts of the surface. Alluvium occurs also along streams and in scattered patches elsewhere in the county.

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The Cretaceous system is represented in Grayson County by rocks of the Comanche series, which crop out only in the northern part of the, county and rocks of the Gulf series, which crop out in most of the remainder of the county. The Comanche series includes the Trinity group and rocks of the Washita and Fredericksburg groups. The Gulf series in Grayson County includes the Woodbine formation, Eagle Ford shale, and Austin chalk. The Trinity group and the Woodbine formation are the principal aquifers in the county. The stratigraphy and water-bearing properties of the formations are summarized in table 1.

The Cretaceous formations, deposited on the uneven erosional surface of the Pennsylvanian rocks, have a regional southeastward dip of about 33 feet per mile. Two prominent folds in Grayson County—the Preston anticline and the Sherman syncline—interrupt the general monoclinal dip of the strata. These structural features have a profound effect on the pattern of outcrop of the strata, which have been deflected to the southeast from their typical northward and eastward strike (pl. 1). The position and magnitude of the structures are well illustrated on plate 3, which shows by contours the altitude of the top of the Trinity group.

The Preston anticline, representing an upwarp of about 1,000 feet, begins in western Marshall County, Okla., plunges southeastward across Grayson County, and becomes indistinct in southern Fannin County. From southern Marshall County the axis of the anticline enters Grayson County, crossing the Preston Peninsula and passing just north of Denison and Ambrose (pl. 1). The position of the axis is represented in the Preston area by an outcrop of the Trinity Group between outcrops of the rocks of the Washita and Fredericksburg groups. The dip of the rocks on the south limb of the anticline ranges from a few feet to more than 300 feet per mile; the steepest dip is in an area 1 to 2 miles northeast of Pottsboro. Most of the north limb of the anticline lies in Oklahoma and was not studied during this investigation; however, according to Bullard (1931, p. 62) the dip of the north limb is less steep than that of the south limb.

The Sherman syncline lies immediately to the south of, and roughly parallel to, the Preston anticline. The axis of the syncline trends southeastward, passing through Gordonville and Sherman (pl. 1). The syncline is a broad, shallow, asymmetrical fold having a steep limb on the north and a gently dipping limb on the south. Numerous subordinate flexures such as noses and terraces are present along the north limb of the syncline. A prominent anticlinal nose just east of Sherman is represented on the surface by an inlier of the Eagle Ford shale along a tributary to Choctaw Creek.

TABLE 1.—*Stratigraphic units and their water-bearing properties, Grayson County, Tex.*

System	Series and group		Formation	Thickness (feet)	Character of rocks	Water-bearing properties
Quaternary	Recent and Pleistocene series		Alluvium	0-60	Sand, gravel, clay, and silt.	Yields small to moderate quantities of water to domestic and industrial wells.
Cretaceous	Gulf series		Austin chalk	0-550	White to buff chalk, marl, and limestone.	Yields small quantities of hard water to shallow domestic wells.
			Eagle Ford shale	0-480	Bluish-black gypsiferous shale; thin beds of shale and limestone.	Yields small quantities of water to domestic wells.
			Woodbine formation	0-500	Crossbedded ferruginous sand, laminated shaly clay, lignite, and gypsiferous clay.	Principal aquifer in Grayson County. Furnishes large supplies for municipal, industrial, irrigation, and domestic use. Water is typically high in iron.
	Comanche series	Washita group	Grayson marl	0-50	Yellowish-brown fossiliferous clay and thin limestone.	Not known to yield water to wells in Grayson County.
			Main Street limestone	0-25	Hard white to brownish-white crystalline limestone alternating with layers of marl.	
			Pawpaw formation	0-80	Reddish-brown calcareous clay and yellowish-brown ferruginous sand.	Yields small to moderate quantities of water to wells in outcrop area.
			Weno clay	0-135	Dark-gray to tan shaly clay and thin beds of sand and limestone, fossiliferous.	Not known to yield water to wells in Grayson County.
			Denton clay	0-60	Brownish-yellow clay; some hard sandstone beds; shell agglomerate in upper part.	
			Fort Worth limestone	0-70	Alternating limestone and marl, fossiliferous.	
			Duck Creek formation	0-130	Alternating limestone and marl; limestone predominating in lower part and marl in upper part; fossiliferous in lower part.	
		Fredericksburg group	Kiamichi formation	0-35	Greenish clay and thin limestone beds; fossils abundant in upper part.	
			Goodland limestone	0-40	White fossiliferous limestone.	
			Walnut clay	0-22	Black gypsiferous fissile shale; ledges of shell breccia.	
		Trinity group	Undifferentiated rocks	500-1,200	Fine to medium sand and beds of red, purple, and gray clay.	Yields large supplies of water for municipal, industrial, and domestic uses. Water is saline in northern part of county.
Pennsylvanian	Undifferentiated			15,000±	Gray to red sandy shale, sandstone, and limestone.	Does not contain fresh water in Grayson County.

According to Harrington (1957, p. 74), the surface expression of the Sherman syncline and Preston anticline is a consequence of subsidence in the Tyler basin of east Texas and seems to reflect a wrinkling of incompetent Pennsylvanian and Cretaceous strata over the flexed Arbuckle limestone, which, when bending to join the corner of the Tyler basin, compressed the less competent beds above.

No major faults were seen at the surface in Grayson County. The narrow outcrop of the Eagle Ford shale between Sherman and Denison suggests a fault, in view of the fact that no steep dips of strata were noted at the surface in that area. This is the area of the so-called Cook Springs fault postulated by Hill (1901, p. 384).

Several small-scale faults are present in widely scattered parts of the county. In a railroad cut 6 miles northeast of Whitesboro, a fault having a 6-foot throw was observed in the Woodbine formation and Eagle Ford shale. Other faults having small displacements were noted on the outcrop of the Austin chalk.

ROCK UNITS AND THEIR WATER-BEARING PROPERTIES

PENNSYLVANIAN ROCKS, UNDIFFERENTIATED

Rocks of Pennsylvanian age do not crop out in Grayson County; however, they are found in most places directly below the Trinity group, although oil tests in a few places in the eastern part of the county penetrated overthrust rocks of possible Mississippian age directly under the Cretaceous cover. Pennsylvanian rocks are found at depths ranging from about 3,500 feet in the southeastern part of the county to 600 feet in the northwestern part. The Pennsylvanian rocks consist of a maximum thickness of about 15,000 feet of gray to red sandy shale, limestone, and sandstone. The rocks have a regional westward dip, in contrast to the overlying Cretaceous beds which dip regionally southeastward. The Pennsylvanian rocks in Grayson County do not contain fresh water.

CRETACEOUS SYSTEM

COMANCHE SERIES

The Comanche series, the lowermost division of the Cretaceous system, includes the Trinity, Fredericksburg and Washita groups. The oldest, the Trinity group, was deposited by an encroaching sea on an erosional land surface. The overlying Washita and Fredericksburg groups are distinguished by their cyclical type of deposition, indicated by an alternating sequence of limestone, clay, and marl, which is characteristic of sediments laid down during transgressions and regressions of the sea. In Grayson County the Comanche series ranges in thickness from about 500 to more than 800 feet.

TRINITY GROUP, UNDIFFERENTIATED

The Trinity group is not differentiated in Grayson County. Throughout Trinity time, Grayson County was near the shore of a sea which had encroached upon the land from the southeast. In Grayson County and vicinity the deposits laid down in the Trinity sea consisted chiefly of sand and minor amounts of clay and gravel. To the south the Trinity sea deposited limestone as well. In Tarrant County, for example, the Trinity group includes, in ascending order: the Travis Peak formation (chiefly sand), Glen Rose limestone, and Paluxy sand. A facies change (representing a difference in the type of deposition) in Denton and Jack Counties south and west of Grayson County caused the Glen Rose limestone to grade into sand, so that in the area north of the facies change the Trinity group consists chiefly of sand, as the Glen Rose limestone is absent.

The Trinity group crops out in massive beds in a narrow belt in the northwestern part of Grayson County that extends along the south shore of Lake Texoma for several miles in the region known as the Western Cross Timbers. Uplift and erosion associated with the Preston anticline have exposed the Trinity in this region; elsewhere in the county it is buried beneath younger rocks. The principal outcrop areas of the Trinity are to the west in Cooke and Montague Counties and to the north in Oklahoma (fig. 6). The Trinity is eroded readily and, where capped by the Walnut clay and resistant Goodland limestone, forms steep bluffs and deep ravines. The outcrop of the Trinity in Grayson County in most places is covered by a loose mantle of alluvium deposited by Red River floods.

In Grayson County, the Trinity group typically begins with a basal conglomerate and passes upward into a fine white to gray poorly consolidated sand in massive beds. Beds of red, purple, or gray clay, scattered throughout the formation, generally in the form of lenses which are not continuous or extensive over large areas, are not effective barriers to the movement of ground water, except locally. Because of the lenticular structure, individual clay beds generally cannot be correlated from place to place. The massive beds near the base and top of the Trinity probably correspond to the Travis Peak formation and Paluxy sand of central Texas. The middle part of the Trinity contains more thin sand beds than either the upper or lower part. Electric logs show some evidence of limestone beds in the middle part of the Trinity in southern Grayson County; these may correspond, in part, to the Glen Rose limestone of central Texas.

Southeast of its outcrop the Trinity group becomes deeply buried. It is penetrated at Sherman at a depth of about 1,500 to 1,600 feet and, in the southeast corner of the county, at about 2,000 feet (pl. 2). The

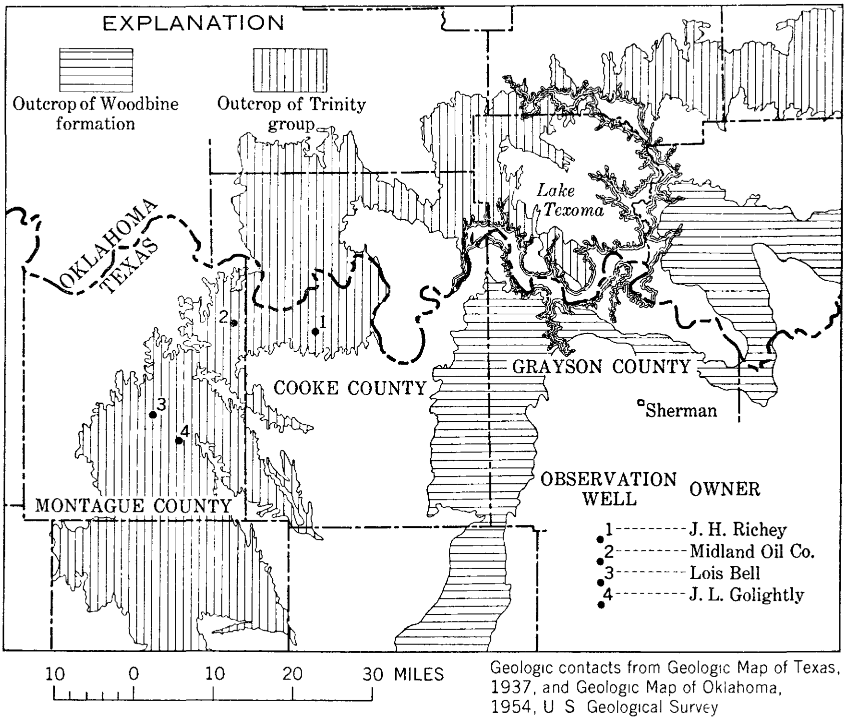

Figure 6.—Geologic map showing outcrop of Woodbine formation and Trinity group in Grayson County and surrounding area and location of observation wells in Cooke and Montague Counties, Tex.

southeastward dip of the Trinity, averaging 48 feet per mile, is greatest on the south limb of the Preston anticline in the northern part of the county. The thickness of the Trinity ranges from about 500 to more than 1,200 feet, increasing in the direction of dip. The extent of the Trinity in the county and the altitude of the top are shown on plate 3.

A zone of saline water is present in the Trinity group in northern Grayson County along a narrow belt having a northwest-southeast trend parallel to the Preston anticline. South of the axis of this zone, the salinity gradually decreases until at Sherman most of the Trinity yields fresh water.

The Trinity group is second in importance to the Woodbine formation as an aquifer in Grayson County, supplying about one-third of the county's ground-water needs. In the northern part of the country, where the Woodbine formation is absent, the Trinity supplies most of the water for municipal, domestic, and stock use. Few wells penetrate the Trinity in southern Grayson County, owing to its depth and to the accessibility of the shallower Woodbine formation.

The following composite section, which includes the Goodland limestone, Walnut clay, and the upper part of the Trinity group, was measured at a roadcut 7.8 miles northwest of Denison and in a bluff, overlooking Lake Texoma, 6.5 miles northwest of Denison.

	Feet
Goodland limestone:	
Limestone, fossiliferous, very hard, massive, white; contains *Gryphaea* sp.; weathers to thin plates	8.6
Limestone, very fossiliferous, chalky, massive, white; contains *Turritella* sp., *Gryphaea*, and *Pecten*	4.0
Total	12.6
Walnut clay:	
Clay, fissile, black; contains streaks of yellow sericite and plates of selenite	1.0
Limestone, very fossiliferous, hard, yellowish-brown; 1- to 2-in. layer of fibrous impure calcite; contains *Exogyra Gryphaea*	2.2
Shale, fissile, black; contains streaks of sericite and incrustations of selenite	4.3
Sandstone, very fossiliferous, calcareous, nodular, hard, brownish-gray; *Exogyra* and *Gryphaea* abundant	.9
Total	8.4
Trinity group:	
Shale, sandy, ferruginous, light-gray; contains carbonized wood fragments	3.0
Sand, coarse to very coarse, light-gray. Grains composed of quartz. Top 3 in. is indurated fine-grained sandstone	3.3
Sand, medium to coarse, light-gray, crossbedded, locally ferruginous; contains pebbles and granules	6.0
Sand, fine, light-gray, slightly indurated; ferruginous near top	3.4
Sand, loose, light-gray. Grades upward into light-brown ferruginous indurated 3-in. sandstone bed containing small pebbles	5.0
Sand, medium, yellowish-brown, crossbedded; contains nodules of pyrite. Grades upward into 3-in. bed of light-gray hard sandstone	1.3
Sand, clayey, light-gray. Grades upward into 2-in. bed of white hard pebbly sandstone	1.7
Total	23.7
Total section measured	44.7

FREDERICKSBURG GROUP

The Fredericksburg group overlies the Trinity group in Grayson County and includes, in ascending order, the Walnut clay, Goodland limestone, and Kiamichi formation. The thickness of the group, chiefly clay and limestone, ranges from 0 to about 100 feet, increasing southward and southeastward. The dip of the rocks averages about 40 feet per mile southeastward.

The formations of the Fredericksburg group are not differentiated on the geologic map; however, their stratigraphic and structural relationships are shown in the geologic cross sections (pl. 2).

WALNUT CLAY

The Walnut clay unconformably overlies the Trinity group and crops out along Lake Texoma in the northwestern part of Grayson County. It consists of black gypsiferous fissile shale and layers of shell breccia containing an abundance of *Exogyra texana* Roemer and *Gryphaea marcoui* Hill and Vaughan. The thickness of the Walnut clay ranges from 8 feet where the section is complete near the outcrop to about 22 feet in southwestern Grayson County. Bybee and Bullard (1927, p. 15–16) assign a thickness of 25 feet to the Walnut clay in southern Cooke County. The Walnut is not known to yield water to wells in Grayson County.

GOODLAND LIMESTONE

The Goodland limestone, named for the town of Goodland in Choctaw County, Okla., conformably overlies the Walnut clay. The Goodland crops out in a sinuous steep northward-facing escarpment extending along Lake Texoma from the Cooke County line almost to Denison. Bullard (1931, p. 22) noted a small inlier of the Goodland limestone on Shawnee Creek east of Lake Randell, about 3½ miles northwest of Denison. The Goodland ranges in thickness from 12 feet where the section is complete near the outcrop to about 40 feet in the southern part of the county. The increase in thickness to the south and downdip is due to the presence of intervening clay and marl beds in the lower half of the formation. Winton (1925, p. 18) reports that the Goodland thickens from 42 feet in northwestern Denton County to 75 feet in the southwestern part. In southeastern Tarrant County the Goodland reaches a maximum thickness of 130 feet (Leggat, 1957, p. 24). At an outcrop northwest of Denison near Lake Texoma, the upper 8 feet of the formation is extremely hard crystalline limestone, which weathers into thin, platy fragments; the lower 4 feet is chalky limestone. The upper part is sparsely fossiliferous; the lower part contains *Pecten*, *Turritella* sp., and *Gryphaea* sp. (See measured section, p. 17.) Throughout Grayson County the Goodland is easily identifiable on electric logs and is a valuable marker for structural mapping. The Goodland limestone is not known to yield water to wells in Grayson County.

KIAMICHI FORMATION

The Kiamichi, named for a river in Choctaw County, Okla., conformably overlies the Goodland limestone in Grayson County. It crops out in benches or terraces between the resistant Goodland limestone and the overlying Duck Creek formation. The Kiamichi, averaging 30 to 35 feet in thickness, consists predominantly of greenish clay. Near the upper part, ledges of hard limestone 4 to 6 inches thick contain an abundance of the typical oyster *Gryphaea navia* Hall. These fossiliferous ledges, which are persistent across the county, constitute one of the most prominent stratigraphic horizons in the Comanche series. The Kiamichi is not known to yield water to wells in Grayson County.

WASHITA GROUP

The Washita group, which overlies the Fredericksburg group with apparent conformity, was named for Fort Washita in Bryan County, Okla. Included in this group, in ascending order, are the Duck Creek formation, Fort Worth limestone, Denton clay, Weno clay, Pawpaw formation, Main Street limestone, and Grayson marl. The Washita group ranges in thickness from 435 to about 550 feet, thickening downdip but thinning southward along the strike. The group, chiefly alternating beds of limestone and marl but containing some sand near the top, forms a large part of the Grand Prairie, an area of gently rolling hills which extends across the northern part of the county. The formations of the Washita group are not differentiated on the geologic map and are mapped together with the formations of the Fredericksburg group (pl. 1). The stratigraphic and structural relationships are shown on the geologic cross sections (pl. 2). The Washita group is not an important source of water in Grayson County. The Pawpaw formation, however, supplies small to moderate quantities of water to shallow domestic wells near its outcrop in the northern part of the county.

DUCK CREEK FORMATION

The Duck Creek formation, named for a creek about 3 miles north of Denison, overlies the Kiamichi with apparent conformity in Grayson County. However, near Fort Worth the presence of rounded pebbles and transported debris at the contact suggests a lack of conformity (Adkins, 1932, p. 349). The outcrop extends across much of the northern part of Grayson County, crossing the Red River northeast of Denison. The formation ranges in thickness from about 90 to 130 feet; the thickness is rather uniform in the downdip direction but decreases along the strike toward the south. The Duck Creek consists chiefly of interbedded nodular limestone and marl; the limestone weathers to form prominent ledges. In the lower 40 to 50 feet, the limestone and marl alternate in thin beds; however, the limestone is predominant, as the limestone beds are thicker. The marl beds greatly predominate in the upper 60 to 70 feet, where the limestone beds are thinner and are separated by increasingly greater thicknesses of marl. The contact with the overlying Fort Worth limestone is gradational from marl to limestone.

The lower part of the Duck Creek formation is very fossiliferous. The large ammonite *Desmoceras brazoense* (Shumard), abundant in a narrow zone 30 to 40 feet above the base of the formation, is valuable for structural mapping because of its limited range. Other fossils in the Duck Creek formation include the ammonites *Hamites* sp. and *Pervinguieria trinodosa* (Böse), several species of the echinoid *Hemiaster*, and the pelecypod *Inoceramus comancheanus* Cragin.

The Duck Creek formation is not known to yield water to wells in Grayson County.

FORT WORTH LIMESTONE

The Fort Worth limestone, named for excellent exposures in the city of Fort Worth, overlies the Duck Creek formation conformably and crops out in northern Grayson County on the south flank of the Preston anticline. The area of outcrop is characterized by cuestas, which result in a rough topography. The Fort Worth is about 60 feet thick near the outcrop and thickens downdip to about 70 feet in the southeastern part of the county. The formation thins southward along the strike and is about 50 feet thick in the southwestern part of the county.

The Fort Worth consists of limestone and marl in alternating beds which may be separated into three distinct lithologic units. The lower unit consists of about 15 to 20 feet of limestone and minor beds of marl; the middle unit, about 20 feet thick, is predominantly marl; and the upper unit, about 15 to 20 feet thick, is chiefly limestone. The Fort Worth limestone is easily confused with the underlying Duck Creek formation, but may be distinguished from it on the basis of fossils. Characteristic fossils in the Fort Worth include the abundant echinoid *Hemiaster elegans* Shumard and the ammonite *Pervinquieria leonensis* (Conrad).

The Fort Worth limestone is not known to yield water to wells in Grayson County.

DENTON CLAY

The Denton clay, which conformably overlies the Fort Worth limestone, crops out in a narrow band across most of northern Grayson County; the most prominent exposures are northwest of Pottsboro along Lake Texoma. Near the area of outcrop the formation is about 60 feet thick, but it thins downdip to about 40 feet in the southeastern part of the county. Winton (1925, p. 25) reports a thickness of 25 to 35 feet of the clay in Denton County. The Denton consists of

Brownish-yellow clay and thick beds of hard light-colored sandstone. A bed of sandy shell agglomerate, containing an abundance of *Gryphaea washitaensis* Hill and *Ostrea carinata* Lamarck, marks the top of the formation.

The Denton clay is not known to yield water to wells in Grayson County.

WENO CLAY

The Weno clay, named for the small village of Weno (now abandoned) on the Red River northeast of Denison, is apparently conformable with the underlying Denton clay and the overlying Pawpaw formation. The outcrop of the Weno extends in a narrow belt across the northern part of the county. The formation ranges in thickness from about 110 to about 135 feet, Bullard (1926, p. 38) reports a thickness of 135 feet in northern Marshall County, Okla. The formation consists of dark-gray to tan shaly clay, thin beds of sand, clay-ironstone concretions, and in the upper part some hard sandstone and limestone beds. The fossils *Ostrea quadriplicata* Shumard and *Turritella* sp. are characteristic of the Weno.

The Weno clay is not known to yield water to wells in Grayson County.

PAWPAW FORMATION

The Pawpaw formation, named for the outcrop on Pawpaw Creek north of Denison, conformably overlies the Weno clay. The outcrop lies in a narrow belt in the northern part of the county. Locally, the Pawpaw forms a topography very similar to that of the Eastern Cross Timbers belt, and the formation may be mistaken for the Woodbine formation. The Pawpaw is about 60 feet thick near the outcrop and thickens downdip to about 80 feet in the southeastern part of the county. The formation thins slightly along the strike to the south; near the Denton County line the thickness is about 50 feet. The Pawpaw consists of reddish-brown calcareous clay in the lower part and poorly cemented yellowish-brown ferruginous sand at the top. The sand at the top of the formation generally is in a massive bed 20 to 30 feet thick. Nodules and pebbles of ironstone are characteristically abundant on the outcrop. Pelecypods, many of them in a good state of preservation, are abundant in the clay.

The sand in the Pawpaw formation yields small to moderate quantities of water to shallow wells in the area of outcrop in Grayson County. South of the outcrop, wells generally do not penetrate the Pawpaw but produce exclusively from the Woodbine formation. However, a few large-capacity wells in the Woodbine, notably at Sherman, include the sand of the Pawpaw in the screened section.

The following section, which includes all the Pawpaw formation, Main Street limestone, Grayson marl, and the basal part of the

Woodbine formation, was measured at the railroad cut of the Pottsboro cutoff of the Missouri, Kansas, and Texas Railroad, about 5½ miles west of Denison.

	Feet
Pawpaw formation:	
Sandstone, brittle, platy, ferruginous, fine-grained	1.0
Shale, slightly sandy, light-gray; surface covered with irregularly shaped limestone nodules; ironstone concretions containing impressions of pelecypods are abundant in upper part	11.0
Sand, platy, very fine, light-brown	.7
Shale, light-gray; contains clay-ironstone concretions, small limestone nodules, and thin beds of sand; weathers red	21.0
Sand, ferruginous, massive, brownish-yellow; contains thin lenses of ironstone having impressions of small pelecypods; upper 5 ft. clayey and highly fossiliferous	22.0
Total	55.7
Main Street limestone:	
Limestone, hard, grayish-white	1.2
Marl, gray; contains *Exogyra arietina* Roemer	.5
Limestone, gray; contains *Exogyra arietina* Roemer	1.5
Marl, dark-gray, fossiliferous	.3
Limestone, gray, fossiliferous	.5
Marl, gray; contains *Exogyra arietina* Roemer	.3
Limestone, hard, grayish-white; contains *Pecten* sp	.5
Marl, yellowish-gray; contains *Kingena wacoensis* (Roemer)	.3
Limestone, hard white; contains *Kingena wacoensis* (Roemer)	1.5
Marl, gray, fossiliferous	.8
Limestone, light-gray; contains *Exogyra arietina* Roemer and *Kingena wacoensis* (Roemer)	.9
Marl, light-gray; contains nodules of limestone	3.0
Total	11.3
Grayson marl:	
Marl, light-gray; contains thin beds and nodules of limestone, *Exogyra arietina* Roemer, and *Gryphaea mucronata* Gabb	11.0
Covered by soil	11.0
Total	22.0
Woodbine formation:	
Covered by sandy soil; surface shows fragments of ferruginous pebbles	6.0
Sandstone, indurated, fine-grained, white	9.0
Clay, plastic, dark-red and light-gray; contains thin sand beds	14.0
Sandstone, ferruginous, slightly indurated, light-brown	12.0
Sandstone, indurated, dark-red, crossbedded; contains beds of conglomeratic ironstone and fragments of petrified wood	14.0
Total	55.0
Total section measured	144.0

MAIN STREET LIMESTONE

The Main Street limestone, named for exposures on the main street of Denison, conformably overlies the Pawpaw formation. The hard limestone crops out in conspicuous ledges along the Red River in northern Grayson County and is easily mapped. Likewise, the Main Street is easily identified on electric logs and serves as a useful stratigraphic marker. The thickness of the Main Street ranges from 11 to 15 feet in the outcrop area. Unlike most of the other formations in the area, the Main Street thickens along the strike toward the south, reaching a thickness of about 25 feet in the southwestern part of the county. The Main Street consists of 1- to 2-foot beds of hard white to brownish-white crystalline limestone alternating with marl layers 1 to 6 inches thick. Generally, the limestone is massive at the base, but it becomes thinner near the top where the marl beds are prominent. Oxidation of pyrite in the limestone causes an iron-stained appearance. *Exogyra arietina* Roemer and *Kingena wacoensis* (Roemer) occur in the upper part of the limestone and *Turrilites brazoensis* Roemer near the base.

The Main Street is not known to yield water to wells in Grayson County.

GRAYSON MARL

The Grayson marl, the uppermost member of the Washita group and Comanche series, crops out in a narrow belt extending across the northern part of the county. Bergquist (1949) described about 17 feet of "unnamed shale and sandy clay (post-Grayson)" directly above the Grayson marl and below the Woodbine formation. These rocks are included with the Washita and Fredericksburg groups on the geologic map (pl. 1) and with the Grayson marl on the cross sections (pl. 2). Ferruginous debris and slope wash from the overlying Woodbine generally cover the Grayson outcrop, and good exposures are rare. The thickness of the formation averages about 15 to 20 feet near the outcrop and thickens to about 25 feet southward along strike. Downdip in the southeastern part of the county, the Grayson marl thickens to nearly 50 feet. It consists of yellowish-brown fossiliferous calcareous clay, bluish-gray marl containing many nodules of limestone, and thin layers of grayish limestone. The more prominent limestone beds near the base represent the gradation from the underlying Main Street limestone. The lower part of the Grayson contains an abundance of *Exogyra arientina* Roemer. Other characteristic fossils include *Gryphaea mucronata* Gabb and *Turrilites brazoensis* Roemer.

The Grayson marl is not known to yield water to wells in Grayson County.

GULF SERIES

Rocks of the Gulf series overlie rocks of the Comanche series unconformably and are represented in Grayson County by the Woodbine formation, Eagle Ford shale, and Austin chalk. These sedimentary rocks have an average southeastward dip of 35 feet per mile and reach a maximum thickness of about 1,500 feet. Cropping out in more than three-fourths of Grayson County, the rocks of the Gulf series form the surface of the Eastern Cross Timbers and Black Prairie belts.

WOODBINE FORMATION

The Woodbine formation, named for the village of Woodbine in eastern Cooke County, is the basal formation of the Gulf series in north Texas. The relation of the Woodbine to the underlying rocks of the Comanche series has not been determined in Grayson County. However, the Woodbine apparently rests unconformably on the underlying Grayson marl, although the contact is obscured in many places by overwash. Bergquist (1949) reported that in the vicinity of Cedar Mills about 9.5 miles northwest of Pottsboro the Woodbine formation, containing reworked shells of *Gryphaea mucronata* Gabb at the base, is channeled through the Grayson marl and rests on Main Street limestone. Electric logs of wells in the Gordonville-Sandusky area, about 8 miles north of Whitesboro, show abnormal relationships at the contact zone. (See wells A–20, A–43, D–3, and D–8 on pl. 2). The contact of the rocks of the Comanche and Gulf series in that area is obscure; the Woodbine appears to overlie rocks that are not lithologically typical of the upper Washita group. It is not known whether erosion removed much of the upper rocks of the Washita in this area before deposition of the Woodbine or whether a local facies change altered the typical composition of the rocks.

The Woodbine outcrop (forming the Eastern Cross Timbers belt in Grayson County) averages 6 miles in width along the Cooke County line, but narrows to 3 miles across the northern part of the county. The outcrop begins to narrow a few miles east of Pottsboro because of steeply dipping beds. The Woodbine weathers to a loose soil which supports a growth of post oak and blackjack oak on the hilly northern outcrop. The surface is gently rolling near the Cooke County line where the proportion of clay is greater, and prairies predominate in that area. The Woodbine formation thickens downdip, increasing from 410 feet near the outcrop to 500 feet in the southeast corner of the county. The Woodbine consists of medium to coarse crossbedded ferruginous sand, much of which is unconsolidated, and laminated shaly clay interbedded with layers of lignite and gypsiferous clay. Beds of hard siliceous sandstone are scattered throughout the Woodbine; locally, the outcrop is covered with residual boulders of siliceous sandstone. Massive reddish sand beds are found in some places; however, the individual beds are highly lenticular and grade into clay within short lateral distances. In most places in Grayson County the thickest sand beds are found at or near the base and in the upper third of the Woodbine. The presence of alunite nodules serves as a criterion for determining the position of the contact of the Woodbine with the overlying Eagle Ford shale (Stephenson, 1946, p. 1765).

Plate 4 shows by contours the altitude of the top of the Woodbine in Grayson County. If the altitude of the land surface is known, the depth to the top of the sand can be computed for any locality in the county. For example, the map shows the altitude of the top of the formation at Sherman to be about 200 feet. The altitude of the land surface is about 750 feet; consequently, the depth to the formation is about 550 feet.

The Woodbine is the principal source of ground water for public supply, industrial, irrigation, and domestic use in Grayson County. It supplies water to all the industrial wells in the Sherman area. Water from the Woodbine typically has a high iron content, but otherwise it is satisfactory for nearly all purposes. Locally, it may be highly mineralized where the water-producing sands contain lignite.

EAGLE FORD SHALE

The Eagle Ford shale, named for the village of Eagle Ford, 6 miles west of Dallas, conformably overlies the Woodbine formation. The outcrop pattern approximates that of the Woodbine, having two distinctly different directions of strike. The 8-mile-wide north-south outcrop turns abruptly eastward near Pottsboro, continues in a narrow belt ½ to 3 miles in width, and leaves the county near the town of Bells. The outcrop of the Eagle Ford shale, forming a part of the Black Prairie belt, is a treeless prairie in most places in Grayson County; locally, near Bells, sandy layers in the upper part of the shale become prominent enough to produce a wooded sandhill topography. The Eagle Ford ranges in total thickness from 440 to about 480 feet in uneroded sections in Grayson County.

The formation consists chiefly of bluish-black gypsiferous shale and some thin lenses and bands of hard limestone. Calcareous concretions are found in the upper and lower parts. Near the top of the Eagle Ford, sand layers—in places hard fossiliferous sandstone—total about 15 to 20 feet in thickness and become thicker eastward. The hard fossiliferous sandstone layers contain an abundance of *Ostrea lugubris* Conrad.

The following section, which includes the upper part of the Eagle

Ford shale and the basal Austin chalk, was measured along the county road and Choctaw Creek, 5½ miles southwest of Sherman.

	Feet
Austin chalk:	
Chalk, hard, white, platy	6.0
Marl, soft, light-brown; sandy near bottom; indurated and layered near top, grading into overlying chalk; contains limestone pebbles	22.0
Conglomerate, slightly cemented; pebbles of crystalline limestone, sand stone, phosphate, and reworked *Ostrea lugubris* Conrad average 2 to 3 in. in size	1.5
Total	29.5
Eagle Ford shale:	
Sandstone, hard; cemented with calcium carbonate; *Ostrea lugubris* Conrad abundant	1.5
Sand, clayey, light-gray to yellow-brown; few hard thin sandstone layers; sparse pelecypod fauna	7.0
Shale, fissile, dark-gray; veins of yellow sericite	15.5
Sandstone, very fossiliferous, hard, light-gray, lenticular; small pebbles of dark-colored jasper; changes in places to a sandy shale with large septarian concretions. *Ostrea* sp. Upper 6 in. contains gastropod fauna	1.0
Shale, sandy, fissile, dark-gray; contains local lenses of hard sandstone	3.0
Total Eagle Ford shale measured	28.0
Total section measured	57.5

The Eagle Ford shale supplies small quantities of water to shallow wells in Grayson County.

AUSTIN CHALK

The Austin chalk, unconformably overlying the Eagle Ford shale, is the youngest formation of Cretaceous age in Grayson County. Underlying about one-third of the county, the Austin chalk forms a westward-facing white escarpment overlooking the broad plain formed by the Eagle Ford shale. The outcrop of the Austin chalk, mainly in the central and southeastern parts of the county, weathers to a black residual soil forming a part of the Black Prairie belt. The maximum thickness of the formation in Grayson County is about 550 feet.

The Austin consists of chalk and limestone interbedded with layers of marl. The deeply buried rocks are bluish gray; those near the surface in the zone of weathering are chalky white. *Inoceramus* sp. and segregations of pyrite, which alter into marcasite, are commonly associated with the limestone beds. The base of the Austin chalk is marked by the presence of a conglomerate containing an abundance of *Ostrea lugubris* Conrad and fish teeth. The basal conglomerate in part, is the so-called fish-bed conglomerate of Taff and Leverett (1893, p. 303).

The Austin chalk supplies small quantities of hard water to shallow dug wells in Grayson County. Many of the wells are dry during extended periods of drought.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES, UNDIFFERENTIATED

ALLUVIUM

Alluvial deposits, which form flood plains and terraces, are Pleistocene and Recent in age but are undifferentiated on the geologic map (pl. 1). Generally, the older alluvial deposits, which are represented by terraces high above the present stream valleys, are dissected and show effects of erosion. In some areas the high-level terraces coalesce near junctions of streams and cap interstream divides. Associated with the high-level terraces are the younger, lower lying deposits, which form benches or broad terraces adjacent to the streams. The lowermost surface is the flood plain which includes the present stream bed.

The alluvium along each stream consists of sediments derived from rocks that crop out within the drainage basin of the stream. Streams draining shaly areas deposit alluvium that consists chiefly of tight, impermeable material; conversely, streams that drain sandy areas deposit alluvium that consists chiefly of permeable material. In some places in Grayson County the alluvium consists almost entirely of relatively impermeable clay or silt. In other places, especially along the Red River where meanders are common, it includes layers of sand, or possibly buried channels of gravel, that may yield water freely. The thickness of the alluvial deposits in Grayson County ranges from 0 to about 60 feet.

The most extensively developed terrace and flood-plain deposits in Grayson County are associated with the Red River. Many of the low-level deposits west of Denison Dam are now covered by Lake Texoma. In the northeastern part of the county, alluvium forms about 17 square miles of flood-plain and terrace deposits along the Red River. The highest deposits, about 200 feet above the river, are poorly exposed and deeply eroded; the younger terrace deposits, nearer the river, are most distinct. A measured section of the deposits of the lower terrace, which is about 40 feet above the river, disclosed about 30 feet of sand, silt, and clay; there is gravel at the base. North of Denison, in an area of about 4 square miles, the alluvium is reported to be as much as 60 feet thick.

Less extensive deposits of alluvium are found in other parts of the county, notably along the upper reaches of Choctaw Creek and along

Isle du Bois, Range, and Buck Creeks (pl. 1). The alluvium in these areas probably is thin and unimportant hydrologically.

The alluvial deposits in Grayson County yield small to moderate quantities of water, chiefly to domestic wells. Only those deposits north of Denison and in the northeastern part of the county are known to be water bearing. The water in the alluvium is hard but otherwise suitable for most uses.

GROUND WATER

OCCURRENCE AND MOVEMENT

Open spaces in rocks, called voids or interstices contain the water that is found in the zone of saturation below the land surface. This water may be recovered through wells and springs. The capacity of a rock to hold water is determined by its porosity, but its capacity to yield water is determined by its permeability. Some deposits, such as silt or clay, may have a high porosity; but because of the minute size of the interstices they transmit water very slowly. Other deposits, such as well-sorted gravel, contain large interconnected openings which transmit water rapidly. Part of the water in any deposit does not drain into wells by gravity because it is held against the force of gravity by molecular attraction. Below a certain level the permeable rocks are saturated with water under hydrostatic pressure. The upper surface of the zone of saturation is called the water table. Wells dug or drilled into the zone of saturation become filled with ground water to the level of the water table.

Artesian conditions exist where permeable strata pass between less permeable strata, and ground water becomes confined under pressure. Water enters the aquifer at its outcrop and percolates slowly down to the water table and then laterally down the dip of the water-bearing formation beneath the overlying confining bed. The water exerts pressure against the confining bed, so that when a well is drilled through the confining bed the pressure is released and water rises above the level at which it is found. If the elevation of the land surface is much below the general level of the area of outcrop, the pressure may be sufficient to cause the water to flow naturally from the well. Artesian conditions prevail in the Trinity group and Woodbine formation where they are overlain by impermeable beds downdip from the outcrop.

The rate of movement of water through an aquifer depends upon the porosity, permeability, and hydraulic gradient. Ground water moves from areas of recharge to areas of discharge under the influence of gravity; however, the movement is generally very slow, especially in sand bodies such as the Woodbine formation and Trinity group. The time necessary for water to move from the areas of recharge of the Trinity and Woodbine to, for instance, the city of Sherman, would be measured in centuries. Present average rates of movement of water in the Trinity group and Woodbine formation are estimated to be about 1 to 2 and 10 to 20 feet per year, respectively.

The presence of large quantities of salt water in the Trinity group along the crest and south flank of the Preston anticline in the northern part of Grayson County is probably related to the natural movement of water. Much of the salt water in the aquifer is probably sea water which moved into the aquifer during the deposition of younger Cretaceous rock strata under marine conditions. Before the development of ground water from the Trinity group, the natural movement of water in the aquifer was from the areas of outcrop or recharge to the areas of natural discharge. Although some of the water in the artesian parts of the aquifer was discharged by vertical movement upward through less permeable rock strata, much of the water moved to other natural outlets. The exposure of the Trinity along parts of the Preston anticline in the Red River valley, where altitudes of 530 feet or less are common compared to altitudes of 700 to 1,100 feet in the recharge areas of Cooke and Montague Counties and adjacent parts of Oklahoma, is a comparatively low area and hence was an area of natural discharge through seepage and possible spring flow into the Red River. The water-level altitude of 535 feet in well B–2 on Preston Peninsula in 1943 was 8 feet higher than the altitude of the Red River before the impounding of Lake Texoma and is evidence of movement of water toward the river. Water movement toward the river from the southeast near the turn of the century is indicated also by a 650-foot water-level altitude in a well in the Trinity a mile south of Denison, as reported by Hill (1901, p. 620). This natural discharge area around the Preston anticline served a large part of the aquifer, and salt water moving from the surrounding area converged on the discharge area, resulting in an accumulation of salt water, part of which was not effectively removed by discharge.

After the development of wells in the Trinity group, accompanied by a general decline in water levels and the impounding of water in Lake Texoma, the gradient or direction of movement of water was reversed. Water is now moving away from the Preston anticline, which has become an area of recharge. Much of the present water movement in the Trinity in Grayson County is probably toward Sherman, where heavy withdrawals have brought about a large decline in the water levels.

Sufficient data are not available to show in detail the direction of movement of water in the Woodbine formation in Grayson County. In general, however, the water is moving downdip from the outcrop

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in the western and northern parts of the county, which results in a southward component of movement. Locally in areas of heavy pumping, for example, at Sherman, water moves from the surrounding areas toward these discharge areas.

Water in the alluvial deposits north of Denison and in the northeastern part of the county probably moves toward the Red River, the river acting as a discharge facility for the alluvium.

RECHARGE

Recharge to ground-water reservoirs results from the infiltration of water from precipitation on the outcrop of the formations, by seepage from lakes or other bodies of surface water, or by vertical and lateral movement of water from one underground reservoir to another. This last process is not a primary source of recharge but only an incident to underground water movement.

Ground water in Grayson County is derived chiefly from precipitation on the outcrop of the formations. The Woodbine crops out in Grayson County and to the west in Cooke County. The Trinity group crops out in places in Grayson County along Lake Texoma; the major outcrop, however, is to the west in Cooke and Montague Counties and north of the Red River in parts of Oklahoma (fig. 6).

The soil mantle and outcropping rocks of the Trinity group and Woodbine formation provide an excellent facility for recharge of ground water. During some periods of rainfall a part of the water runs off directly into streams, part is evaporated, part is transpired by vegetation, and the remainder percolates downward to the water table. Recharge is most effective during periods of long, heavy rainfall when the requirements of evaporation and transpiration are quickly satisfied, allowing the excess water to escape these consumptive processes and to run off or penetrate to the water table. Recharge from precipitation may occur in any month of abundant rainfall; but it is least likely in the latter part of the growing season in July, August, and September because of the usual soil-moisture deficiency during those months. A substantial rise of water levels in wells in the recharge area of the Trinity group and Woodbine formation in Grayson, Cooke, and Montague Counties indicates that there was considerable recharge during May 1959 (fig. 7).

Recharge to the alluvial deposits near the Red River is derived chiefly from precipitation on their sandy surface and to a lesser extent from runoff from adjacent slopes.

In addition to recharge from precipitation, water may enter the formations by infiltration from lakes impounded on the outcrop of the aquifers or by streams flowing over the outcrop. Lake Texoma, the largest surface-water reservoir in Grayson County, covers a part

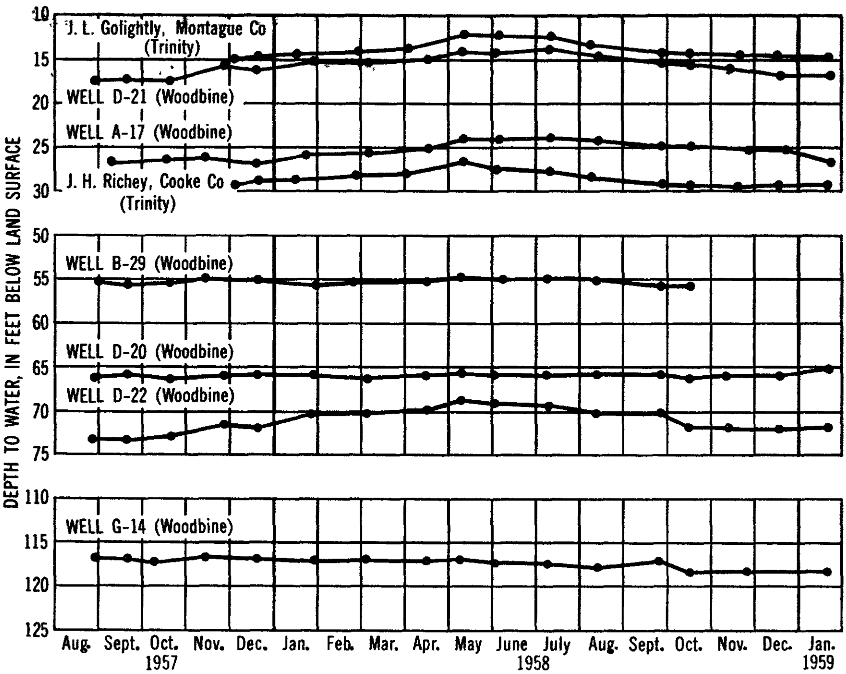

FIGURE 7.—Fluctuation of water levels in wells in the outcrop of the Woodbine formation and Trinity group, Grayson, Cooke, and Montague Counties, Tex.

of the outcrop of the Trinity group and a smaller part of the outcrop of the Woodbine formation. The lake is both influent and effluent. Of the two principal aquifers, only the Trinity group receives water by seepage from the lake. The Woodbine supplies ground water to Lake Texoma through the discharge of flowing wells and seeps in and around the Big Mineral Arm of the lake west of Pottsboro. In this region the surface of the lake is lower than the water table and piezometric surface of the Woodbine.

The hydrographs of well B–2 (tapping the Trinity group) and the water level in Lake Texoma (fig. 8) indicate that infiltration, or recharge, to the Trinity group from the lake has occurred in this area. At the time the well was drilled in September 1943, the static water level was 173 feet below the land surface and at an altitude of 535 feet, 8 feet higher than the altitude of the surface of the water in the Red River at that time. Thus, before the regulated impounding of water in Lake Texoma, which began in October 1943, the surface of the Red River was lower than the water table or piezometric surface of the Trinity group and water was discharged from the Trinity into the river. After the impounding of water in the lake, the water level in the well rose about 80 feet. The lake surface is now slightly higher than the water level in the Trinity group, indicating that water is moving from the lake into the Trinity.

The alluvium in northern Grayson County apparently is not receiving recharge from the Red River. In an area about 8 miles east of Denison the river is flowing over bedrock, the base of the alluvium being about 10 feet above the stream. In the area north of Denison the alluvium is much thicker and is in contact with the Red River, which flows over it for a short distance. However, the altitude of the water level in well C-1 tapping the alluvium is reported to be 515 feet, about 10 feet higher than an average altitude of the water surface of the Red River nearby; this indicates that the river is effluent in this area.

DISCHARGE

NATURAL

Water in the underground reservoirs in Grayson County is discharged naturally through springs and seeps, evaporation, transpiration by plants, underflow out of the county toward the southwest, and in the artesian part of the reservoirs, by upward movement of water through less permeable, confining strata.

Ground water is discharged through springs and seeps wherever the land surface intersects the water table. Before the development of wells in the Trinity group and the impounding of water in Lake Texoma, the area around the Preston anticline where the Trinity is exposed was a natural discharge point for water in the Trinity, and water undoubtedly was discharged through seeps and springs in that area. Some water is discharged through seeps and springs in the area of outcrop of the Woodbine between Sherman and Denison along tributaries to Choctaw Creek. This discharge can be considered rejected recharge; that is, water that enters the outcrop but cannot move down the dip under present hydraulic gradients and thus is forced to come to the surface and to flow off. Springs in the Austin chalk occur in many places, especially in banks of deeply incised creeks where the water table is shallow. The springs are intermittent, becoming dry in periods of insufficient rainfall. Considerable ground water is discharged through seeps and springs in the permeable alluvium along the Red River. In the northeastern part of the county, numerous seeps and contact springs discharge along the bank of the Red River and at places where impermeable bedrock is exposed between terrace levels.

Ground water is discharged by evapotranspiration chiefly from the outcrop of the Woodbine formation and Trinity group. Most of the water transpired is discharged by phreatophytes (plants that obtain their water supply from the zone of saturation) and by cultivated plants. The discharge is greatest in areas of dense vegetation where the water table is close to the surface. The amount of water discharged by evapotranspiration varies seasonally, being greatest in the summer.

The natural discharge of water by movement upward through the overlying rock strata takes place in the artesian part of the aquifer. Under natural conditions this is the principal method of discharge of ground water.

ARTIFICIAL

Before development of ground water in Grayson County, the aquifers were virtually in a state of equilibrium—the amount of recharge equaled the amount of discharge. Artificial discharge by wells is thus a new condition imposed upon the previously stable system, and the discharge must be balanced by an increase in the amount of recharge, a decrease in the natural discharge, a loss of water from storage in the aquifers, or by a combination of these methods.

Estimates of ground-water pumpage in 1944 (Livingston, 1945, p. 3) show that 1.6 mgd (million gallons per day) was pumped in the Sherman area for public supply and industrial use. This represents about a 33-percent increase in pumpage over an 11-year period extending back to 1933, when 1.2 mgd was pumped. The larger part of this increase in pumpage was due to a substantial increase in the population of Sherman during World War II.

The withdrawal of ground water in the Sherman area was materially increased again from 1944 to 1958, from 1.6 to about 2.6 mgd. Dieselization of the railroads in 1955 resulted in abandonment of several large industrial wells; however, industrial expansion outward from Sherman and the development of additional wells offset any decline in pumping by the railroads.

About 5 mgd of ground water was pumped in Grayson County in 1957 for all purposes. Of this amount, about 61 percent, or 2.8 mgd, was pumped from the Woodbine; about 36 percent, or 2 mgd, from the Trinity group; and about 3 percent, or 0.15 mgd, from the Pawpaw formation, Austin chalk, and alluvial deposits. About 65 percent of the artificial ground-water discharge in Grayson County takes place through wells in the Sherman area.

Flowing wells in Grayson County discharge about 50,000 gpd (gallons per day). The production comes mostly from about 20 wells in the Woodbine in an area around the Big Mineral Arm of Lake Texoma, west of Pottsboro. Most of these wells have been flowing since 1900. They are not capped, and their discharge goes into Lake Texoma.

FLUCTUATIONS OF WATER LEVELS

Water levels in aquifers fluctuate almost continually from artificial and natural causes. In general, the major factors that control the changes of water levels are the rates of recharge to and discharge from the aquifer. Changes of water level are caused also by variations in atmopheric pressure, tidal fluctuations, earthquakes, and other disturbances. The fluctuations are usually gradual, but it is not uncommon in some wells for the water level to rise or fall several inches or feet in a few minutes.

Fluctuations due to natural processes generally occur in cycles—daily, annual, or other periods. Cyclic fluctuations during a day are caused chiefly by tidal and barometric effects and by changes in the rate of evapotranspiration. Annual fluctuations generally are the result of changes in the rate of precipitation and evapotranspiration throughout the year and, consequently, the amount of water available for recharge.

Fluctuations of considerable magnitude, especially in artesian aquifers, result chiefly from artificial processes. Withdrawals of ground water cause cones of depression to form in the water table or the piezometric surface, the cones being centered at centers of pumpage. The amount of influence of the cone of depression decreases with distance from the point of discharge. Water levels in the artesian reservoirs in Grayson County usually begin a period of decline in June, reaching a low in August when pumping is generally greatest. Recovery of the water levels takes place chiefly during the preiod from about September to May.

TRINITY GROUP

Little information is available regarding the artesian pressure in the Trinity group in Grayson County before development of wells in the county. A comparison of early reported levels in the Woodbine formation at Sherman and in the Trinity group at Denison indicates that the water level in the Trinity at Sherman in the early part of the 20th century probably was about 100 feet below the land surface. The water levels declined steadily after wells were drilled in Grayson County and in areas to the west, where many flowing wells in Cooke and Denton Counties have ceased to flow and are now equipped with pumps. A rapid decline of artesian pressure took place in the Sherman area during and after World War II because of increased withdrawals of water for public supply and industrial use.

During the period 1909 to 1958, water levels in wells in the Trinity at the Fairview municipal pumping station in Sherman declined at least 180 feet; however, 63 percent of this decline, or 113 feet, took place after 1945. At other places in the city the wells in the Trinity are more widely spaced and the declines have been less. For example, in well E–55 the water level declined 65 feet during the period 1947 to 1958, and in well E–36 the water level declined 78 feet from 1944 to 1958. Hydrographs of short-term water levels in the Sherman area (fig. 9) show that artesian pressures in the Trinity group are at their lowest in August, generally the month of greatest water pumping.

Water levels in the Trinity group have declined considerably also in the western part of Grayson County in the vicinity of Collinsville and Whitesboro, where water is pumped for public supply from the Trinity. During the period 1935 to 1957 the water level in well E–26 at Whitesboro declined 72 feet, an average of almost 3.5 feet per year. This area is midway between Sherman and Gainsville, both centers of heavy pumping, and the water levels here may be affected slightly by pumping in those cities.

Hydrographs of wells in the outcrop of the Trinity group in Cooke and Montague Counties (fig. 7) show fluctuations of water levels in response to recharge from rainfall on the outcrop of the aquifer. During 1958 the water levels in the J. L. Golightly well in Montague County and the J. H. Richey well in Cooke County fluctuated about 3 feet, the former showing no net decline for the year, the latter showing a net decline of 0.5 foot.

Figure 8 shows the fluctuations of the water level in well B–2 tapping the Trinity group in the vicinity of the outcrop in Lake Texoma, compared with fluctuations of water levels in the lake. Before October 1943, when water was first impounded in Lake Texoma, the water level in the well fluctuated independently of the water level in the Red River. After the formation of Lake Texoma, the water level rose nearly 80 feet in the well during the 14-year period from 1943 to 1957, indicating recharge from the lake into the sand. The water level, controlled almost entirely by the lake, fluctuates several feet below the level of the lake. Figure 7 shows also that changes in the lake level are reflected almost instantaneously at the well, indicating a pressure change followed by a slow transfer of water. The low permeability of the Trinity does not permit rapid movement of water in the aquifer; consequently, infiltration from the lake is a slow process.

WOODBINE FORMATION

Water levels in the Woodbine in the Sherman area have shown large declines since the drilling of the first municipal wells early in the 20th century. During the 49-year period 1909–58, the water levels in the wells at the Fairview pumping station in Sherman declined about 240 feet; however, 65 percent of this decline, or 156 feet, occurred during the 13-year period 1945–58. In well E–26 in the north-

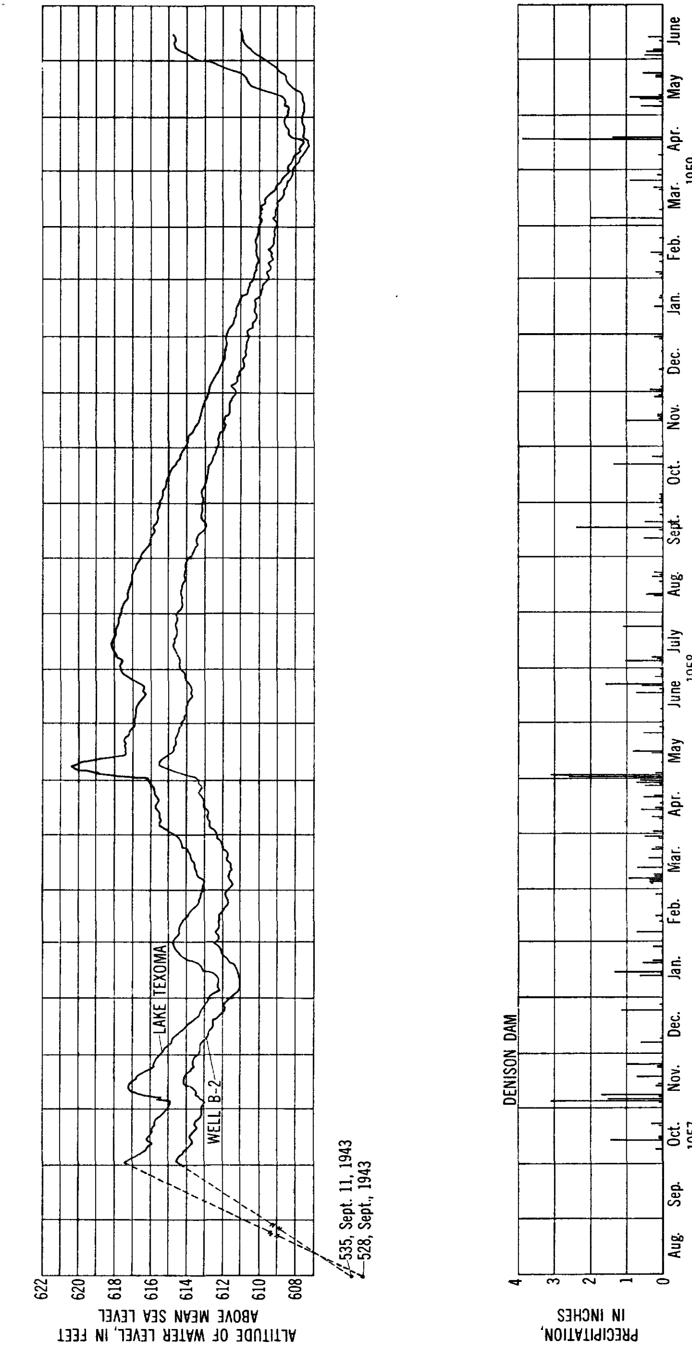

FIGURE 8.—Fluctuation of water level in well B-2 and in Lake Texoma and precipitation at Denison Dam, Grayson County, Tex.

central part of Sherman, the water level declined 166 feet from 1933 to 1958, an average of about 6.5 feet per year. Water levels have declined rapidly since 1945, owing to increased withdrawal of ground water during the postwar period. Water levels in some of the municipal wells during pumping are at or below the top of the Woodbine, indicating at least local overdraft. The short-term hydrographs of wells E–50 and E–59 (fig. 9) show the decline in water levels and fluctuations due to seasonal pumping at Sherman.

Although the decline of artesian pressure has been widespread in Grayson County, the magnitude of decline diminishes with distance from the centers of heavy pumping. Since the drilling of the first well in the heavily pumped Perrin Air Force Base well field, 6 miles northwest of Sherman, the water level declined 72 feet in well E–9 during the period 1941 to 1957, an average of 4.5 feet per year. In well E–14, also in the Perrin Air Force Base well field, the water level declined 35 feet from 1953 to 1957, an average of 9 feet per year. Three miles north of Perrin Air Force Base at Pottsboro, the water level in well B–27 declined an average of 6.5 feet per year from 1952 to 1958.

Water levels in and near the outcrop of the Woodbine formation in Grayson County probably have not been seriously affected by the large withdrawals of water downdip. Hill (1901, p. 624) reports a number

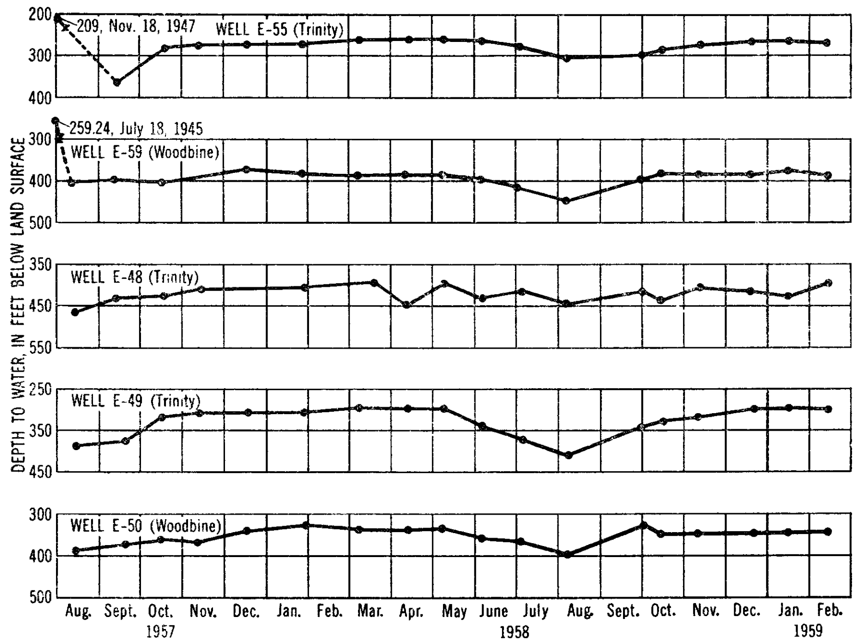

FIGURE 9.—Fluctuation of water levels in wells in the Trinity Group and Woodbine formation at Sherman, Grayson County, Tex.

of flowing wells at altitudes of 650 feet or less in an area 6 miles west of Pottsboro. Most of these wells are still flowing with little apparent loss of head. Furthermore, recharge is probably still being rejected in the outcrop area along Choctaw Creek between Sherman and Denison. The hydrographs of wells on the outcrop of the Woodbine (fig. 7) show, for the most part, fluctuations in response to recharge from rainfall—the highest water levels usually coinciding with the months of greatest rainfall. The effect of evapotranspiration, greatest in late summer, causes a decline of water levels during that period.

WATER-BEARING FORMATIONS

The principal water-bearing formations in Grayson County are the Trinity group and Woodbine formation, which supply more than 95 percent of the ground water used in the county. Other water-bearing formations of lesser regional importance, which yield small to moderate amounts of water, include the alluvial deposits, Pawpaw formation, Eagle Ford shale, and Austin chalk.

TRINITY GROUP

HYDRAULIC CHARACTERISTICS

The yield of a well is usually measured in gallons per minute or cubic feet per second. Yield depends upon the ability of the aquifer to transmit water, the thickness of the water-bearing material, the efficiency of the well, and the allowable drawdown.

Very few wells in Grayson County penetrate and are screened through the entire thickness of the water-bearing sands; therefore, the yields of the wells in general are less than the maximum that could be developed if the wells penetrated to the bottom of the aquifer and were screened through the entire saturated thickness.

The yields from the Trinity group range from less than 1 to 700 gpm (gallons per minute), the largest yields being from the Sherman city wells. Most of the Sherman wells penetrate the full thickness of the fresh-water-bearing part of the aquifer and are screened opposite all the water-bearing sands. Most of the wells having low yields are in the western and northwestern parts of the county and are windmill wells constructed to furnish only enough water for stock and domestic use on farms. The potential yield of wells in the Trinity group increases across the county from northwest to southeast because of an increase in thickness of the formation in that direction.

The specific capacity of a well is expressed as a ratio of the discharge to the drawdown, generally expressed in gallons per minute per foot of drawdown, and it is assumed to be a direct proportion. For instance, if the discharge of a well is doubled, the drawdown will be doubled. The specific capacity of 11 wells in the Trinity group in Grayson

County ranged from 0.57 to 4.2 gpm per ft (gallons per minute per foot) averaging about 2.25 gpm per ft (table 2).

TABLE 2.—*Yields and specific capacities of selected wells in the Trinity group in Grayson County, Tex.*

Well	Diameter of screen (in.)	Yield (gpm)	Drawdown (ft)	Time since pumping stopped (hr)	Specific capacity (gpm per ft)
A-21	7	25	43.9	1	0.57
B-2	10¾	112	65.0	----------	1.7
D-25	5½	330	104	1	3.2
E-12	8⅝ / 6⅝	100	156	24	.6
36	6⅝	543	260	24	2.1
48	8⅝	400	173	2¾	2.3
49	8⅝	600	203	3	2.9
55	7	354	160	½	2.2
58	10¾	560	366	24	1.5
61	10¾	602	170	24	3.7
G-1	5½	110	26	3	4.2

Pumping tests were made on five wells in the Trinity group to determine the coefficients of transmissibility and storage, which govern the ability of the aquifer to transmit and yield water. The coefficient of transmissibility is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer that is 1 foot wide and extends the vertical thickness of the aquifer, under a hydraulic gradient of 1 foot per foot, and at the prevailing temperature of the water. Thus, the volume of water that will flow each day through each foot of the water-bearing material is the product of the coefficient of transmissibility and the existing hydraulic gradient. Therefore, the smaller the coefficient of transmissibility, the greater the hydraulic gradient required for the water to move through the aquifer at a given rate. Many of the wells tested penetrate only thin sections of the formation, and the coefficients obtained are not representative of the full thickness. Therefore, the field coefficient of permeability is used for expressing the ability of the aquifer to transmit water per unit of thickness. The coefficient is determined by dividing the field cofficient of transmissibility by the thickness in feet.

The coefficient of storage is defined as the volume of water the aquifer releases from or takes into storage per unit surface area per unit change in the component of head normal to that surface. Under artesian conditions, the coefficient of storage is a measure of the ability of the formation to yield water from storage by the compression of the formation and the expansion of the water as the head is lowered. The coefficient of storage for an artesian aquifer, like the Trinity group and most of the Woodbine formation in Grayson county, is small; consequently, after pumping starts, a cone of depression is developed over a wide area in a short time. Under water-table conditions the coefficient of storage reflects gravity drainage of the aquifer and is very much larger.

The coefficients of transmissibility determined from the pumping tests ranged from a low of 300 gpd per ft at well A–21 to a high of 4,700 gpd per ft at well E–61 (table 3). The increase in the coefficient of transmissibility southward and southeastward can be attributed to an increase in thickness of the formation in those directions. Average values of the coefficients of transmissibility and storage of the Trinity group are approximately 2,800 gpd per ft and 0.00003, respectively.

The coefficients of transmissibility and storage can be used to predict the general order of magnitude of the future drawndown in water levels caused by pumping a well or by a general increase in the pumping in an area. Theoretical drawdown curves in figure 10 were computed from the average coefficients determined for the Trinity group in the artesian part of the aquifer. The curves show the theoretical drawdown caused by pumping 100 gpm continuously for periods of 1 day, 1 month, 1 year, and 10 years at distances of 1 to 10,000 feet from the pumped well. The drawdown caused by pumping is directly proportional to the rate of pumping. As an example, if the drawdown 1 foot from a well is 10 feet while 100 gpm is being pumped, the drawdown would be 20 feet at 200 gpm. The total drawdown at any one place within the cone of influence of several wells would be the sum of the influences of all wells.

Drawdowns in wells may be reduced by reducing the pumping and (or) spacing the wells farther apart. Records should be kept of pumpage and water levels, and new wells should be pump tested when completed. These records afford a basis for controlling the pumping so as to keep drawdown to a minimum.

As long as the pumping level is not below the top of an artesian aquifer from which it draws water, the aquifer is still full of water and the decline in water level represents only a decline in pressure. However, when the pumping level declines below the top of the aquifer, dewatering begins, resulting in a decrease in the saturated thickness of the aquifer, which, in turn, causes a decrease in the coefficient of transmissibility and, consequently, a decrease in the yield of the well. On the other hand, when the water level declines into the aquifer, water-table conditions are set up, and the rate of expansion of the cone of depression is greatly retarded.

FUTURE DEVELOPMENT

The volume of fresh water in transient storage in the Trinity group in Grayson County is estimated to be about 60 million acre-feet. Only

Table 3.—*Coefficients of transmissibility, permeability, and storage determined from pumping tests on selected wells in the Trinity group, Grayson County, Tex.*

Well	Date	Coefficient of transmissibility (gpd per ft)	Coefficient of permeability (gpd per ft²)	Coefficient of storage	Remarks
A-21	Aug. 13, 1958	400	13		Well is screened for 30 ft only. Not used in computing average.
A-21	do	300	10		Not representative and not used in computing average.
E-36	July 18, 19, 1945	3,200	10	0.00002	
38	do	2,200		.00008	
38	July 19, 20, 1945	3,700		.00002	
E-36	July 20, 21, 1945	2,500	8		
38	do	2,800		.00002	
58	Mar. 19, 20, 1959	2,000	4		
58	Mar. 20, 21, 1959	1,600	3		
61	Jan. 30, 1959	4,700	11		
Average		2,800		0.00003	

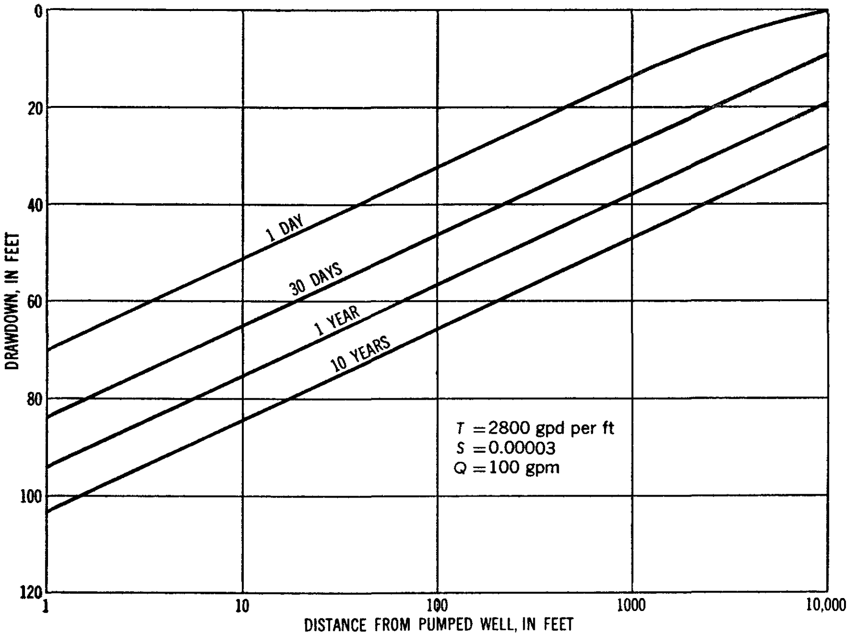

FIGURE 10.—Theoretical drawdown due to pumping 100 gpm from an infinite aquifer (Trinity group).

a fraction of this water is available for recovery through wells, however, because of the great depth at which it occurs in much of the county and because much of the water would be held in the sand by forces of capillarity, against the pull of gravity.

The Trinity group is the most favorable source of additional ground water in the heavily pumped Sherman area. Even though water levels in the Trinity in Sherman have declined more than 100 feet since 1945, pumping levels presently are more than 800 feet above the top of the aquifer. In well E–48 at Old Settler's Park, the pumping level in August 1957 was 648 feet below the land surface, or 812 feet above the top of the Trinity; in well E–49 at Cherry Park, the pumping level in August 1958 was 615 below the land surface, or 885 feet above the top of the formation; in well E–58 at Roscoe Russell pumping station, the pumping level in March 1959 was 718 feet below the land surface, or 872 feet above the top of the formation; and in well E–61 at Tuck pumping station, 6 miles south of Sherman, the pumping level in August 1959 was 480 feet below the land surface, or 1,100 feet above the top of the formation. Although a large margin of safety presently exists before dewatering of the aquifer begins, the economics of higher lifting costs from declining pumping levels probably will be an important factor limiting the full development of water from the Trinity group in the Sherman area. If additional declines in the water levels are to be minimized, future wells of large capacity drilled to the Trinity group will have to be spaced as far apart as economically possible.

The threat of salt-water encroachment in the Trinity group should also be considered. Large quantities of salt water in the Trinity group on the Preston anticline in northern Grayson County are moving southward toward the heavily pumped Sherman area. However, this movement poses little threat in the foreseeable future because of its slow rate. Increased withdrawal of water at Sherman could cause a coning-up of the basal salt water, possibly resulting in some salt-water contamination in wells and an increase in the salinity of the fresh water being pumped. This situation should not discourage future development of the Trinity, however, because the amount of fresh water in the Trinity in the Sherman area is large in proportion to the amount of salt water.

Large quantities of additional ground water can be developed from the Trinity group in other parts of Grayson County. High artesian pressures and large available drawdowns prevail throughout most of the county because of the altitude of the outcrop area and the deep position of the aquifer. However, the factor limiting large ground-water development in the Trinity group is the amount of saturated fresh-water sand available in the area. Plate 5 shows the thickness of saturated sand in various parts of Grayson County. The amount of sand increases southward from the outcrop in the northern part of the county, reaching a maximum in the southern part. The increase is due not only to the thinning of the Trinity group section toward the outcrop but also to the inclusion of progressively greater amounts of salt-water-bearing sand northward to the Preston anticline. The thickness of saturated sand exceeds 600 feet about 3 miles east of Tioga. The thickness is in excess of 500 feet in a large area from Tioga to Gunter; other small areas of similar thickness are about 2 miles northeast of Collinsville, 3 miles north of Howe, and 2 miles south of Sherman. Large developments of ground water from these sections of thick sand are possible, whereas the thin sections of fresh-water sand and low transmissibilities in the northern part of the county preclude the development of large-capacity wells in that area.

WOODBINE FORMATION

HYDRAULIC CHARACTERISTICS

The yields of wells in the Woodbine formation range over wide limits, from less than 1 gpm in windmill wells on the outcrop to about 600 gpm at Sherman. The extreme range is caused largely by the type of well construction. Many of the wells are constructed so as to produce only sufficient quantities of water for domestic or stock use. In most places much larger yields could be obtained from properly constructed wells.

The specific capacities of wells in the Woodbine range from 0.36 to 6.0 gpm per ft. Here again the range is largely the result of differences in well location and construction. The wells having the highest specific capacities are those in the thicker sand sections downdip from the outcrop. The average of the specific capacities in 12 wells tested in about 2.9 gpm per ft. (table 4).

Pumping tests made on 9 wells in the Woodbine indicate that the average coefficient of transmissibility is about 3,200 gpd per ft; the average coefficient of storage in 5 of the wells was 0.00001 (table 5). The theoretical drawdown curves in figure 11 were computed from an average of the coefficients determined for the Woodbine in the artesian part of the aquifer. The curves show the theoretical drawdown caused by pumping 100 gpm continuously for periods of 1 day, 1 month, 1 year, and 10 years and at distances of 1 to 10,000 feet from the pumped well.

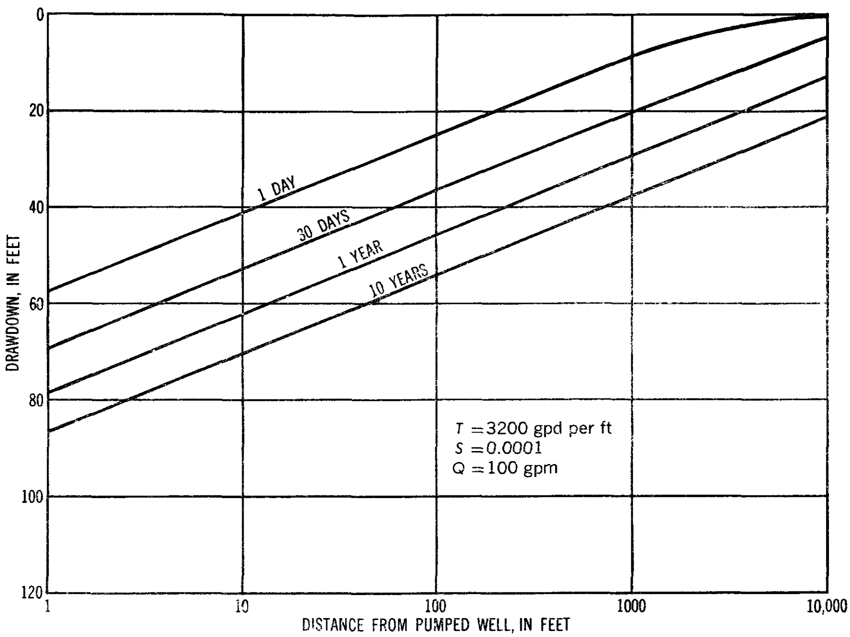

FIGURE 11.—Theoretical drawdown due to pumping 100 gpm from an infinite aquifer (Woodbine formation).

TABLE 4.—*Yields and specific capacities of selected wells in the Woodbine formation, Grayson County, Tex.*

Well	Diameter of screen (in.)	Yield (gpm)	Drawdown (ft)	Time since pumping stopped (hr)	Specific capacity (gpm per ft)
B-27	4½	73	32.5	1	2.2
E-9	6	60	167	9½	.36
10	7	120	161	----------	.75
14	8⅝	77	166	1	.46
35	8⅝	350	110	48	3.2
47	8⅝	500	83	2¾	6.0
50	8⅝	350	134	3	2.6
62	10¾	602	132	36	4.5
67	8⅝	145	26	6	5.6
H-21	4½	100	54	1½	2.0
28	4½	52	10	10	5.2
J-11	6	69	35	1½	2.0

FUTURE DEVELOPMENT

The volume of water in transient storage in the Woodbine formation in Grayson County is estimated to be about 25 million acre-feet. Only a fraction of this water is recoverable through wells because of the great depth at which much of it occurs and because much of the water would be retained in the sand by capillarity.

It does not seem practical to develop large additional amounts of ground water from the Woodbine in Sherman. Increased withdrawals of ground water in Sherman since 1945 have caused large water-level declines. The pumping level in well E–47 at Old Settler's Park in August 1958 was 525 feet below the land surface, or 40 feet below the top of the sand and 55 feet above the screen. In well E–50 at Cherry Park the pumping level was 528 feet in August 1958, or 25 feet below the top of the sand and 95 feet above the screen. In well E–62 at Tuck pumping station, 4 miles south of Sherman, however, the pumping level was about 500 feet in October 1959, or 70 feet above the top of the sand and 300 feet above the screen. Further development from the Woodbine in Sherman would cause dewatering of the formation and declines in yields of the wells, especially as the decline due to the present pumping can be expected to continue for sometime before the water level gradually becomes stabilized.

Concentrated pumping at Perrin Air Force Base has caused excessive drawdowns in that area. The pumping level in well E–14 in July 1957 was 425 feet below the land surface, or 43 feet below the top of the formation and 45 feet above the screen. Other wells in the Woodbine in the Perrin well field had similar pumping levels at that time.

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TABLE 5.—*Coefficients of transmissibility, permeability, and storage determined from pumping tests on selected wells in the Woodbine formation, Grayson County, Tex.*

Well	Date	Coefficient of transmissibility (gpd/per ft)	Coefficient of permeability (gpd/per ft²)	Coefficient of storage	Remarks
A-10	Aug. 20, 1958	16, 700	----------	----------	Short test under water-table conditions; results may be considerably in error. Not used in average. Short test.
25	July 15, 1958	7, 900	190	----------	Not used in average. Short test under water-table conditions; results may be considerably in error. Not used in average.
B-27	Mar. 24, 1958	2, 700	17	----------	
27	do	2, 200	14	----------	
E-37	July 13, 15, 1945	2, 100	37	0. 00006	
39	do	2, 200	44	. 00009	
42	do	2, 400	21	. 0002	
43	do	2, 300	37	. 0002	
44	do	2, 300	38	. 0002	
E-37	July 15, 16, 1945	2, 400	42	. 00004	
39	do	2, 400	48	. 00009	
E-42	July 15, 16, 1945	2, 500	22	. 0002	
43	do	2, 600	41	. 0001	
44	do	2, 500	41	. 00002	
62	Jan. 30, 1959	6, 000	26	----------	
H-28	Mar. 24, 1958	12, 500	110	----------	
J-11	Mar 26, 1958	1, 400	20	----------	
Average		3, 200		. 0001	

As long as the pumping levels remain above the top of the aquifer from which the well draws water, the aquifer is still full of water and any declines in water level represent declines in artesian pressure. But when the pumping levels drop below the top of the aquifer, dewatering of the aquifer takes place. As a consequence, the well yield declines as the thickness of the saturated sand decreases. For these reasons, distribution of wells over as large an area as possible will minimize future water-level declines. Thus, the lowering of the water level at any one place would be held to a minimum and, hence, the life of the development would be extended.

Moderate to large additional supplies of ground water can be obtained from the Woodbine formation elsewhere in Grayson County. Large available drawdowns and relatively high artesian pressures are favorable to considerable future development in the southern part of the county, where the Woodbine formation is deeply buried. High artesian heads prevail in other areas distant from present centers of heavy pumping. Large to moderate yields are generally obtainable on the outcrop of the Woodbine also where water-table conditions minimize the rate of expansion of cones of depression. The area between Sherman and Denison, in and near the outcrop of the Woodbine, offers opportunity for maximum utilization of ground water. Ground water being discharged through springs and seeps (rejected recharge so far as the downdip portion of the aquifer is concerned) could be recovered by wells located near this area of natural discharge. Pumping this water would cause a minimum lowering of the water level in the aquifer downdip.

Plate 6 shows the thickness of saturated sand in various parts of Grayson County. Generally, areas of thickest saturated sand have the greatest potential for water developments. Saturated sand in excess of 250 feet in thickness is present near the east side of Sherman, midway between Sherman and Whitewright, about 6 miles west-southwest of Sherman, and midway between Van Alstyne and Gunter. More than 150 feet of saturated sand is present in the outcrop of the Woodbine formation from Whitesboro northward to Big Mineral Arm of Lake Texoma about 6.5 miles west of Pottsboro. Water-table conditions, in addition to thick deposits of sand, are favorable to large future developments of ground water in this area.

OTHER FORMATIONS

The Pawpaw formation, Eagle Ford shale, Austin chalk, and alluvium constitute less important water-bearing formations in Grayson County. Of these, only the alluvium is of sufficient importance to warrant further mention.

The only alluvial deposits in the county that are known to contain considerable quantities of ground water are those along the Red River north of Denison and in the northeastern part of the county. A few records are available from wells in the alluvium, which are mostly small and used for domestic supply. Well C-1 in the alluvium north of Denison, however, is used for industrial supply and has a reported yield of 35 gpm.

Development of moderate to large supplies of water from the alluvium may be possible. However, more information on the alluvium is needed before definite conclusions can be reached.

USE OF GROUND WATER

Records of 305 water wells and 4 springs were obtained during the investigation in Grayson County. Of these, 200 wells and 2 springs were used for domestic and stock purposes, 43 wells were used for public supply, 9 wells were used for industrial purposes, and 6 wells were used for irrigation. The remaining 47 wells were not being used. The wells inventoried are only a part of the total number of wells in Grayson County; however, records of most of the public-supply, industrial, and irrigation wells in the county were obtained.

DOMESTIC AND STOCK

Water used for domestic and stock purposes in Grayson County is obtained chiefly from wells, but some is obtained from springs. Most of the wells are equipped with small-capacity pumps powered with electricity. The accessibility of available ground water determines in large measure the type and depth of the well used. Shallow dug and drilled wells predominate in and near the areas of outcrop of the Trinity group and Woodbine formation, Pawpaw formation, and alluvial deposits where the water table is close to the surface. Downdip from the outcrop areas, progressively deeper drilled wells are required to tap the water. In the southern and southeastern parts of the county, in the outcrop of the Austin chalk, shallow dug wells prevail owing to the deep position of other water-bearing formations in that area. About 15 percent of the total ground water withdrawn in Grayson County in 1957, or about 750,000 gpd, was used for domestic and stock requirements.

PUBLIC SUPPLY

Public supplies accounted for about 3.3 mgd, or two-thirds of the ground water withdrawn for all purposes in Grayson County in 1957. The pumpage for public supplies was almost equally divided between the Trinity group and Woodbine formation, 53 percent from the Trinity and 47 percent from the Woodbine. Sherman, the largest user of ground water in the county, accounts for about 70 percent of the total ground water used for public supply. Water in Sherman is pumped from 14 wells, 8 in the Trinity and 6 in the Woodbine, having a total potential of about 8.6 mgd. Whitesboro, Collinsville, and the community of Gordonville about 10 miles north of Whitesboro are the only towns depending entirely on ground water from the Trinity group. Other towns in the county pump only from the Woodbine formation. Numerous resorts near Lake Texoma, having wells in either the Trinity or the Woodbine, use comparatively small amounts of water. Perrin Air Force Base supplements ground water from wells in the Woodbine with surface water obtained from the Denison municipal supply.

INDUSTRY

Withdrawal of ground water for industrial use in Grayson County in 1957 was about 900,000 gpd, or 20 percent of the water pumped for all purposes. About 92 percent of the industrial pumpage, or 828,000 gpd, came from the Woodbine formation and about 8 percent, or 72,000 gpd, from the Trinity group. A relatively small amount of water for industrial use, probably less than 1 percent, is pumped from the alluvium north of Denison. Most of the industrial use of ground water before 1950 was by industries in Sherman. Since 1950, withdrawals of ground water by industry in the county have more than doubled. Most of the increase was for new industry in rural areas, the largest individual consumer being the Line Material Co., 6 miles west of Sherman, which pumps about 570,000 gpd. Dieselization of the railroads caused an abandonment of railroad wells in Sherman in about 1955 and resulted in a slight decrease in pumping at that time.

IRRIGATION

Irrigation is relatively new in Grayson County. The first large irrigation well of record, D–24, was drilled in 1955 near Whitesboro in the western part of the county. From 1955 through 1958, five more irrigation wells were drilled—A–10 and B–15 in 1956, A–19 and A–24 in 1957, and A–25 in 1958. All the irrigation wells, except well B–15 which produces from the Trinity group, produce from the Woodbine formation in its outcrop in the western part of the county. The principal irrigated crops include peanuts and grain sorghums, a total of about 110 acres being irrigated in 1958. The water is applied with sprinklers. The wells, 8 to 10 inches in diameter, are equipped with turbine pumps powered with electricity. The wells have yields ranging from about 30 to 260 gpm. The amount of water withdrawn for irrigation varies with soil-moisture requirements, the wells being used primarily to supplement rainfall; when rainfall is above normal or well distributed, the irrigation requirement decreases. Well A–10, which may be considered a representative irrigation well, pumped about 14 acre-feet of water during 1957, a year of above-normal rainfall. The total pumpage for irrigation in 1957 averaged about 70,000 gpd.

QUALITY OF WATER

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter that the water contains. The mineral matter is dissolved principally from the soil and rocks through which the water passes; consequently, the differences in the chemical character of the ground water reflect in a general way the differences in the geologic formations with which the water has had contact. The concentrations of the chemical constituents commonly are expressed in parts per million. A part per million is 1 unit weight of constituent in 1 million unit weights of sample.

Samples of water were obtained from 219 wells, 2 springs, and 2 lakes in Grayson County. The wells and springs sampled are shown by bars over the location numbers on figures 2 and 3; the results of the analyses of the samples are available for inspection in the offices of the Geological Survey in Austin, Tex. Figure 12 shows graphically the composition of representative samples from the principal aquifers in Grayson County. Table 6 shows a comparison of the quality of the ground water in the county with standards proposed for various uses. Most of the samples were collected during the present investigation; however, a few were collected at various times previously. Except as indicated in the table, the analyses were made in the laboratory of the Geological Survey at Austin, Tex.

The U.S. Public Health Service (1946, p. 382–383) has established standards for drinking water used on common carriers engaged in interstate commerce. These standards are widely used in evaluating water for drinking. The recommended maximum concentrations for certain of the chemical constituents according to the standards are listed below.

Constituent	*Maximum concentration (ppm)*
Iron (Fe), Manganese (Mn)	0.3
Magnesium (Mg)	125
Chloride (Cl)	250
Sulfate (SO_4)	250
Fluoride (F)	1.5
Dissolved solids	[1] 500

[1] In water of good chemical quality; however, if such water is not available, a dissolved-solids content of 1,000 may be permitted.

These tolerances were set primarily as a protection against digestive disturbances and because they represent limits beyond which the taste

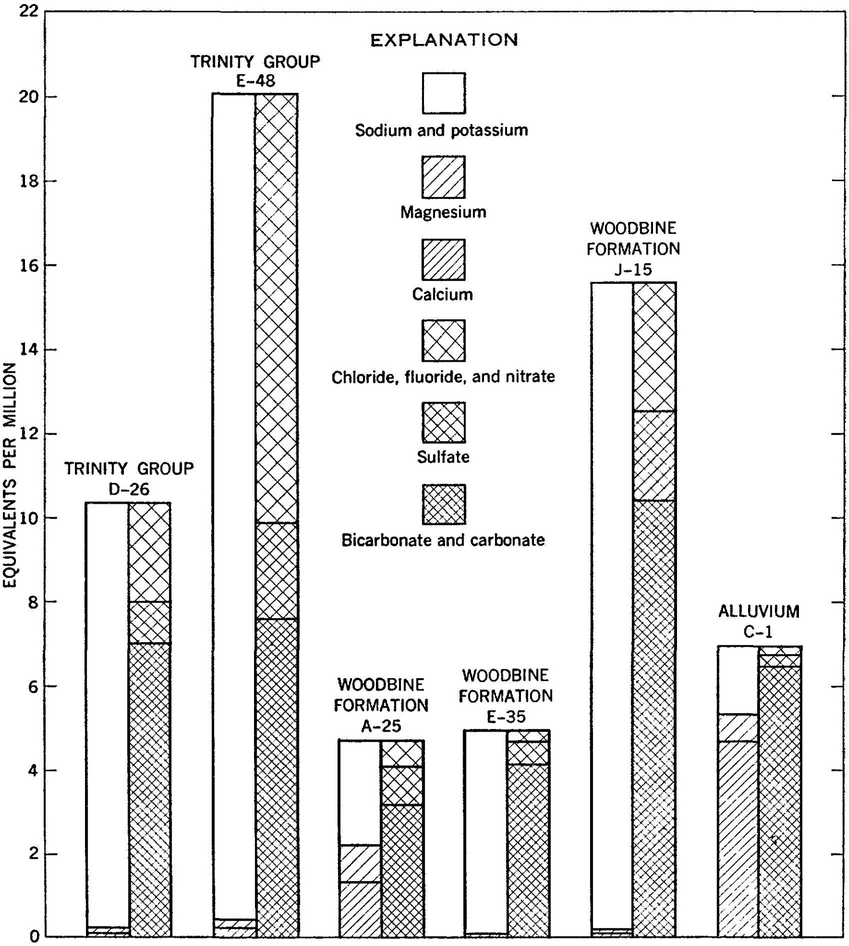

FIGURE 12.—Composition of ground water, Grayson County, Tex.

may become objectionable. Water having a chloride content exceeding 250 ppm (parts per million) may have a salty taste. Water having a magnesium and sulfate content exceeding the standards may have a laxative effect. Water having a fluoride content exceeding 1.5 ppm may cause teeth of children to become mottled (Dean and others, 1935, p. 424–442) ; however, fluoride concentrations of about 1.0 ppm appear to reduce the incidence of tooth decay (Dean and others, 1942, p. 1155–1179). Water that contains more than 45 ppm of nitrate has been related by Maxcy (1950, p. 271) to the incidence of infant cyanosis (methemoglobinemia or "blue baby" disease) and may be dangerous for infant feeding High nitrate content may be an indication of pollution from organic matter, and water containing excessive nitrate

TABLE 6.—*Comparison of the quality of ground water in Grayson County with standards recommended by U.S. Public Health Service and others*

[Chemical constituents, in parts per million]

Source	Silica [1] (SiO_2)		Iron, total (Fe) and Manganese (Mn)		Magnesium (Mg)		Sulfate (SO_4)		Chloride (Cl)		Fluoride (F)		Nitrate [2] (NO_3)		Boron [3] (B)		Dissolved solids)			Hardness		Sodium adsorption ratio [4]		Specific conductance [4]	
	Determinations (total and the number exceeding the indicated recommended concentrations)																								
	Total	20	Total	0.3	Total	125	Total	250	Total	250	Total	1.5	Total	45	Total	1.0	Total	500 [5]		Total	60 [6]	Total	14	Total	2,250
All wells	47	1	47	19	49	0	70	7	223	16	43	5	44	0	32	4	48	26	5	223	106	43	30	209	16
Trinity group	14	0	14	4	14	0	14	0	25	2	12	2	12	0	11	2	14	14	2	35	6	11	11	24	1
Woodbine formation	27	0	30	14	32	0	42	7	134	9	28	3	29	0	21	2	31	10	3	134	51	31	19	131	13
Pawpaw formation	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	8	7	0	0	8	0
Eagle Ford shale	0	0	0	0	0	0	1	0	4	1	0	0	0	0	0	0	0	0	0	4	2	0	0	3	0
Austin chalk	0	0	0	0	0	0	9	0	30	1	0	0	0	0	0	0	0	0	0	30	30	0	0	21	1
Alluvium	1	1	1	0	1	0	1	0	2	0	1	0	1	0	0	0	1	0	0	2	2	1	0	2	0

[1] Moore (1940, p. 263).
[2] Maxcy (1950, p. 271).
[3] Wilcox (1955, p. 11).
[4] Wilcox (1955, p. 16).
[5] 1,000 ppm oermitted.
[6] Upper limit of soft water.

should be tested for bacterial content if it is to be used for domestic purposes.

Calcium and magnesium are the principal constituents in water that give it the property called hardness. Hard water causes excessive soap consumption and incrustations in boilers, water pipes, and hot-water heaters. The hardness equivalent to the carbonate and bicarbonate content is called carbonate hardness; the remainder is called noncarbonate hardness. The figures given for the hardness of water may be evaluated by comparing them with the commonly accepted standards of hardness for public and industrial supplies given in the following table.

Hardness (ppm)	*Classification*
60 or less	Soft.
61–120	Moderately hard.
121–200	Hard.
More than 200	Very hard.

The presence of moderated amounts of silica in water is not objectionable for most purposes; however, for some industrial uses it may be undesirable. Silica in boiler-feed water is undesirable because it forms a hard scale, the scale-forming tendency increasing with the pressure in the boiler. The following table shows the maximum suggested concentrations of silica for water used in boilers (Moore, 1940, p. 263).

Concentration (ppm)	*Boiler pressure*
40	<150
20	150–150
5	151–400
1	>400

Excessive iron and manganese concentrations cause reddish-brown or dark-gray precipitates that stain clothes and plumbing fixtures. The staining properties are especially objectionable in certain manufacturing processes. Water containing more than 0.3 ppm of iron and manganese together will probably cause noticeable staining. The concentration of manganese in the ground water in Grayson County was not determined; however, generally the manganese concentrations are small and for the most part negligible. Many water analyses include two values for iron, total iron and iron in solution at the time of analysis. The value for total iron includes iron precipitated from the sample during transportation and storage and redissolved with acid, and it represents the maximum value of iron present in water in place in the aquifer. Where iron in solution alone is given on the analytical report, it can generally be assumed that the water was stable and iron did not precipitate between the times of collection and analysis; otherwise, the chemist would have made a total-iron determination.

In appraising the quality of water for irrigation, both the concentration and the composition of dissolved constituents should be considered. The chemical characteristics that appear to be most important in evaluating the quality of water for irrigation in Grayson County are, in order of their importance, (1) proportion of sodium to total cations (an index to the sodium hazard), (2) total concentration of soluble salts (an index to the salinity hazard), and (3) concentration of boron. A system of classification commonly used for judging the quality of a water for irrigation was proposed in 1954 by the U.S. Salinity Laboratory Staff (1954, p. 69–82). The classification is based primarily on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the sodium-adsorption-ratio (SAR).

The relative importance of the dissolved constituents is dependent upon the degree to which they accumulate in the soil. Kelley (1951, p. 95–99) cited areas having an average annual precipitation of about 18 inches in which salts did not accumulate in the irrigated soil. Wilcox (1955, p. 15) stated that the system of classification of irrigation waters proposed by the Salinity Laboratory Staff "is not directly applicable to supplemental waters used in areas of relatively high rainfall." Thus in Grayson County, where the average annual precipitation is about 39 inches, the system of classification probably is not directly applicable. Wilcox (1955, p. 16) indicated that water generally may be used safely for supplemental irrigation if its conductivity is less than 2,250 micromhos per centimeter at 25° C and its SAR is less than 14. Each individual situation should be appraised when consideration is being given to irrigating with water in which the specific conductance and SAR values exceed these limits, where soil or drainage conditions are unfavorable, or when the crop to be grown is especially sensitive to the hazards of sodium and salinity.

An excessive concentration of boron will make a water unsuitable for irrigation. Wilcox (1955, p. 11) has indicated that 1.0 ppm of boron is permissible for irrigating boron-sensitive crops, and 3.0 ppm is permissible for boron-tolerant crops.

TRINITY GROUP

The Trinity group in Grayson County generally yields water that is suitable for most purposes except in the northern part of the county, in the vicinity of the Preston anticline, where the lower part contains saline water. Most of the fresh water has a high sodium bicarbonate content and is very soft. The hardness of 35 samples ranged from 1 to 426 ppm; however, in only 6 samples did it exceed 60 ppm. The dissolved-solids content in 14 samples ranged from 516 to 1,180 ppm. In all the 14 samples, it exceeded 500 ppm; however, only in 2 did it exceed 1,000 ppm. The iron content in 14 samples ranged from 0.02 to 2.1 ppm; in 4 of the samples the content exceeded 0.3 ppm.

The water from the Trinity group is of questionable quality for irrigation. In only 1 sample of 24 did the specific conductance exceed 2,250 micromhos; however, of 11 values of SAR all exceeded the safe limit of 14. Of 11 determinations of boron, 2 exceeded the permissible limit of 1.0 ppm for boron-sensitive crops.

WOODBINE FORMATION

The water from the Woodbine formation ranges more widely in chemical composition than does the water in the Trinity group. However, in general, the water of the Woodbine is suitable for most purposes. The iron content in water from the Woodbine poses the most serious problem so far as public supply is concerned. Of 30 determinations of iron content, 14 exceeded 0.3 ppm. The dissolved-solids content of 31 samples from the Woodbine ranged from 114 to 2,620 ppm; in 10 of the samples it exceeded 500 ppm, and in 3 it exceeded 1,000 ppm. The hardness of the water ranged from 0 to 1,070 ppm in 134 samples; however, most of the water is soft, the hardness exceeding 60 ppm in 51 of the 134 samples analysed. In general, the water from the Woodbine is hardest in and near the area of outcrop, the hardness decreasing with depth.

The water from the Woodbine in the outcrop area generally is suitable for irrigation. However, at depth the sodium content increases and the water becomes questionable for irrigation. Of 131 determinations of specific conductance, only 13 exceeded 2,250 micromhos; however, of 31 values of SAR, 19 exceeded the limit of 14. In only 2 of 21 samples did the boron content exceed 1 ppm.

OTHER FORMATIONS

The quality of water from the other formations in Grayson County varies widely. Water from the Pawpaw formation appears to be of excellent chemical quality, except that most of it is hard. Hardness of 7 of 8 samples exceeded 60 ppm. The water from the Austin chalk is probably suitable for most purposes except that it is hard. Of 30 determinations of hardness, all 30 exceeded 60 ppm. Only 4 samples of water were obtained from the Eagle Ford shale and 2 from the alluvium. The small number of samples cannot be considered representative, and generalizations concerning the quality of water in the two formations should not be made.

SUMMARY AND CONCLUSIONS

The principal ground-water reservoirs in Grayson County are the Trinity group and Woodbine formation, supplying more than 95 percent of the ground water used in the county. Other water-bearing formations supplying small to moderate amounts of water include the alluvial deposits, Pawpaw formation, Austin chalk, and Eagle Ford shale.

Recharge to the Trinity group and Woodbine formation is derived chiefly from precipitation on the outcrop, although a small amount is contributed to the outcrop in Lake Texoma.

The ground-water resources of Grayson County are only partly developed. The amount of fresh water in transient storage in the Woodbine formation and Trinity group is estimated to be about 25 million and 60 million acre-feet, respectively. Most of the water is not recoverable because of the depth at which it occurs. However, relatively high artesian heads and large available drawdowns, prevailing over much of the county in both the Trinity group and Woodbine formation, are favorable to future development. A factor limiting any large well development, however, is the volume of saturated fresh-water sand available in the area. The amount of fresh-water sand in the Trinity decreases northward, chiefly as a result of an increase in the amount of salt water in the northern part of the county. Consequently, in much of northern Grayson County, large developments of fresh ground water from the Trinity are not feasible. Large to moderate amounts of fresh water may be obtained from the Woodbine in most of Grayson County, especially in the outcrop area and in areas where the amounts of saturated sand are greatest. Withdrawal of moderate to large amounts of water from the alluvial deposits north of Denison and in northeastern part of the county may be possible, but more information is needed before definite conclusions can be reached.

Large withdrawals of ground water from the Trinity group and Woodbine formation have resulted in large declines of water levels in the heavily pumped Sherman area. Concentrated pumping in Sherman has resulted in some dewatering of the Woodbine in that area. Distribution of pumping over a larger area will be necessary if further declines in water level in the Woodbine in the Sherman area are to be minimized. The Trinity group is the most favorable source of additional ground water in the Sherman area. Pumping levels in the Trinity, still several hundred feet above the top of the aquifer, have a large margin of safety before dewatering of the sand begins. However, the economics of higher pumping lifts caused by declining pumping levels will tend to limit the full development of the aquifer. To minimize additional declines in water levels, in either the Trinity or the Woodbine, the pumping would have to be distributed evenly among the wells, and future wells spaced as far apart as possible.

The ground water in Grayson County is suitable for most purposes. The Trinity group generally yields soft water that has a high bicarbonate content but is questionable for irrigation because of a high sodium content. Water from the Woodbine formation is generally soft but may have a high iron content. The water of the Woodbine is generally suitable for irrigation in the outcrop area but unsuitable downdip because of a high sodium content. The other water-bearing formations yield water that is apparently acceptable for most purposes.

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