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ARTESIAN WATER IN SOMERVELL COUNTY TEXAS

BY

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ABSTRACT

Somervell County is part of the Grand Prairie region of north-central Texas. An excellent supply of artesian water is available from the Trinity reservoir at no great depth. The first flowing well in Somervell County was drilled in 1880, and the first flowing well in Glen Rose, the county seat, was drilled in 1881. Since 1880 more than 500 wells have been constructed, probably more than half of them prior to 1900. Many of these early wells have been abandoned, either because the well hole caved in as a result of the absence or deterioration of casing or because the wells ceased to yield water by natural flow.

The artesian water has always been used chiefly for domestic supply and for watering stock. Only a comparatively small area of farm land is now irrigated. The quantity used to supply the needs of tourist camps and outdoor swimming pools forms a relatively large percentage of the total amount withdrawn from the artesian reservoir in Somervell County.

The artesian water is contained chiefly in the permeable sandstone beds—the "basal sands"—of the Trinity group. Some shallow wells of small capacity are supplied by water in the crevices and solution channels in limestone that apparently is near the base of the Glen Rose formation and probably derives its water by leakage from the underlying Trinity reservoir. The wells encounter from one to three aquifers, the number depending upon their depth and location. At and around Glen Rose, the area in which most of the flowing wells are concentrated, the first aquifer is the creviced portion of the limestone, which is encountered at about 50 feet but does not everywhere yield water. The second and third aquifers, both of which are part of the "basal sands" of the Trinity group, are much more uniform and persistent; the second is encountered at Glen Rose at depths of 100 to 135 feet, and the third at depths of about 275 to 330 feet.

The artesian reservoir is supplied by water that falls as rain or snow upon the outcrop of the "basal sands" on the higher lands west and north of Somervell County. These permeable beds dip eastward and southeastward beneath the county and are covered by the less permeable beds of the overlying Glen Rose formation. As the water that reaches the zone of saturation percolates down the dip of the beds it is confined under artesian pressure, and wells that penetrate these beds at lower altitudes yield water by natural flow.

Originally the artesian pressure was sufficient to raise the water in tightly cased wells in the northwestern part of Somervell County to a maximum altitude of about 750 feet above sea level, but at Glen Rose the original artesian head was probably not more than 710 feet. From the information avail-

able it would appear that the original head of the water in the upper aquifers was not nearly as great as that of the lower aquifer. The head has declined generally throughout the county. At Glen Rose in June 1930 the artesian head of the water from the deepest aquifer of the Trinity reservoir was about 639 feet above sea level, and the head of the water from the upper aquifers was about 15 feet less. The decline in head still continues, but at a very much slower rate than formerly. With the decline in head the size of the area of artesian flow has decreased, though in recent years the shrinkage has been comparatively little.

The draft from the artesian reservoir in Somervell County during the summer is estimated at about 1,000,000 gallons a day, distributed as follows: Domestic use, 150,000 gallons; stock use, 60,000 gallons; recreation pools, 250,000 gallons; irrigation, 180,000 gallons; and waste, not including underground leakage, 360,000 gallons. In winter the daily draft is probably about 370,000 gallons less than in summer.

The 360,000 gallons a day permitted to flow from wells without being used for any beneficial purposes is an unnecessary drain upon the artesian reservoir. The head of many of the flowing wells in Glen Rose and vicinity is already low, and a further decline of only a few feet will greatly reduce their flow or cause them to stop flowing. Surface waste can be controlled by repairing all defective wells and placing valves on them to control the flow. Such a program of conservation is so simple and relatively so inexpensive that its execution should not be longer delayed. Definite assurance cannot be given that the stopping of surface waste will prevent all further decline in head, but it will certainly result in considerable benefit to the water users of the area.

Considerable study has been made of the problem of underground leakage from wells, which may be determined by three general methods. The pressure method consists essentially of noting, by means of a pressure gage, differences in the shut-in pressure of otherwise similar wells. In the meter method a specially constructed current meter is lowered into the well, and the difference in the velocity of the water at various depths serves to locate the leaks and to afford a measure of the quantity of water that is leaking away. In the packer method a string of pipe is lowered into the well and a packer is seated at the bottom; if, as a result of this installation, the flow and head are increased, it is evident that water was being wasted underground. In Sommervell County the use of the pressure method was not considered practicable because the artesian wells are subject to great mutual interference and many of them cannot be closed for lack of valves. The exploration of the wells by either the meter or the packer method was seriously handicapped on account of obstructions in the casings and the manner in which the wells are finished at the top. The available information, therefore, is not complete enough to warrant an estimate of the total underground leakage in the county, but this leakage does not appear to be excessive at present.

The quality of the water obtained from a depth of more than 50 feet is satisfactory for domestic use, but the shallow ground water in the surficial deposits is at least in part polluted and hence unsuitable for drinking and cooking. Shallow, insufficiently cased artesian wells and unplugged abandoned wells offer opportunity for the entrance of this polluted water into the artesian supply. Any further lowering of the artesian head will increase the danger of such pollution.

The studies made indicate that the present draft upon the aquifers in Somervell County is about equal to the safe yield of these aquifers in the county.

The following program for conservation of the artesian water is recommended:

1. All wells that are wasting water at the surface should be repaired and equipped with valves, which should be closed whenever the water is not needed. All useless flow, including unnecessary flow to recreation pools during the winter, should be stopped. This can be effected by enforcing existing laws of the State relative to the waste of water and the casing of wells.

2. The users of large quantities of artesian water, especially from wells located on low-lying land, should for the public good be encouraged to reduce the draft as much as practicable.

3. Wherever a new well is to be drilled to replace a defective well or one that no longer yields sufficient water, the owner should be required to have all old wells on the property properly plugged or repaired, so as to prevent all surface and underground waste.

4. Every new well should be tightly cased to the water-bearing bed that supplies the well. If the casing cannot be seated to make a watertight seal it should be properly cemented. This procedure is recommended to prevent leakage of water from the lower aquifer into the upper aquifer with consequent loss of pressure, also to prevent the possible entrance of pollution into the well.

5. To safeguard the purity of the artesian water supply it is very desirable to abolish all privies, cesspools, and septic tanks and to substitute a modern system of sewage disposal.

6. Because of the scanty information as to the quantity of underground leakage and the particular wells that are leaking it is not considered advisable at this time to recommend a general program of plugging and recasing defective wells. After proper steps have been taken to eliminate the surface waste more definite information upon the source and amount of the underground leakage can be obtained by drilling several test wells and making detailed observations on the effects of improper construction and insufficient casing.

INTRODUCTION

LOCATION AND GENERAL FEATURES OF THE AREA

Somervell County lies in north-central Texas and is bounded on the east by Johnson County, on the south by Bosque County, on the west by Erath County, and on the north by Hood County. It has an area of about 184 square miles and is next to the smallest county in the State. According to the 1930 census, the county had a population of 3,016. Glen Rose, the largest town and the county seat, is practically in the center of the county, about 42 miles southwest of Fort Worth, and had in 1930 a population of 983.

The higher lands in the southern part of the county reach an altitude of about 1,300 feet, and the lowlands in the valley of the Brazos River, in the eastern part of the county, have an average altitude of about 560 feet. The eastern part of the county is drained by the Brazos River, and the remainder chiefly by the eastward-flowing Paluxy Creek and the southeastward-flowing Squaw Creek which enter the Brazos River at a point about midway between the north and south boundaries of the county.

No railroads cross the county, the nearest railroad point being at Granbury, Hood County, which is 15 miles north of Glen Rose on the Fort Worth & Rio Grande Railway. Glen Rose is connected by improved roads with Cleburne, Johnson County, on the east, and with Stephenville, Erath County, on the west.

The soil is generally shallow and in the valleys is chiefly a reddish-brown sandy clay. The slopes of the hills and mesa-capped uplands are generally stony, owing to the breaking down of the many thin ledges of limestone and alternating layers of yellowish clay. The prevailing timber growth is chiefly post oak and cedar, with some pecan trees along the streams. Native grasses furnish good feed for cattle during periods of abundant rainfall.

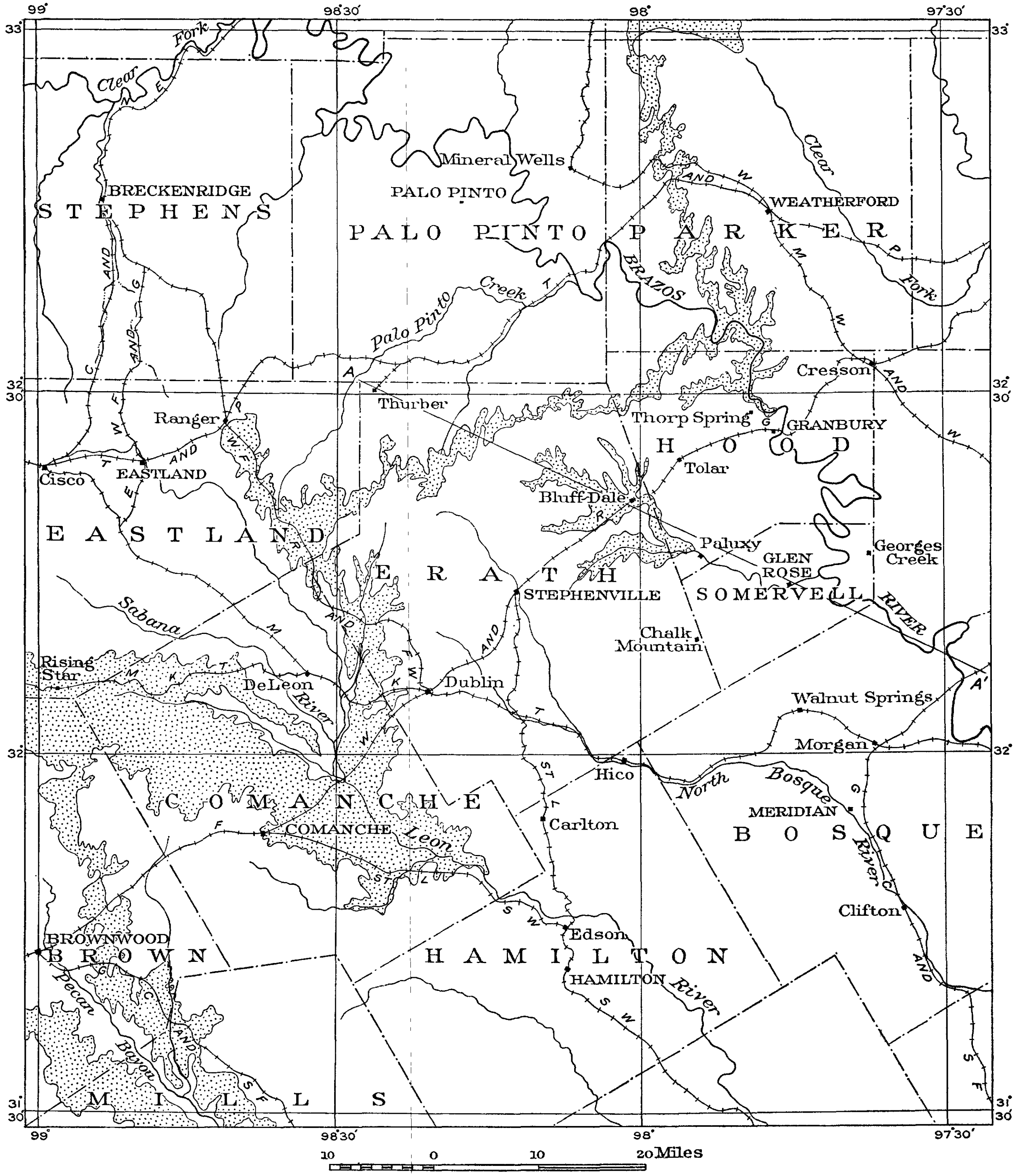
About one-fourth of the county is devoted to crop lands, the agricultural development being confined chiefly to the broader stream valleys and to the tablelands at higher altitudes. The principal crops are cotton, corn, hay, oats, wheat, and feed. The raising of livestock and poultry is also an active industry. By reason of its location along the picturesque Paluxy Creek and the occurrence of flowing artesian wells, Glen Rose has been extensively developed as a resort community. A number of sanatoriums are located here, to which people come from all parts of the State for medical treatment, rest, and recreation.

SCOPE OF INVESTIGATION

The development of the area, which has been most active in the vicinity of Glen Rose, is based chiefly on the fact that flowing artesian water may be obtained from wells drilled in this locality. Because of the large number of wells drilled and the resultant draft upon the artesian reservoir, many of the early wells have ceased to flow and the artesian head has declined markedly on all the wells. This condition has not been unnoticed by the residents of the area, and at the instigation of a number of public-spirited citizens a ground-water investigation was made possible through the enactment of legislation which provided an appropriation for ground-water surveys to be expended under the supervision of the Texas State Board of Water Engineers.[1] This board entered into a cooperative agreement with the United States Geological Survey to make the investigations, and the writer was assigned to the study of the ground-water problems of Somervell County.

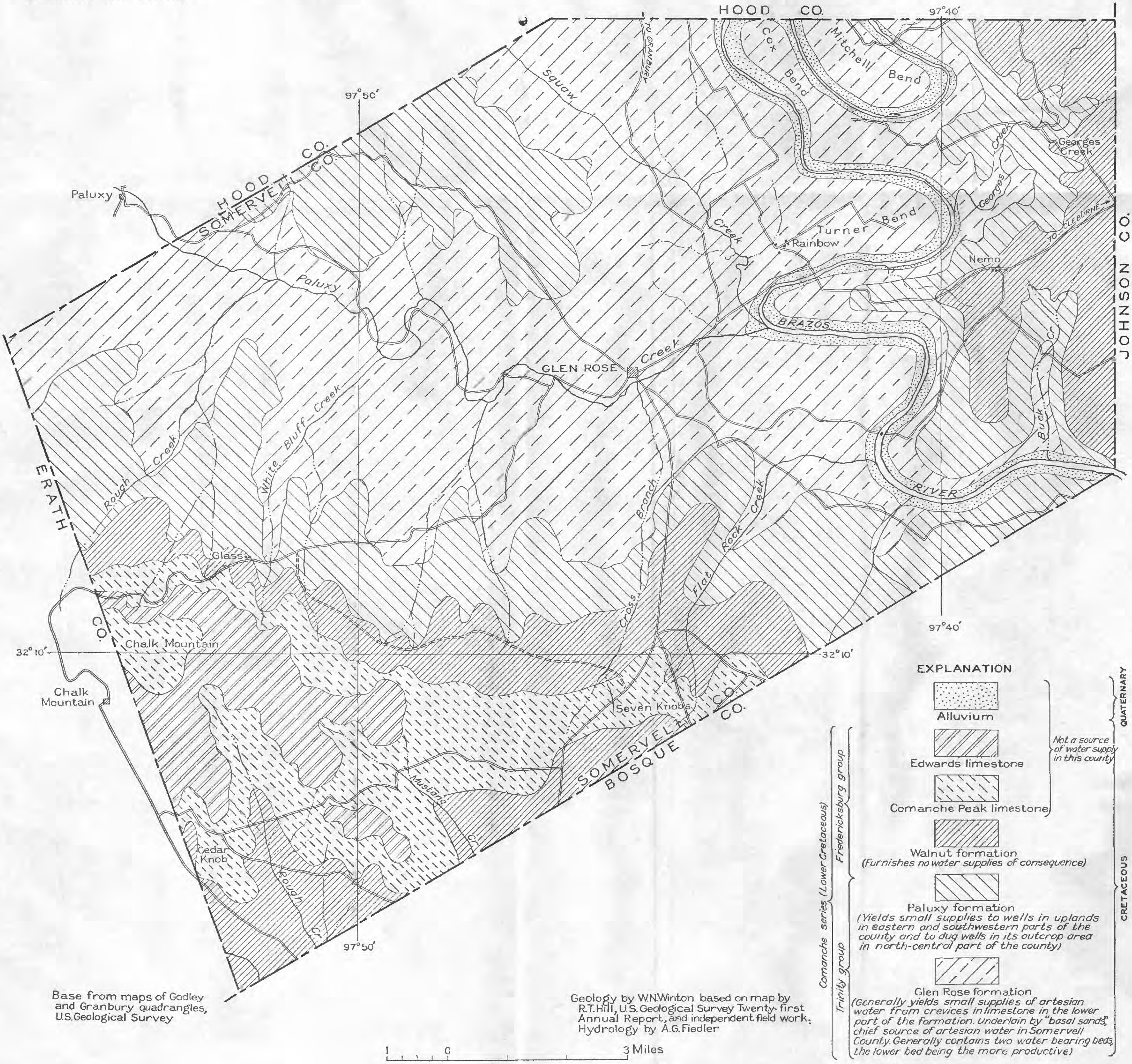
Field work in the area was done chiefly during November and December 1929 and a short period in June 1930. The geology of the region was not studied in detail except with respect to such features as have a bearing upon the general problem of conserving the artesian water. The general investigation comprised a study of the

[1] 41st Texas State Legislature, 2d called sess., ch. 37 (H. Bill 16), approved July 8 1929.

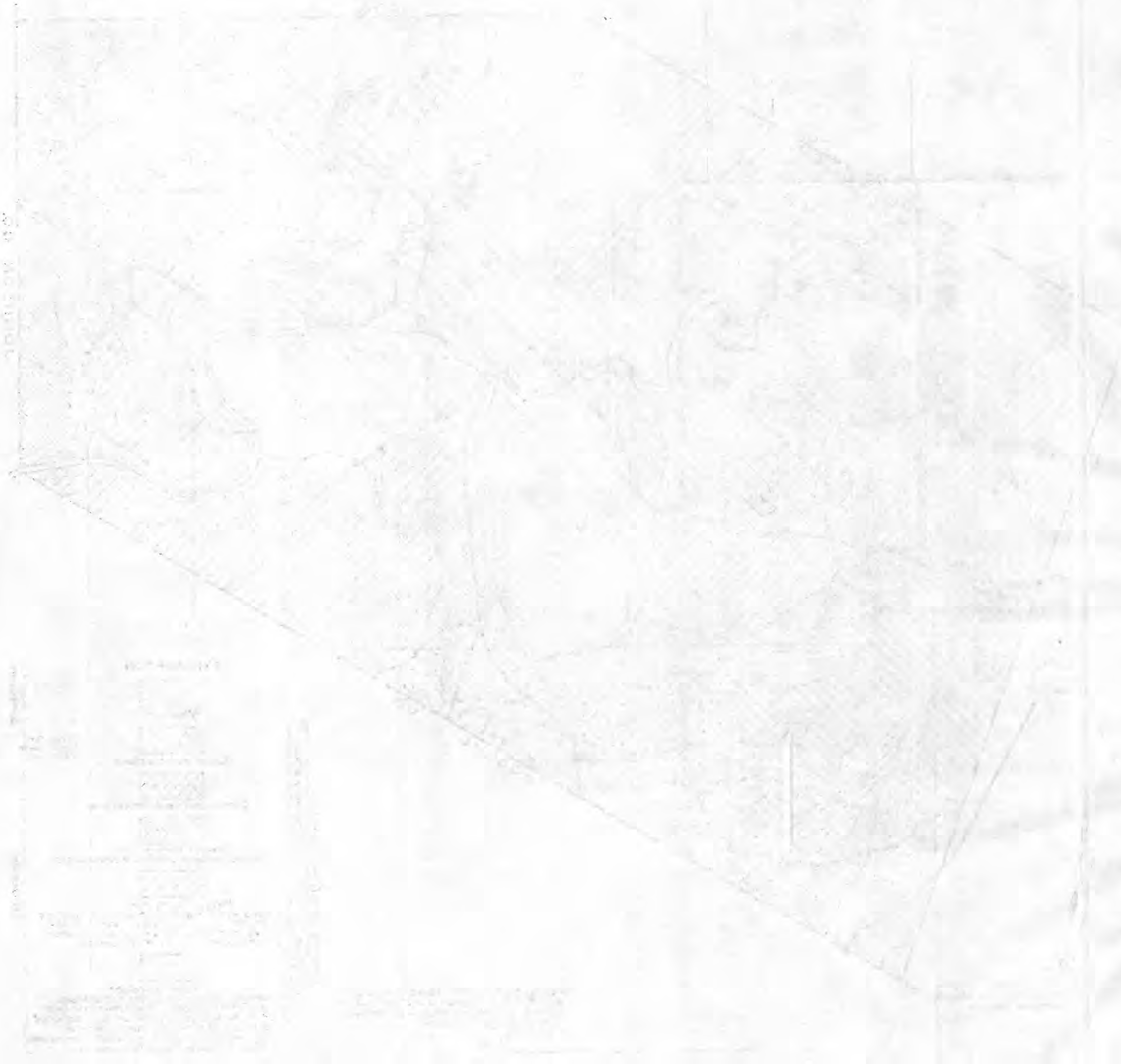


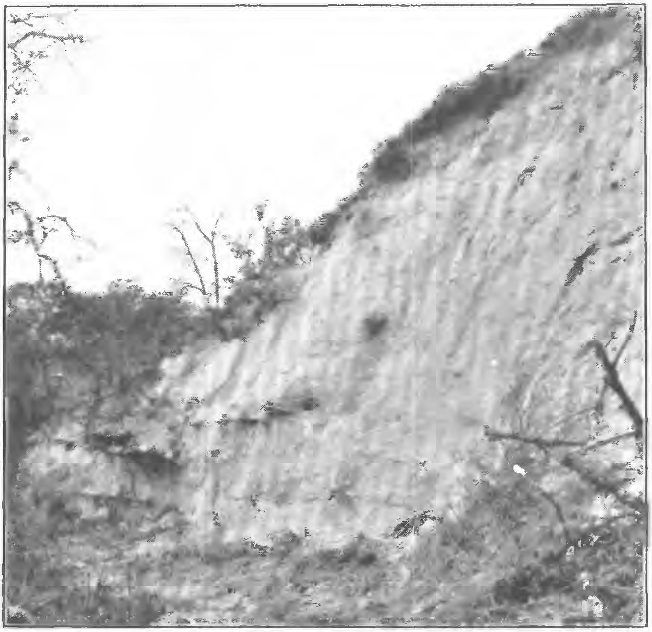
MAP SHOWING LOCATION OF SOMERVELL COUNTY, TEX., AND OUTCROP OF "BASAL SANDS" OF THE TRINITY GROUP.

Outcrop shown by stippling.

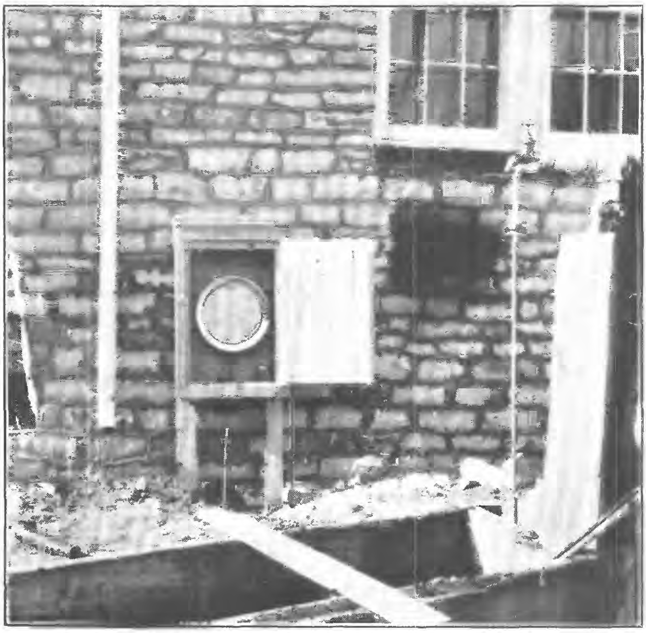


MAP SHOWING GENERALIZED GEOLOGY OF SOMERVELL COUNTY, TEX.





A. OUTCROP OF "BASAL SANDS" NEAR THORP SPRINGS, TEX.



B. RECORDING PRESSURE GAGE ATTACHED TO FLOWING WELL.

use and waste of artesian water, the safe yield of the artesian reservoir, underground leakage of wells, methods of constructing wells, and other related features necessary for the formulation of a conservation program. It was beyond the scope of this investigation to visit all the wells in the county that tap the artesian aquifers. Because of the lack of adequate base maps the location of some of the wells outside of Glen Rose and vicinity (see pl. 6) may be somewhat in error, but such information as was obtainable regarding the wells is given in the table of well records on pages 76–84. The investigation was conducted under the general supervision of Oscar E. Meinzer, geologist in charge of the division of ground water, United States Geological Survey, who, with John A. Norris, chairman of the Texas State Board of Water Engineers, had made a preliminary study of the artesian problems in the area in September 1926. A preliminary report summarizing the results of the investigation was issued in 1930.[2]

ACKNOWLEDGMENTS

Acknowledgments are due to John A. Norris, chairman, C. S. Clark, and A. H. Dunlap, of the Texas State Board of Water Engineers, for helpful cooperation throughout the investigation; to Chester Cohen, of the Texas State Department of Health, for the section of this report on the sanitary quality of the waters; to C. E. Ellsworth, district engineer, United States Geological Survey, Austin, Tex., for the use of recording gages and other equipment supplied by his office; to W. N. Winton, Texas Christian University, for furnishing a geologic map of Somervell County and other information on the geology of the county; to J. B. Winder, chief engineer, city of Dallas, for samples of drill cuttings obtained from a well drilled by the city; to R. L. McAllister, mayor of Glen Rose, for information regarding the general problem of conservation; to the Lane & Sons Motor Co., for furnishing a car for the use of the writer while engaged in field work. Much information regarding the wells in the county was supplied by Perry Embree and T. W. Nickell, well drillers of Glen Rose. Acknowledgments are also due to Mr. Nickell for checking the list of wells published in this report.

CLIMATE

Somervell County lies in the northwestern part of the portion of the State classified by the United States Weather Bureau as central Texas. No Weather Bureau stations are maintained within the

[2] Survey of the underground waters of Texas: U.S. Dept. Interior Press Mem., Feb. 16, 1930 (mimeographed).

county, and the summary of climatic data given below is that for neighboring stations in the surrounding counties.

This section of Texas is subject to occasional sudden and great changes of temperature, which occur chiefly during the winter in conjunction with storms and cold waves that sweep at irregular intervals over the State. The winters are generally mild, with minimum temperatures not greatly below the freezing point, though at times temperatures near zero have been recorded. The summers are long and rather warm, but because the clear skies at night are conducive to active radiation the oppressive noonday heat is generally followed by pleasant nights. The annual snowfall rarely exceeds 1 or 2 inches, and the snow does not remain on the ground for any great length of time.

The annual precipitation, as estimated from records obtained at stations in the surrounding counties, averages about 32 inches. The largest part of the precipitation normally occurs during the crop-growing season. However, the distribution of the precipitation is rather erratic and is marked by extended wet or dry periods occurring at irregular intervals.

Summary of climatic data for stations in the vicinity of Somervell County, Tex.

[From U.S. Weather Bureau]

Station	Altitude above sea level (feet)	Mean annual precipitation (inches)	Mean annual temperature (° F.)	Mean annual snowfall (inches)
Cleburne, Johnson County	758	34.90	65.4	
Dublin, Erath County		28.61		3.6
Fort Worth, Tarrant County	670	33.13	65.4	2.3
Kopperl, Bosque County	576	32.98		1.6
Panter, Hood County	1,000	30.62	64.7	2.0

SURFACE FEATURES

Somervell County is situated in the heart of the Lampasas Cut Plain, in the Grand Prairie region of Texas. The valleys of Paluxy Creek, which runs from west to east, and the Brazos River, in the eastern part of the county, are cut deeply below the level of this plain. The southwestern part of the county, which rises to an altitude of about 1,300 feet, is capped by the hard Edwards limestone, and the valleys of Paluxy Creek and the Brazos River are developed in the softer underlying formations, which have been deeply eroded.

The subdivisions of the Lampasas Cut Plain that are most prominently developed in Somervell County are the Walnut Prairie, the Paluxy Cross Timbers, and the Glen Rose Prairie. The Walnut Prairie is not very extensive; it occupies only a narrow strip running east and west across the southwestern part of the county and is coincident with the outcrop of the Walnut formation. Below the outcrop of the Walnut formation and parallel with Paluxy Creek is the somewhat wider and more prominent strip formed by the Paluxy Cross Timbers; it is identified by the deep sandy soil of reddish color and is characterized by growths of timber, largely post oak and blackjack. In the north-central part of the county near the boundary of Hood County the sands of the Paluxy formation are part of the wide plateau that extends westward in Hood County from the base of Comanche Peak and southward into Somervell County. The Glen Rose Prairie, which is seen so typically in the vicinity of Glen Rose, occupies a strip of varying width along the valleys of Paluxy and Squaw Creeks. Its soil has a rather characteristic brownish-yellow color, and because of the breaking down of the thin lenses of limestone that alternate with the clay beds its surface is generally stony. The alternating beds of varying hardness produce the terraced type of topography with rather prominent wide benches. Adjacent to the streamways the Glen Rose formation makes rather steep bluffs and in places assumes a steplike character.

GEOLOGY

GENERAL FEATURES

The geology of Somervell County was not studied in detail during this investigation, and the following description, which is based largely on Hill's study of the Black and Grand Prairies,[3] deals chiefly with the formations that have a direct bearing upon the problem of ground-water conservation.

The formations exposed in Somervell County, with the exception of the alluvium, are of Lower Cretaceous (Comanche) age. From oldest to youngest they are the Glen Rose, Paluxy, and Walnut formations and the Comanche Peak and Edwards limestones. The "basal sands" of the Trinity group underlie the Glen Rose formation, but according to Winton (see pl. 2) they are not exposed in Somervell County. They are, however, reached by many artesian wells and are the chief source of water of the area. In general the Cretaceous formations in this area are fairly uniform and have an eastward dip. Information in regard to the water-bearing properties of the Paleozoic rocks that underlie the Trinity group was not obtained. From the meager information at hand it would appear that they are not probable sources of water supply for the county, and they are not considered in this report.

[3] Hill, R. T., Geography and geology of the Black and Grand Prairies, Tex.: U.S. Geol. Survey 21st Ann. Rept., pt. 7, 1901.

LOWER CRETACEOUS (COMANCHE) SERIES

TRINITY GROUP

"BASAL SANDS"

The "basal sands" of the Trinity group underlie the entire county. They include beds of sand that form an excellent source of water supply and furnish most of the water for domestic and farm use in the county. At Glen Rose the wells enter the uppermost sand at depths ranging from 100 to 135 feet and strike the lowest sand at about 275 feet. As no deep wells were drilled in Somervell County during the course of the present investigation and no detailed logs are available, it is impossible to give a detailed section of the "basal sands." The following generalized log and the log of the well at the Somervell County courthouse are considered typical of conditions at and near Glen Rose. Both sections begin in the lower part of the Glen Rose formation; the "basal sands" probably begin at a depth of about 115 feet in the generalized log and about 100 feet in the log of the courthouse well. The two sections show about the average variation in the depth and thickness of the formations for this locality.

Generalized log of well at Glen Rose

[Supplied by Perry Embree from memory]

	Thickness (feet)	Depth (feet)
Soil	10	10
Gravel	5	15
Rock, chiefly limestone; some water that rises under artesian pressure is encountered at a depth of about 50 feet	100	115
Blue shale	35	150
Mixed shale and sand; some water that rises to the surface under artesian pressure	20	170
Sand; artesian water	25	195
Mixed red and blue clay with increasing amounts of sand	85	280
White sand; main source of artesian water	30-35	310-315

Log of well at Somervell County courthouse, Glen Rose, Tex.

[Supplied by R. L. Nickell, driller]

	Thickness (feet)	Depth (feet)
Chiefly blue and white limestone; some water in crevices	100	100
Blue sticky shale	30	130
Clean, sharp water-bearing sand with interbedded lenses of shale and gravel	40	170
Red beds, chiefly gummy, puttylike shale; set 4-inch casing at 235 feet	90	260
Coarse, clean white water sand; strong artesian flow	31	291

The "basal sands" of the Trinity group at Glen Rose contain generally two and in some places three beds of water-bearing sand. Each of these beds is composed of fine-grained, poorly cemented brownish to white sand. (See pl. 3, *A*.) The uppermost bed is apparently somewhat finer in grain than the lowermost bed and generally is somewhat darker in color. The lowermost bed consists of moderately coarse white sand with well-rounded individual grains that are fairly uniform in size. The "basal sands" are readily drilled, and though they are only loosely cemented the uncased drill holes will generally remain open without serious caving.

The "basal sands" of the Trinity group are completely covered in this county, and wells drilled at the lower altitudes in the valleys at Glen Rose and vicinity produce flowing artesian water. On the high lands adjacent to the valleys the water rises in the wells under artesian pressure but does not overflow.

GLEN ROSE FORMATION

The Glen Rose formation is the lowest formation exposed in the county. It is composed of alternating beds of clayey or sandy limestone and thin sandy clay. The beds differ in thickness, but individual beds show a very uniform thickness where they can be traced along the outcrops. The stratification is conspicuous, and the weathering of the softer beds gives rise to typical stratum plains and terraces. The indurated beds are white, gray, or yellow; the clayey beds are mostly yellow, red, or brown. According to Hill the Glen Rose formation has a total thickness of about 300 feet as measured in outcrops in the Brazos and Paluxy Valleys near Glen Rose.

The Glen Rose formation has the greatest areal extent of the formations exposed in the county. It occupies a strip 4 to 5 miles in width along the valley of Paluxy Creek across the central part of the county and another strip of similar width in the north-central part of the county from a point about 1½ miles west of Squaw Creek to a point within about 2 miles of the eastern county line.

The Glen Rose formation in Somervell County is not completely confined by impervious beds, and, in general, wells drilled into it do not yield water that will flow by artesian pressure. However, in some areas wells ending in what appears to be the Glen Rose formation yield flowing artesian water. This water comes from the lower limestone of the formation, which contains either joints or solution channels, and it is undoubtedly derived by leakage from the uppermost of the underlying "basal sands." Such conditions are rather local.

PALUXY FORMATION

The Paluxy formation, which has a maximum thickness of about 100 feet, is composed of fine-grained porous sand and bands of impure clay. The lower part of the formation is somewhat calcareous, but the upper part is distinctly clayey. Its color ranges from gray to yellowish red or brown, according to the amount of iron staining.

The formation is exposed in a strip 1 to 2 miles wide parallel to Paluxy Creek on the south side of the valley; in a narrow belt on the east side of the Brazos River in the eastern part of the county; and in a lobelike area in the north-central part of the county between the valleys of Squaw and Paluxy Creeks, where it is the southern extension of the wide, high plateau that lies at the base of Comanche Peak in Hood County.

The Paluxy formation is not generally a source of water supply in Somervell County, as it is not sufficiently well confined to yield water by artesian pressure. However, several wells in the uplands in the eastern and southwestern parts of the county obtain from it supplies sufficient for farm use. A few dug wells in the outcrop area in the north-central part of the county also derive small supplies from this formation.

FREDERICKSBURG GROUP

WALNUT FORMATION

The Walnut formation in Somervell County rests upon the Paluxy formation. It is somewhat less than 100 feet thick and is composed of alternating beds of laminated clay and shell agglomerate. The upper part grades upward into the limestones of the Comanche Peak formation. The clayey portions of the formation are distinctly yellow, and in grading upward into the limestone the color changes to cream and bluish white. The Walnut beds crop out in a narrow strip parallel to the Paluxy formation on the south side of Paluxy Creek and in a small area in the eastern part of the county and extend over into Johnson County on the east. These beds do not furnish any water supplies of consequence.

COMANCHE PEAK LIMESTONE

The Comanche Peak limestone is white and chalky and is about 30 feet thick. It crops out in the southwestern part of the county, where it forms the base of the upland surrounding Chalk Mountain and caps the Seven Knobs. The Comanche Peak limestone grades upward without apparent break into the harder Edwards limestone.

EDWARDS LIMESTONE

Along the southwestern county line adjacent to Erath County a small hill known as Chalk Mountain is capped by the Edwards limestone. This formation is largely a firm white limestone of great durability and is distinguishable from the Comanche Peak limestone by the presence of flint nodules and characteristic fossils. It is not a source of water supply in this county, though it is a valuable source in other parts of Texas.

QUATERNARY ALLUVIUM

The alluvial deposits in Somervell County form a narrow strip along each side of the Brazos River. The strip is generally less than a quarter of a mile wide and in some places only a few hundred feet, the width depending largely on the steepness of the adjacent river bank. The material is characterized by a distinctly reddish color, which stands out conspicuously in contrast to the lighter grayish colors of the bluffs and hillsides. It probably does not exceed 25 feet in thickness and is composed chiefly of red sands with considerable clay which has been eroded from the upper reaches of the Brazos.

GROUND WATER

DEFINITION OF TERMS

Beneath a certain depth, which varies greatly in different localities, there is, as a rule, a zone in the crust of the earth in which all the pores, cracks, and crevices in the rocks are filled with water under hydrostatic pressure. This zone is called the "zone of saturation." A large part of the water that enters the rocks beneath the surface is drawn down by gravity to the zone of saturation. This water in this zone is called ground water. The upper surface of the zone, where it forms a free water surface, is called the "water table." The water table, in most places, is not a plane surface but has "hills", "valleys", and "depressions" that are generally related but not comparable in form to the surface features above them. Where the water table is very far below the surface there may be no relation between its irregularities and those of the land surface above it. The water table does not remain at a constant level but fluctuates constantly from day to day, month to month, and year to year in response to local additions to or subtractions from the zone of saturation. It is generally highest in winter and lowest in summer. Ground water, like surface water, tends to move from higher to lower levels, though much more slowly.

The zone between the main water table and the surface of the earth is called the "zone of aeration." The interstices of the rocks in this zone are not (except temporarily) filled with water under hydrostatic pressure, but they may contain water that is held by capillarity. This water is not called "ground water."

Where an aquifer that slopes downward from its intake area is overlain by an impermeable bed, the water contained may be under pressure sufficient to cause it to rise in tightly cased wells drilled through the overlying beds into the aquifer. Such wells are called "artesian wells." The water that supplies them is said to be under artesian pressure and is called "artesian water." An artesian aquifer is simply an aquifer that yields water under artesian pressure, and the artesian aquifers of an area may be spoken of collectively as an "artesian reservoir." If the pressure is great enough to cause the water to rise above the surface of the ground at the point of issue, the well is called a flowing artesian well, and the area in which such wells occur is an area of artesian flow. An artesian slope is a geologic structural feature or combination of such features which causes or cause water to be confined under artesian pressure.

An aquifer is a formation, group of formations, or part of a formation that yields water to wells and springs in sufficient quantity to be of consequence as a source of supply. The terms "water-bearing formation", "water-bearing bed", and "ground-water reservoir" are used as synonyms for "aquifer." It should be noted that a water-bearing formation, as here defined and as the term is generally used, means a water-yielding formation—one that supplies water to wells and springs—and not a formation that merely contains water.

Intake or recharge of ground water comprises the processes by which water is absorbed and is added to the zone of saturation; these terms are not applied to the absorption of water that does not reach the zone of saturation. The terms "intake" and "recharge" are also used to designate the quantity of water that is added to the zone of saturation. An intake area of an aquifer is an area in which there is absorption of water that eventually reaches a part of the aquifer within the zone of saturation; the term is not applied unless the water reaches that zone. The catchment area of an aquifer comprises its intake area and, in addition, all areas that contribute surface water to the intake area.

The hydrostatic level, or static level, of the artesian water at any place is the level to which the water will rise in a tightly cased well drilled to the artesian reservoir at that place. If the static level is above the surface of the land at the place where the well is drilled the well will overflow, or if it is tightly cased and capped the artesian water will exert a pressure that can be measured by means of a pressure gage and is generally expressed in pounds to the square inch. To determine the height in feet above the point at which the pressure is measured to which the water from a flowing well will rise if the casing is extended above the surface, the pressure in pounds to the square inch should be multiplied by 2.3.

The piezometric surface, or artesian-pressure surface, of an artesian aquifer is an imaginary surface that everywhere coincides with the static level of the water in the aquifer. A piezometric surface of an artesian reservoir may be shown by means of lines drawn through points of the same static level.

The artesian pressure is lowered by natural leakage from the artesian aquifers at points where they crop out or through the confining beds and by withdrawal of water from artesian wells. The piezometric surface declines from the intake area to the area of escape. This decline is known as the hydraulic gradient and can be expressed in feet to the mile or in other units.

SOURCES OF GROUND WATER

Somervell County is part of the Grand Prairie region of Texas, in which the Trinity reservoir is an excellent source of ground-water supply. The geologic conditions in this section are especially favorable for the procurement of flowing artesian water, as the water-bearing beds underlie the whole county, and in a large portion of it at no great depth. The "basal sands" of the Trinity group crop out in zones west and north of Somervell County. They dip eastward and southeastward beneath the county and are confined by the less permeable beds of the Glen Rose and overlying formations. (See fig. 1.) They receive their water supply by downward percolation from the precipitation that falls as rain or snow upon the outcrop area and from seepage losses from streams that cross the outcrop area. As the water that reaches the zone of saturation percolates down the dip of the inclined strata of the Trinity group, it is confined under pressure, and at the lower altitudes in the vicinity of Glen Rose wells drilled into the water-bearing sands of this formation yield water by natural flow. As the "basal sands" of the Trinity group are confined throughout the county, wells drilled into these sands practically anywhere within the county encounter water that rises under artesian pressure. All the essential factors necessary for the occurrence of artesian flows are therefore present. These factors have been classified by Fuller[4] as follows: (1) An adequate source of water supply, (2) a retaining agent offering more resistance to the passage of water than the well or other opening, (3) an adequate source of pressure.

The average dip of the Edwards limestone in the region between the Brazos and San Gabriel Rivers is given by Hill as about 17.5 feet to the mile, and its direction in general is east-southeast. Owing to the thickening of the beds of the Glen Rose formation to the east, the "basal sands" of the Trinity group dip at a greater angle than the Edwards limestone. However, through Somervell County the thickening of the Glen Rose formation is not nearly so great as it is to the south and east, and the "basal sands" do not dip more than about 20 feet to the mile. In view of the absence of reliable

[4] Fuller, M. L., Summary of the controlling factors of artesian flows: U.S. Geol. Survey Bull. 319, p. 316, 1908.

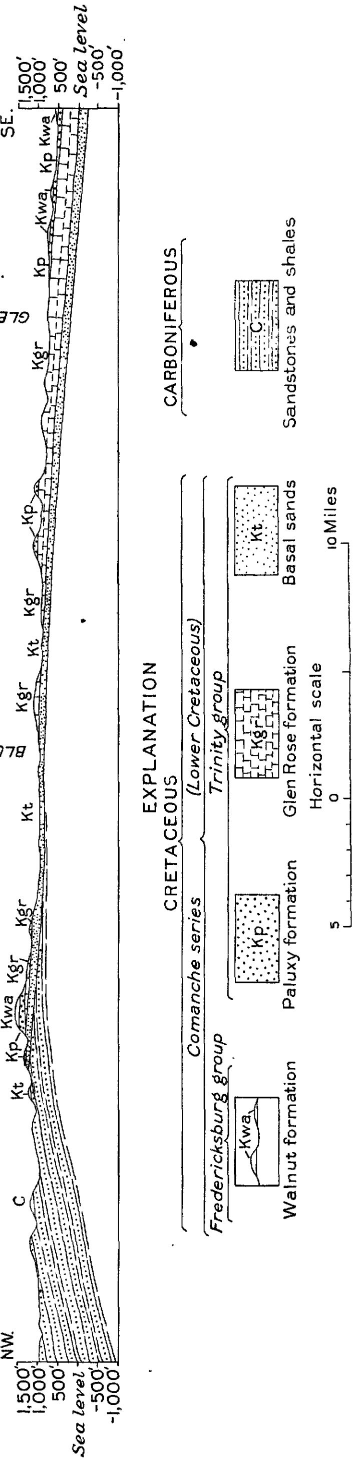


FIGURE 1.—Geologic section along line A–A', plate 1. (After R. T. Hill.)

well records or samples of drill cuttings this estimate may be somewhat in error.

The denser portions of the lower part of the Glen Rose formation generally act as the upper confining bed for the Trinity reservoir in this locality. The upper, more permeable beds of the Glen Rose formation are nowhere sufficiently well confined within the county to afford artesian flows. In view of the accessibility of the "basal sands" of the Trinity group and the superior quality of the water from that source, the Glen Rose formation, though it contains some water, is not a valuable source of water supply in this county. Several wells in the vicinity of Glen Rose, however, yield flowing water which apparently comes from the base of the Glen Rose formation. Every such well was reported to have a noticeable effect on other deep wells in the vicinity, and the occurrence of flowing water from the base of the limestone in the lower part of the Glen Rose formation is undoubtedly due to leakage from the underlying Trinity reservoir. This water doubtless is contained in joints and possibly some solution channels in the lower part of the Glen Rose formation; otherwise the limestone is relatively impermeable.

The sands of the Paluxy formation, which lie above the Glen Rose formation, are also relatively porous and absorb considerable water in their outcrop area. In the north-central part of the county they furnish small supplies to shallow wells. Throughout the major valleys of Squaw Creek and Paluxy Creek they have been completely eroded away, but in the southern, southwestern, and eastern portions of the county they dip beneath the relatively impermeable beds of the Walnut and overlying formations. Their confinement in these areas is not sufficient to supply water under artesian pressure, but they furnish moderate quantities of water to pumped wells in these upland portions of the county. In these localities the Paluxy sands are utilized only because of the much greater depth to the "basal sands" and because the surface altitude is so great that water will not rise high enough to flow in wells tapping the Trinity reservoir.

The formations above the Paluxy yield little water and are not of value in this county as sources of water supply.

SPRINGS

Along the banks of Paluxy Creek in Glen Rose small seepage springs issue from joints and crevices in the limestone. The discharge from the individual outlets is relatively small, and during the summer the outlets are more or less obscured by weeds and grasses, but in the winter the line of seepage is marked rather prominently by ice that forms along the banks. According to the increase in flow in this stretch of Paluxy Creek the total flow of the springs is estimated at nearly 100 gallons a minute.

Just below the Glen Rose-Cleburne Bridge over Wheeler Branch there is a spring flowing from the limestone along the right bank. The spring apparently issued originally from crevices in the limestone near the base of the channel, but at some places it was dammed up with concrete to make it flow at a higher level, so that it might be better utilized. Most of the concrete has been broken away, and the spring now flows from a point about 1 foot above the channel. The water as it issues from the spring has a temperature of 71° F., and the total flow is estimated at about 10 gallons a minute. The water from the spring supplies a few head of stock, but otherwise it is not utilized and flows down Wheeler Branch for about 200 yards into Paluxy Creek. A partial analysis of the water from this spring is given on page 56.

Porter Springs are probably the largest springs within the county. They issue from crevices and solution channels in the limestone on the right bank of the Brazos River just above the highway bridge on the Glen Rose-Cleburne road. The springs have been developed to furnish water to a swimming pool at the foot of the bank along the river. The temperature of the water is 66° F., and the total flow is estimated at about 50 gallons a minute. A partial analysis of the water from these springs is given on page 56.

HISTORY OF DEVELOPMENT OF ARTESIAN WATER

Considering the large number of wells that have been drilled in Somervell County, it is rather surprising that so little reliable information is available regarding the development of artesian water in the county. So far as is known no reliable record of the wells has ever been kept. As the geology of the county is relatively simple and the water-bearing formations are rather uniform and persistent, the drilling of only a few wells furnishes the driller with a fairly good idea of the nature of the formations and the depths at which they are encountered; consequently, there has been no great incentive to keep detailed records.

Hill[5] states that, in spite of the drilling of about 200 wells in the county up to the time of his report (1901), very little information concerning them was available. Hill's report dealt primarily with the geology of the region, and no attempt was made to cover the ground-water conditions in detail. The well drillers who constructed the first wells that tapped the artesian aquifers have since either died or moved from the locality, and because no comprehensive records have been kept, much information that has a vital bearing upon the present problems of the area has been lost.

[5] Hill, R. T., op. cit., pp. 474–479.

The first flowing well in Somervell County is said to have been drilled in 1880, and the first flowing well in Glen Rose in 1881. Some information on a few of the early wells is given in this report, but in view of the absence of sufficient data it is impossible to give a detailed history of the development and note how the drilling of the wells with the consequent increased draft upon the artesian aquifers has contributed to the problems of today. Many of the wells drilled prior to Hill's investigation have been abandoned because they have caved in as a result of the absence of casing or the deterioration of the small amount of casing generally used. Others have been abandoned because the artesian head has declined to such a level that the wells no longer yield water by natural flow or because farming did not prove profitable and the lands were given over to cattle raising. Wells drilled since 1900 have been constructed largely in the vicinity of Glen Rose, where flowing artesian water can still be obtained.

The artesian water has always been used chiefly for domestic supply and for watering stock, though in the early days some irrigation was attempted. The use for irrigation was apparently never very great, partly because only wells of small diameter had been drilled and hence the quantity of water was limited, partly because the farmers were inexperienced in irrigation methods. Conditions in this respect have not changed greatly during recent years. The artesian water is still used chiefly for domestic supply and for watering gardens and stock, and only a relatively small acreage of farm land is irrigated. Though periodic attempts have been made, chiefly in Glen Rose and vicinity, to conserve the artesian water by capping the wells when they are not in use, such regulation has not proved to be very successful, and after a short period of control the wells are again opened and the water permitted to waste. The owners of wells on high ground are the first to suffer from such waste of water, as the artesian head is no longer very great and decline in head reduces the flow of the border-line wells until their yield is of little value or else the flow ceases entirely.

Some of the domestic wells are fitted with covered wooden or concrete troughs through which the water is permitted to run. These troughs are used for preserving perishable food during the warm months, and though the water as it issues from the well has a relatively uniform temperature of about 70° F., the increased evaporation from the trough keeps the temperature in the food compartment lower than the temperature of the outside air.

In Glen Rose proper the largest individual user of water from wells supplied by the artesian aquifers is the Glen Rose Laundry. The draft upon the well supplying this establishment is not known, but by reason of the nature of the use it is undoubtedly greater than that from any other well. Outside of Glen Rose the two largest users of water within the county obtain water from artesian wells to supply outdoor swimming pools. One of these pools is an artificial one constructed of concrete; the other has been created by building a dam across a natural depression adjacent to Paluxy Creek.

Detailed information regarding the number, year of drilling, size, depth, amount of casing, yield, and quality of water in the wells in Somervell County is not available. Of the nearly 200 wells in the county reported by Hill,[6] 70 were located within a radius of half a mile of the courthouse and about 80 were flowing artesian wells. Most of these wells were apparently drilled during the period 1888 to 1897. During the present study a record of 223 wells in Glen Rose and the immediate vicinity (see p. 76 and pl. 4) was obtained. In addition meager information was gathered on 97 other wells (see p. 82 and pl. 6) scattered throughout the county. Though the information on all the wells is very incomplete, that recorded in Glen Rose and vicinity is considered rather accurate, but no record was obtained for many other wells scattered throughout the area. From the number of farms in the county, it is estimated that there are at least 200 additional farm wells not recorded in the list of wells on pages 76–84. These wells are practically all nonflowing wells that are pumped either by pitcher pumps, force pumps, or windmills to supply water for general farm use.

In considering the problems of the artesian water supply of Somervell County it should be remembered that the Trinity reservoir, which is the chief source of supply, does not lie wholly within the boundaries of the area here described. It underlies most of the Black and Grand Prairie region of Texas and is tapped in other parts of the State by many wells that furnish water for municipal and domestic supplies. Somervell County, however, is especially favored in location because flowing artesian water can be obtained here from relatively shallow wells.

HEAD OF ARTESIAN WATER

ORIGINAL HEAD

The exact altitude to which the water from the lower artesian aquifers of the Trinity reservoir would rise in tightly cased wells in Somervell County before the artesian aquifers were tapped by many wells is not definitely known. Hill[7] states that it was about 750 feet. His investigations were made at different times during the period from 1882 to 1900, and he gives no specific date in conjunction

[6] Hill, R. T., op. cit., pp. 474, 476.
[7] Idem, p. 477.

with this statement, but it is assumed that his observation is applicable to the period from 1897 to 1900. It has been impossible to check this figure definitely, but a study of the information obtained during the present investigation would indicate that an altitude of 750 feet was probably the maximum that might be expected.

Because of the draft from wells, leakage from natural openings such as springs, and the migration of water down the dip of the beds, the water undoubtedly did not rise as high in wells in the southern and eastern parts of the county as it did in the northern part, which is closer to the outcrop of the artesian aquifers. The slope of the piezometric surface about 1897 is not known, but its direction at that time probably differed very little from the slope noted in 1930. For these reasons it is believed that the maximum altitude to which the water would rise in tightly cased wells at Glen Rose was probably not more than about 710 feet.

The water in wells that tap the upper aquifers of the Trinity reservoir is under lower pressure and would not rise nearly as high as that from the lower aquifers. The difference in head was probably as great at that time as it is at present. The greatest difference in head noted between the lower and upper aquifers in 1930 was about 14 feet. If the difference was the same in 1897 as at present the water from the upper aquifer would have risen to an altitude of about 695 feet at Glen Rose.

Definite information on the head of the water from the middle aquifer is not available because of the manner in which the wells are cased. Not all the wells encounter three aquifers in the "basal sands", and it would appear that the head of the water from the middle aquifer, where present, was not much different from that of the uppermost aquifer.

HEAD IN 1929–30

During November 1929 and June 1930 a large number of observations were made of the pressure of flowing wells in Glen Rose and vicinity. (See table, pp. 21–23.) The static level in these years was not nearly so high as in 1897; it varied according to location and was generally higher in the part of the county nearest to the outcrop of the "basal sands."

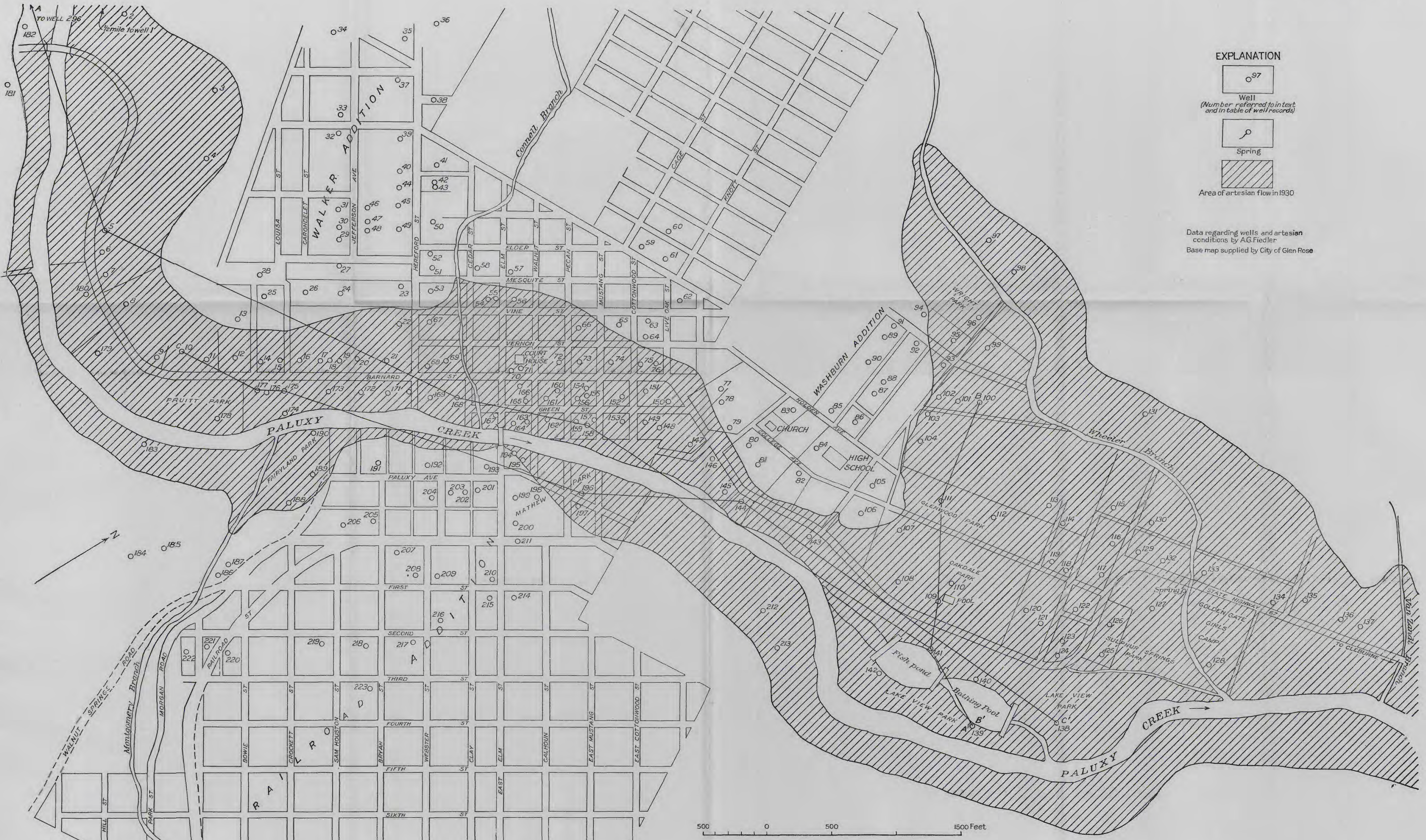
On November 15, 1929, the pressure in well 296 (see pls. 4 and 6 for location of wells) was sufficient to raise the water to an altitude of about 660 feet above sea level. This well is in the valley of Paluxy Creek about 1¾ miles west of Glen Rose and is somewhat apart from the area in which the draft from wells is the greatest. The pressure in well 168, at the rear of the Snyder Sanatorium, which supplies both the sanatorium and the Glen Rose Hotel, on June 13, 1930, would raise the water to an altitude of 639 feet above sea level. The water of well 141 on June 14, 1930, would rise to an altitude of 624 feet above sea level. On June 19, 1930, the static level of the water of well 274, at the Young Women's Christian Association Camp, 2¼ miles northeast of Glen Rose, was about 623 feet above sea level.

All these wells are reported to be drilled to the lowest aquifer of the Trinity reservoir. Thus it is seen that the static level of the water from the lowest aquifer ranged from 660 feet above sea level 1¾ miles west of Glen Rose to 623 feet 2¼ miles northeast of Glen Rose. During the present investigation it was impracticable to make observations on the static level of the water in nonflowing wells drilled to the lowest aquifer, for such wells as were visited were either found to be obstructed or were covered with pumps that prevented observations.

Several of the wells are cased with two separate casings, one of them seated above the first sand and the other seated with an improvised packer near the top of the lowest sand. In this manner water from two aquifers is obtained from the same well, the water from the first sand coming up through the space between the outer and inner casings and the water from the lower sand issuing from the inner casing. It is therefore possible to measure the pressure of the water in two different aquifers at the same well. However, because of the nature of the formation it is difficult to secure a watertight seat with the casing, and the variation in the pressure of the water from the two aquifers tapped by wells finished in this manner indicates that there is generally some leakage between the different aquifers.

Well 168, at the Snyder Sanatorium, has double casing. On June 13, 1930, the static level of the water of the upper aquifer at this well was found to be 623 feet above sea level, or 16 feet lower than that of the lowest aquifer on the same day. On June 26, 1930, observations of the pressure in well 141 indicated a static level of 628 feet above sea level for the water in the lower aquifer and 614 feet above sea level for the water in the upper aquifer, a difference of 14 feet.

Observations made on wells 10 and 177, which were drilled in 1929, furnish valuable information on the static level of the water in the upper and intermediate aquifers of the Trinity reservoir. Well 177 is 53 feet deep, and its bottom is 568 feet above sea level. Well 10 is 175 feet deep, and its bottom is 449 feet above sea level. The wells are at about the same altitude, about 650 feet apart, and each is cased with about 20 feet of pipe. Well 10 encountered practically no water at a depth of 50 to 75 feet, which is the average depth for obtaining water from the upper aquifer if conditions are favorable. It is considered, therefore, that the water supplied by this well comes



MAP OF GLEN ROSE, TEX., AND VICINITY SHOWING LOCATION OF WELLS AND AREA OF ARTESIAN FLOW.

A–A′, B–B′, C–C′, Lines of sections in plate 7.

almost entirely from the intermediate aquifer, which was encountered at a depth of about 150 feet. On June 14, 1930, the pressure in well 177 was sufficient to raise the water to an altitude of 632.1 feet above sea level, whereas in well 10 it would rise to 633.8 feet above sea level. The small difference of 1.7 feet which was noted could probably be accounted for by the normal hydraulic gradient or the slope of the piezometric surface.

Because of the fact that the shallower artesian wells are usually cased with only one or at the most not more than two joints of casing, considerable leakage can occur from one artesion aquifer to the other, and as a result the head in the two aquifers has been largely equalized. Although the observations, therefore, are not necessarily conclusive as indicating that the artesian head of the upper and intermediate aquifers has always been nearly the same, they indicate that no great difference in pressure existed and that at present the artesian waters in the upper and intermediate aquifers of the "basal sands" of the Trinity group have essentially the same static level.

The observations of the head of most of the wells recorded in the following table were made with a pressure gage, and the observed pressure in pounds to the square inch was converted to equivalent pressure in feet of water by multiplying by 2.3, the resulting figure indicating the height in feet to which the water would rise above the point of observation. The head of flowing wells with only a small pressure was measured with a tube and a graduated rod, the reading being made directly in feet above the bench mark. The depth to the water level in nonflowing artesian wells was measured with a steel tape.

Measurements of head in observation wells in Somervell County, Tex., November 1929 to June 1930

[The altitude of the bench marks is referred to sea level]

10. John Anderson. Bench mark, chisel-cut cross on discharge tee, 3.2 feet above ground; altitude 626.9 feet

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Nov. 9	+7.8	634.7
June 14	+10.1	637.0

35. —— Childress. Bench mark, edge of casing, 1.0 foot above ground; altitude not determined

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Nov. 9	−61.1	
Nov. 13	−60.7	
Nov. 16	−60.4	
Nov. 30	−60.4	
Dec. 10	−60.3	
June 14	−61.5	

36. J. L. Collings. Bench mark, three chisel cuts in edge of 5⅝-inch casing, 0.3 foot above ground; altitude 726.4 feet

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Nov. 9	−79.2	647.2
Nov. 13	−80.8	645.6
Nov. 16	−81.3	645.1
Nov. 30	−80.9	645.5
Dec. 10	−82.0	644.4
Dec. 12	−81.1	645.3
Dec. 15	−81.3	645.1
Dec. 22	−79.6	646.8
Dec. 29	−79.3	647.1
Jan. 5	−79.1	647.3
Jan. 12	−78.7	647.7
Jan. 19	−78.4	648.0
Jan. 26	−78.1	648.3
Feb. 2	−77.9	648.5
Feb. 9	−77.6	648.8

36. J. L. Collings—Continued.

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Feb. 16	−77.8	648.6
Feb. 23	−77.7	648.7
Mar. 2	−77.3	649.1
Mar. 10	−77.2	649.2
Mar. 16	−77.2	649.2
Mar. 23	−77.4	649.0
Mar. 30	−78.1	648.3
Apr. 6	−78.1	648.3
Apr. 12	−78.6	647.8
Apr. 20	−79.4	647.0
June 17	−80.9	645.5

71. Somervell County Court House. Bench mark, chisel-cut cross on top of discharge tee, 3.0 feet above ground; altitude 622.5 feet

Nov. 8	+16.7	639.2

109. H. J. Cox. Bench mark, chisel-cut cross on top of discharge tee, 3.0 feet above ground; altitude, 622.5 feet

Nov. 25	+9.7	629.3
	+12.4	632.0
Nov. 30	+16.5	636.1
June 16	+6.8	626.4
June 26	+10.8	630.4

110. H. J. Cox. Bench mark, chisel-cut cross on concrete curb of faucet drain on northeast side of bath house, 0.5 foot above ground; altitude 619.6 feet

Nov. 25	+14.4	634.0
	[a] +11.8	631.4
Nov. 26	[a] +11.8	631.4

[a] Well 109 open.

111. R. L. McAllister. Bench mark, chisel-cut cross on elbow of discharge pipe, 1.7 feet above ground; altitude 626.2 feet

Nov. 25	+7.3	633.5
Nov. 26	+7.3	633.5
Nov. 30	+9.4	635.6
June 14	+3.7	629.6
June 26	[b] +3.1	629.3
June 26	[c] +4.3	630.5

[b] Well 141 open.
[c] Well 141 closed.

112. R. L. McAllister. Bench mark, chisel-cut cross on bushing at top of well, 0.6 foot above ground; altitude 618.7 feet

Nov. 25	[d] +15.3	634.0
Nov. 26	[d] +14.0	632.7
Nov. 30	[d] +16.8	635.5
June 14	[d] +8.9	627.6
Nov. 26	[e] +9.5	628.2
Nov. 30	[e] +10.5	629.2
June 14	[e] +4.9	623.6

[d] Water from lower aquifer.
[e] Water from upper aquifers.

138. G. I. Daniels. Bench mark, chisel-cut cross on elbow of discharge pipe, 2.8 feet above ground; altitude 608.4 feet

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Nov. 25	+4.9	613.3
Nov. 30	+5.1	613.5
June 14	+3.3	611.7

139. G. I. Daniels. Bench mark, chisel-cut cross on concrete well curb, 2.0 feet above ground; altitude 606.2 feet

Nov. 25	+11.8	618.0
Nov. 30	+15.8	621.9
June 14	+7.2	613.4

141. G. I. Daniels. Bench mark, chisel-cut cross on discharge pipe, 2.5 feet above ground; altitude 610.2 feet

Nov. 8	[d] +18.6	628.8
Nov. 25	[d] +19.6	629.8
Nov. 26	[d] +20.2	630.4
Nov. 30	[d] +24.6	634.6
June 14	[d] +14.2	624.4
June 26	[d] [f] +14.1	624.1
	[d] [g] +18.2	628.4
Nov. 8	[e] +3.8	614.0
Nov. 25	[e] +3.8	614.0
Nov. 26	[e] +4.0	614.2
Nov. 30	[e] +6.1	616.3
June 26	[e] [f] +3.3	613.5
	[e] [g] +3.8	614.0

[d] Water from lower aquifer.
[e] Water from upper aquifers.
[f] Observation made following extended period of flow.
[g] Observation made after well had been closed 3 hours.

142. G. I. Daniels. Bench mark, chisel-cut cross on top of north discharge pipe, 2.4 feet above ground; altitude 612.4 feet

Nov. 30	+16.2	628.6

144. —— Gresham. Bench mark, chisel-cut cross on discharge elbow, 2.8 feet above ground; altitude 613.4 feet

Nov. 8	+8.1	621.5

154. Lane & Sons garage. Bench mark, chisel-cut cross on discharge pipe, 1.7 feet above ground; altitude 618.1 feet

Nov. 8	+18.5	636.6
June 14	+18.5	636.6

158. L. J. Wardlaw. Bench mark, chisel-cut cross on discharge elbow, 4.4 feet above ground; altitude 617.7 feet. Pressure recorder installed Feb. 10, 1930, removed June 21

Nov. 15	+19.3	637.0
Feb. 10	+20.7	638.4
Feb. 16	+19.8	637.5
Feb. 20	+20.3	638.0

158. L. J. Wardlaw—Continued.

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Feb. 24	+19.8	637.5
Mar. 4	+20.7	638.0
Mar. 6	+19.3	637.0
Mar. 11	+20.3	638.4
Mar. 15	+20.7	638.4
Mar. 19	+19.8	637.5
Mar. 23	+20.3	638.0
Mar. 28	+21.2	638.9
Mar. 31	+21.7	639.4
Apr. 3	+20.7	638.4
Apr. 4	+21.2	638.9
Apr 7	+19.3	637.0
Apr. 12	+17.5	635.2
Apr. 17	+19.3	637.0
Apr. 21	+17.3	635.0
Apr. 26	+16.8	634.5
Apr. 28	+18.7	636.4
Apr. 30	+18.8	636.5
May 5	+20.0	637.7
May 11	+19.1	636.8
May 15	+20.3	638.0
May 18	+21.2	638.9
May 22	+20.3	638.0
May 26	+20.7	638.4
May 31	+18.7	636.4
June 4	+17.9	635.6
June 7	+19.6	637.3
June 13	+16.6	634.3
June 15	+15.7	633.4
June 18	+15.4	633.1
June 21	+14.3	632.0
June 22	+15.4	633.1

168. George Snyder. Bench mark, chisel-cut cross on discharge tee, 2.8 feet above ground; altitude 618.8 feet

June 13	[d] +20.7	639.5
	[e] +4.0	622.8

[d] Water from lower aquifer.
[e] Water from upper aquifers.

169. George Synder. Bench mark, chisel-cut cross on discharge elbow, 2.5 feet above ground; altitude 619.3 feet

June 13	+17.5	636.8

175. R. L. Nickels. Bench mark, chisel-cut cross on discharge elbow, 2.0 feet above ground; altitude 623.7 feet

June 14	+6.2	629.9

177. Jack Morris. Bench mark, chisel-cut cross on discharge elbow, 2.2 feet above ground; altitude 623.8 feet

Date	Head above or below bench mark (feet)	Altitude above sea level (feet)
Nov. 9	+11.8	635.6
June 14	+7.4	632.1

178. Pruitt's Park. Bench mark, chisel-cut cross on discharge tee, 2.7 feet above ground; altitude 623.9 feet

June 14	+8.5	632.4

196. T. K. Mathews. Bench mark, nail in post 5 feet northeast of well, 1.6 feet above ground; altitude 618.5 feet

Nov. 18	+3.0	621.5
June 14	+2.7	621.2

197. T. K. Mathews. Bench mark, cross on northwest corner of concrete curb; altitude 617.9 feet

Nov. 18	[d] +6.9	624.8
June 14	[d] +6.9	624.8
	[e] +1.0	618.9

267. S. W. Stewart. Bench mark, chisel-cut cross on discharge elbow, 3.1 feet above ground; altitude 635.6 feet

June 19	+5.8	641.4

274. Young Women's Christian Association. Bench mark, chisel-cut cross on reducing elbow, 3.7 feet above ground; altitude 607.1 feet

June 19	+15.8	622.9

296. Miss Daniels. Bench mark, chisel-cut cross on discharge elbow, 2.8 feet above ground; altitude 648.8 feet

Nov. 15	+11.5	660.3
June 14	+10.6	659.4

DECLINE IN HEAD

The decline of the artesian head has been noted for a number of years, but as accurate observations have not been made and recorded no definite comparison for different periods is possible. As is typical of newly developed artesian areas, it is likely that there was originally a fairly rapid decline, for the draft upon the artesian reservoir was increased considerably during a relatively brief period at the time of Hill's investigation, which coincided more or less with the early period of drilling. Afterward the decline doubtless proceeded more gradually, as during the next 20 years there appears to have been no special period of marked drilling activity. Within the last 10 years several wells of somewhat more than average capacity have been completed, and as a result the head has probably declined at a somewhat greater rate.

Because the static level of the artesian water is generally higher in winter than in summer, observations made during the winter will be used as a basis for comparison to determine the amount of the decline in head. On November 18, 1929, the static level of the artesian water at the well in front of the county courthouse at Glen Rose was 639 feet above sea level. By comparison with the altitude of 710 feet assumed for 1897 it is seen that the head had declined 71 feet during a period of 32 years, or at the rate of 2.2 feet a year. At well 141 the maximum static level observed, which was on November 30, 1929, was 634 feet above sea level. This represents a decline of 76 feet from the assumed level for 1897. As the level assumed for 1897 may be somewhat in error the amount of decline is also subject to the same error, but a total decline of about 70 to 75 feet would appear to be a reasonable estimate for this locality.

Without more information it is impossible to state definitely whether the decline in head of the artesian water from the upper aquifers of the Trinity reservoir was more or less than that estimated for the lowest aquifer. The amount of fluctuation observed during this investigation indicates that the decline in the artesian head of the waters of the upper aquifers was certainly no more than that for the lower aquifer and probably was considerably less.

The decline in head has not been completely arrested, and though it does not appear to be progressing at an excessive rate at the present time it offers a real menace to the well owners. From an inspection of the map of the area of artesian flow (pl. 6), it is evident that wells will flow only in a relatively small part of the county. The highest pressure observed in any of the wells during the present study was only sufficient to raise the artesian water 25 feet above the ground surface. This observation was made during the winter, when the head is the highest. During the summer the pressure in the same well was only sufficient to raise the water about 15 feet above the ground surface. In most of the flowing wells the pressure will raise the water only a few feet above the surface; during the summer these wells barely flow and some cease flowing altogether. Thus it is seen that a further reduction of artesian pressure amounting to only a few feet will seriously affect many wells, and only the wells on the lowest lands in the county will continue to flow. It is evident, therefore, that the efforts of the well owners should be directed toward such measures of conservation as will tend to arrest the continued decline in head.

FLUCTUATIONS IN HEAD

GENERAL RELATIONS

The static level of the water in an artesian well in the area under consideration is dependent upon the hydrostatic pressure in the respective aquifers tapped by the well. The pressure head or, as it is commonly called, the head in a well is the pressure on the particular aquifer when the water is at rest. Actually the water in any artesian aquifer in this area is never at rest but is always moving slowly toward the points of discharge. However, unless the well is appreciably affected by the operation of other wells, the difference in head caused by the imperceptible movement of the water is small.

The head of the artesian water is constantly fluctuating more or less rapidly, and the chief causes of fluctuations are: (1) Interference of wells, (2) seasonal variation in draft (3) variation in rainfall, (4) changes in atmospheric pressure.

INTERFERENCE OF WELLS

In view of the widespread comment by residents of the Glen Rose community regarding the effect of wells upon one another, several tests were made to determine the extent of the interference. Because of the large number of wells in Glen Rose and vicinity well owners are prone to believe that certain large wells, either nearby or at a considerable distance, affect their wells so greatly that the reduction in pressure and the resultant lower yield can be readily noticed as soon as these large wells are opened. To a certain extent this is true, but the tests made indicate that in many places the interference is not due to the particular well or wells suspected but is due to some other well which may not have attracted attention. This was very pointedly brought out in the study of a well near the border of the area of artesian flow, where a very slight reduction in pressure causes the flow to stop. The owner of the well insisted that the pressure and yield of his well were being reduced by a neighboring well. Investigation showed, however, that on the day of the test the supposed offending well was not in operation nor had it been in operation for several days. Further study indicated that the interference was probably due to another well considerably more distant.

So many wells are concentrated in so small an area around Glen Rose that it is difficult to attribute interference to a particular well without having complete information upon the opening and closing of all wells for a considerable distance around the one affected. Without this complete information interference is frequently attributed to the wrong well or wells.

The cause of such interference may be explained briefly as follows: In an artesian well in this area, the level to which the water will rise is dependent upon the pressure in the aquifer or aquifers tapped by the well. This level, known as the static level, may be determined by ascertaining the shut-in pressure of the well in pounds to the square inch and multiplying it by 2.3. The result indicates the height in feet to which the water will rise above the point at which the pressure was measured. When an artesian well is opened and permitted to flow a reduction in pressure occurs. This reduction in pressure is the result of the expenditure of energy in causing the flow and in overcoming the friction of the moving water. The reduction in pressure in the aquifer is greatest at the flowing well and decreases in amount at points farther and farther away from it. The piezometric surface at the flowing well is therefore depressed in the shape of a cone with curved sides. The apex of the cone is at the well, and the sides slope upward, at first steeply, then more gradually, and finally flatten out until the depression in the piezometric surface is imperceptible. The boundary of the area in which the piezometric surface is noticeably depressed is known as the circle of influence. Where two or more wells are so close to each other that their circles of influence overlap, the yield of the wells is reduced and they are said to interfere with one another.

In the area of artesian flow in the vicinity of Glen Rose, where measurements could be most readily made, most wells are subject to interference by surrounding wells. The interference from wells of small flow is hardly detectable, but the effect of the operation of some wells of large yield is measurable at wells 1,500 feet or more distant. The time required before the interference can be noticed varies with the distance between the wells, being least for wells close by and greatest for wells farther away. The time required before the full effect of the interference is experienced may also vary, ranging from several hours to several days.

The partial closing of a large well in November 1929 afforded an opportunity to note the recovery of head in other wells in the vicinity. The head for several days prior to the closing of the well was practically stationary, and though it cannot be definitely stated that the full recovery of pressure noted was due solely to the closing of this one well, as far as could be determined no other conditions were responsible. Within 2 days after the yield of the large well was reduced from 60 to 15 gallons a minute the head of a well 380 feet away rose 4.2 feet. The recovery during the same period in two other wells, one 689 feet and the other 828 feet from the large well, was 3.9 feet. The recovery in a well 1,475 feet away was 2.7 feet. It was impracticable for various reasons to close the large well completely, and no other wells that were not subject to interference by many wells were available for observation.

On June 26, 1930, several observations were made to ascertain the effect which the closing of well 141 had upon well 111, 1,125 feet away. Well 141 had been flowing for several weeks at the rate of about 50 gallons a minute, and at the time of closing it had a pressure head of 12.6 feet. No effect was noticed on well 111 half an hour after closing well 141. Within 3 hours, however, the pressure head of well 111 had risen 1.4 feet and the head of well 141, which had been closed, rose 4.4 feet. After 3 hours further rise was very gradual, and because well 141 had to be reopened the test was discontinued.

The wells that were available for observation had been flowing for some time, and it was not feasible to close these wells for a period long enough to obtain stable conditions of head before reopening them in order to note the effect of the drawdown. Noting the recovery of the head while the wells were closed after a period of extended operation, though the reverse process, gives essentially the same information upon the amount of interference.

SEASONAL FLUCTUATIONS

For the purpose of determining the seasonal fluctuations in the head of the artesian water a Bristol recording pressure gage was attached to a deep well that had been recently completed. The writer was unable to find a nonflowing well not in use that tapped the lower water-bearing formations, and hence it was necessary to make the observations on a well that was being used for domestic supply.

Well 158, to which the pressure gage was attached (pl. 6), was drilled in 1929 to a depth of 290 feet and was cased to 212 feet. As the upper water-bearing formations were cased off, the shut-in pressure of the well indicated the pressure in the lowest aquifer of the Trinity reservoir. There was considerable fluctuation in the pressure due to the opening and closing of faucets supplied by the well and also a general lowering of the pressure following extended periods of draft which required several hours for recovery. During the day, therefore, the average pressure was not truly indicative of the prevailing pressure in the aquifer, as it was greatly influenced by the draft. At night, when the well was not drawn upon, the pressure again became stable. For this reason the pressure at midnight was chosen as indicating the pressure for the preceding day. Though this rather arbitrary record might be somewhat in error as indicating the average pressure for any individual day, over a period of time it would show essentially the average pressure in the aquifer tapped by the well.

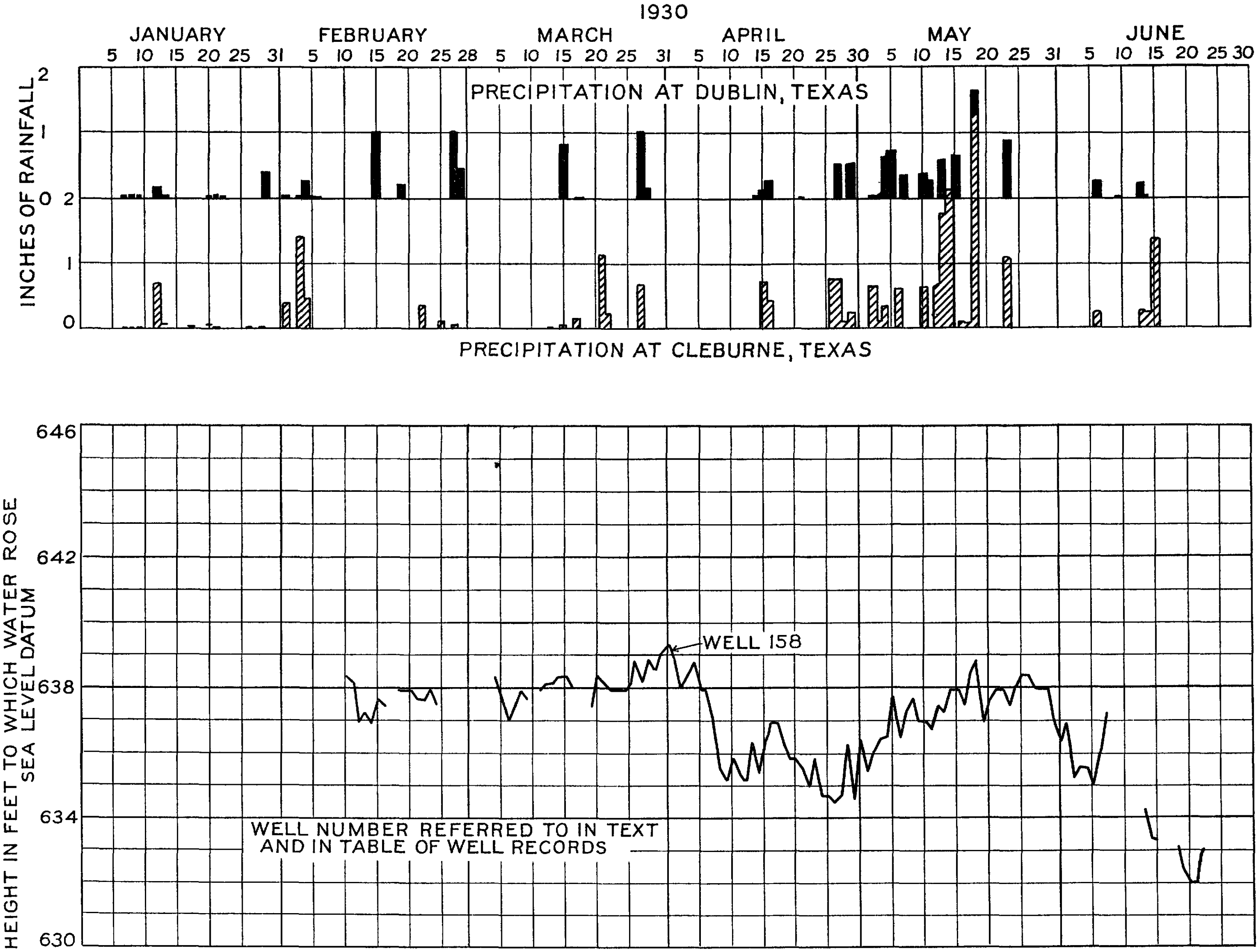
The fluctuations in artesian head for well 158 are shown in plate 5. The pressure in pounds to the square inch as recorded by the gage was converted to equivalent pressure in feet of water and referred to sea-level datum. The graph shows that the pressure is highest during the early part of the year. A marked decline of more than 3 feet is noticed for April 1930. This coincides with the first period of heavy draft occasioned by warm spring weather. The head was at a relatively high level during May, then declined rapidly during June; at the low point during June it was more than 7 feet lower than the high point at the end of March. In view of the unusually hot, droughty period which was so general during the summer of 1930, it is greatly regretted that records were not obtained during the period July to September, for it is quite certain that a minimum head lower than any previously experienced in this area would have been recorded. In the vicinity of Glen Rose recovery in head generally occurs during the fall and extends through the winter. This condition is in many respects similar to that noted in other artesian areas where the major draft from wells is largely seasonal.

The marked seasonal fluctuation in head is caused largely by the seasonal variation in the draft, which is greatest in summer and least in winter. Though the amount of water used primarily for domestic supply increases considerably during the summer, this increase represents only a small part of the total additional draft. The major increase is caused by a few wells of large capacity which furnish water for outdoor swimming pools.

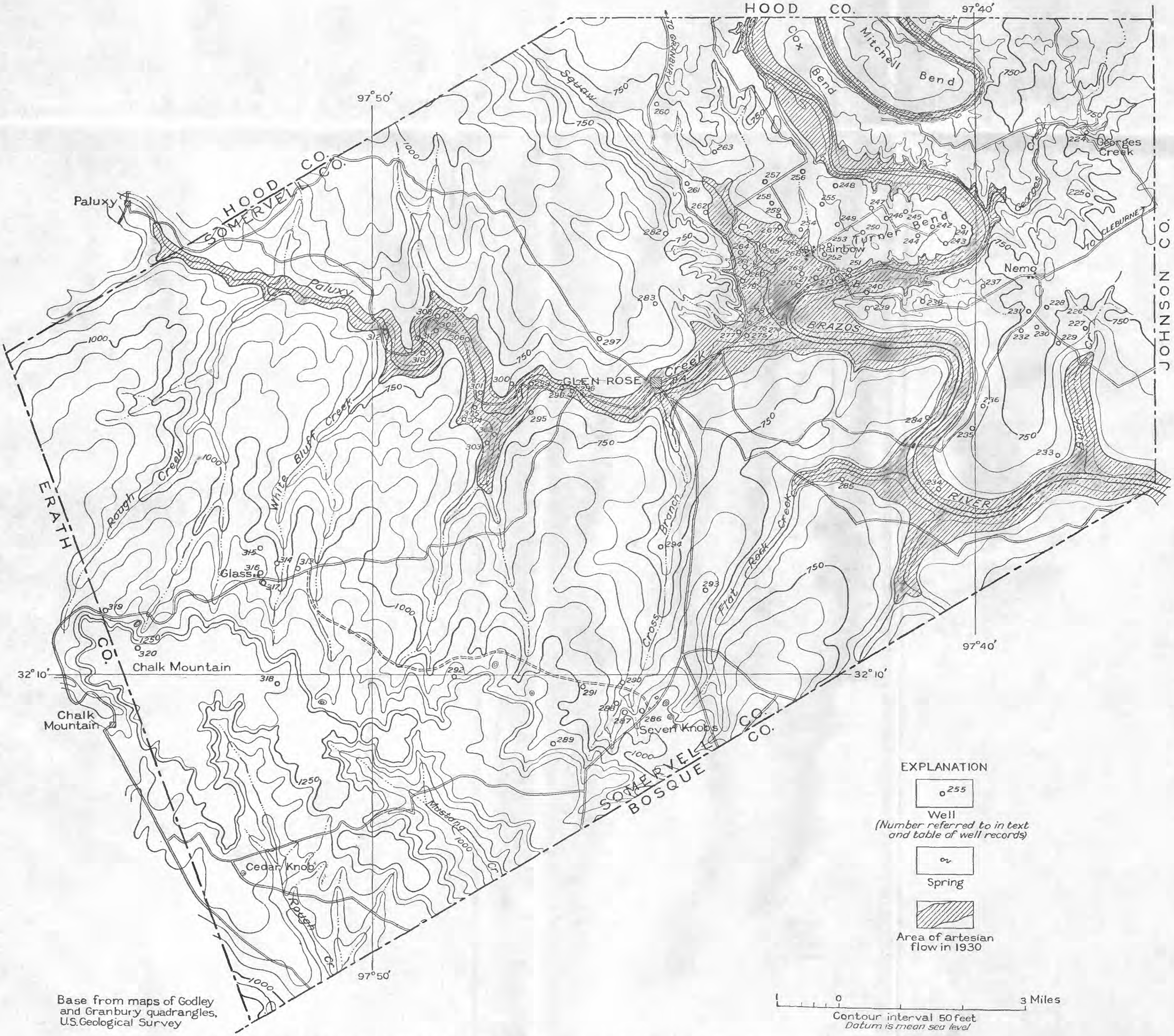
FLUCTUATIONS DUE TO RAINFALL

The water in the artesian aquifers is derived from precipitation that falls as rain or snow on the intake area or is absorbed from the run-off of the tributary streams that cross the intake area. As the "basal sands" of the Trinity group, which supply the artesian water in Somervell County, are entirely covered by formations that are more or less impervious and hence confine the water under pressure, the precipitation which falls in Somervell County cannot penetrate the confining beds and thereby directly produce fluctuations in the pressure head of the wells. This precipitation, however, produces indirectly certain fluctuations of head by causing a reduction of the draft from wells.

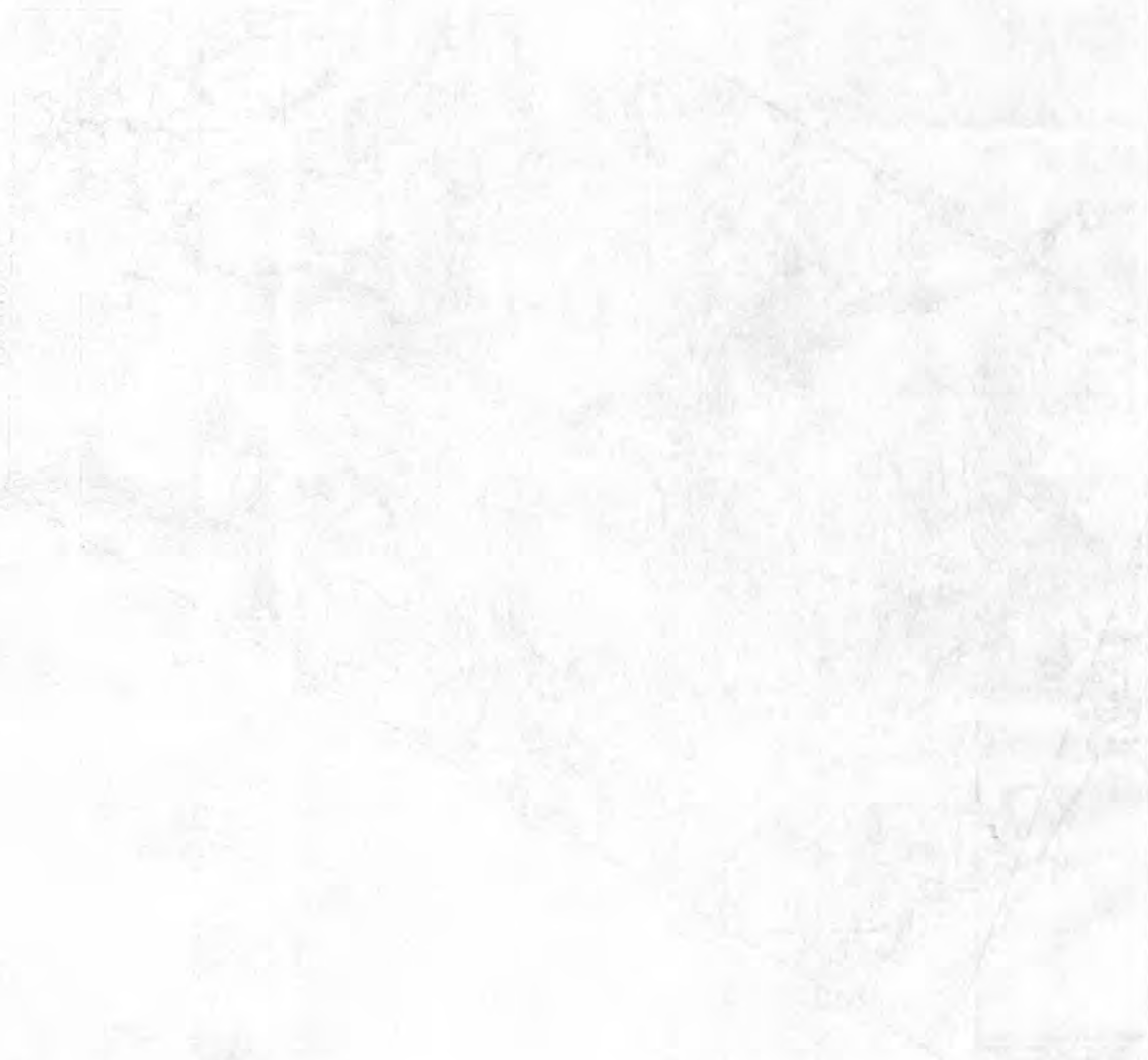
Fluctuations caused by changes in draft due to heavy precipitation or to lack of precipitation are shown by plate 5. During the early part of April 1930 there was a general lack of precipitation in the area, as shown by the record for Cleburne, which is the nearest point at which precipitation records are available. The artesian head declined noticeably during that period. During May the precipitation in the area was considerably above normal and the draft from

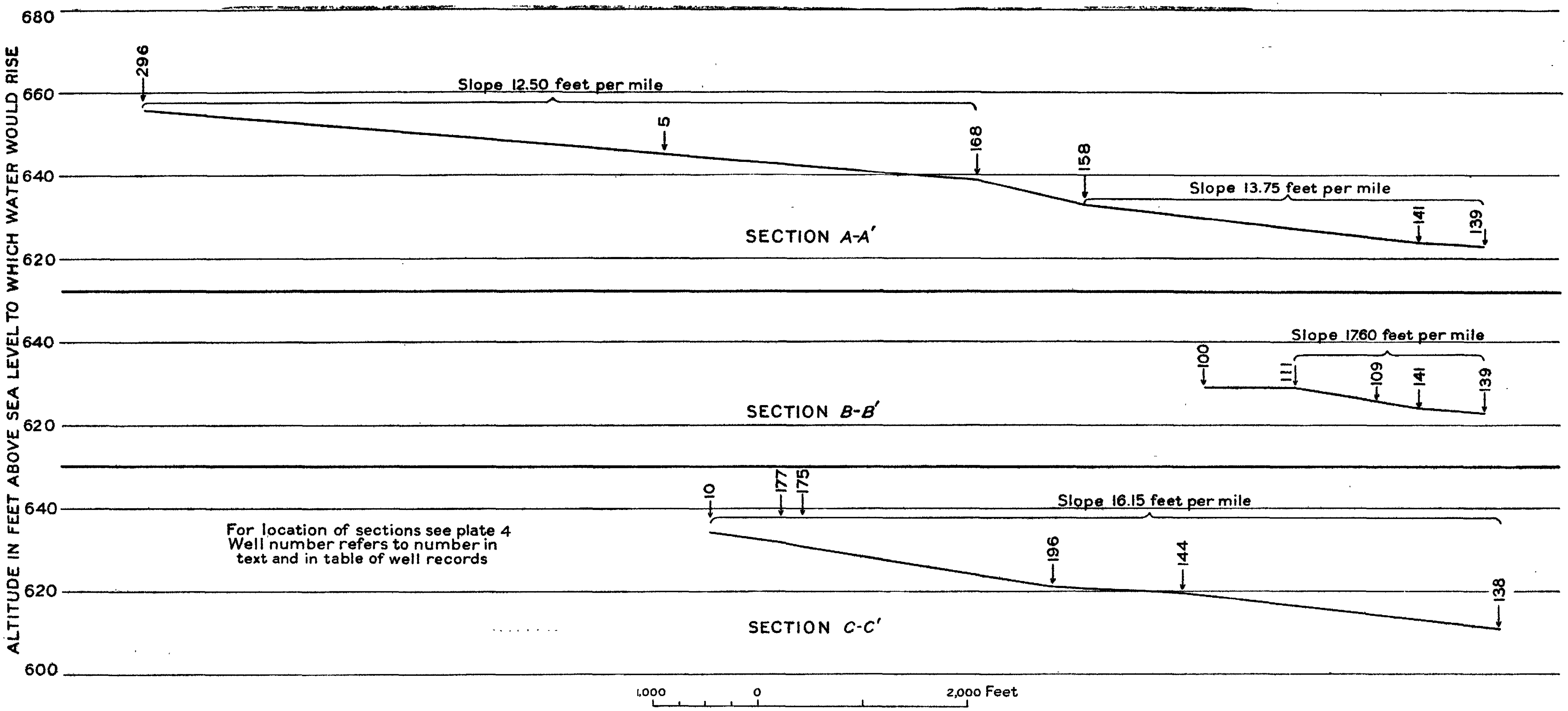


GRAPHS SHOWING FLUCTUATION IN ARTESIAN HEAD IN A REPRESENTATIVE WELL AND PRECIPITATION AT CLEBURNE AND DUBLIN, TEX.



MAP OF SOMERVELL COUNTY SHOWING LOCATION OF WELLS AND AREA OF ARTESIAN FLOW.





DIAGRAMS SHOWING HYDRAULIC GRADIENT ALONG SECTIONS INDICATED ON PLATE 4.

wells was consequently reduced, particularly from the wells of large capacity used for outdoor swimming pools. Plate 5 shows a recovery of head corresponding to the general period of increased precipitation and a marked decline during June corresponding to a period of increased draft which occurred with the arrival of warm weather and a deficiency of precipitation.

The well at which the records were made is influenced considerably by the operation of wells in the vicinity, and hence it is difficult to discern a marked relation between precipitation in the intake area, as shown by records of precipitation at Dublin, and the fluctuation in head at the observation well in Glen Rose. It is to be expected that there would be considerable lag between precipitation in the intake area and its effect on the pressure of the wells. Though information regarding all influences which affect the artesian head is not available, it would appear that the rise in pressure on May 31 was more or less directly caused by the precipitation on May 27, as this precipitation was general in character and undoubtedly produced some recharge to the artesian aquifers. The heavy precipitation in May was also undoubtedly the direct cause of part of the recovery in head noted during that month.

INFLUENCE OF ATMOSPHERIC PRESSURE

Changes in atmospheric pressure are another cause of fluctuations in the pressure head of artesian wells. The effect of such changes is summarized by Meinzer [8] as follows:

> If a shallow well ends in a formation that lies at the surface and is freely permeable throughout, only slight barometric effects or none at all are to be expected, because any change in the atmospheric pressure is transmitted almost as freely upon the water table through the permeable material as upon the water level in the well. If a well ends in an artesian formation and this formation or the overlying confining beds have sufficient strength completely to resist deformation by slight changes in pressure at the surface, the well will act as a barometer. The fluctuations of its water level will have virtually the same range of fluctuations as would be shown by a water barometer, or 13.5 times the range in a mercury barometer. However, the movements of the water level in the well will always be in the opposite direction from those in the barometer. If this well is near the seashore its water level will not show any tidal influences.
>
> If a well ends in a somewhat elastic artesian formation that is confined beneath beds, such as soft shale, that are impermeable but yield more or less to even slight pressure, its water level will have smaller fluctuations resulting from atmospheric pressure changes than that of a water barometer, and the ratio of the movements in the well to the corresponding movements in the barometer will give a measure of the resistance of the watêr-bearing and confining beds.

[8] Meinzer, O. E., Methods of estimating ground-water supplies, pt. 1, Outline of available methods (paper presented at annual technical session of Society of Economic Geologists, December 1928), p. 23; also in U.S. Geol. Survey Water-Supply Paper 638, pp. 140–141, 1932.

If such a well is near the seashore its water level will fluctuate more or less with the tide.

If a well ends in a formation that is effectively covered by an impermeable bed but is unsaturated in its upper part, thus having an air chamber between the water table and the overlying impermeable bed, the water level in the well will behave like that in an artesian well in competent beds. It will fluctuate through about the same range as the water level in a water barometer, because, as in the other cases, the counter pressure will remain nearly constant.

The well under observation was not sufficiently free from other influences to show any pronounced fluctuations of the water level that might be definitely attributed to changes in atmospheric pressure, and the information is not sufficient to warrant any statement as to whether the confining beds are of sufficient strength completely to resist deformation by changes in atmospheric pressure.

In considering the various fluctuations of head it should be remembered that the forces tending to produce such fluctuations are of varying intensity and are acting at the same time. The graph representing the fluctuations of head therefore shows the result of the action of a combination of forces, for it is practically impossible to evaluate properly the effect produced by the operation of each force.

AREA OF ARTESIAN FLOW

The only information available regarding the size of the original area of artesian flow in Somervell County is contained in the report by Hill,[9] published in 1901. Hill's outline of the area of artesian flow was apparently based on the area included within the 750-foot contour line as shown on the United States Geological Survey topographic map of the Granbury quadrangle, which was surveyed in 1887. The contour interval on that map was 50 feet, and recent more detailed surveys of a portion of Somervell County indicate that the position of the 750-foot contour line is somewhat in error. It is probable that, owing to meager data, no allowance was made for the fact that because of the general slope of the piezometric surface the artesian water doubtless did not rise as high in the southeastern part of the county as it did in the northwestern part, and in the light of present information it is believed that the area in which the flowing wells could probably have been obtained was doubtless somewhat smaller than is shown on Hill's map.

With the decline in the artesian head the size of the area of artesian flow also decreased, but because the land in the major stream valley slopes at a rather steep angle, the size of the area of artesian flow has not changed greatly, considering the extent of the decline in artesian head. This condition is shown by figure 2.

[9] Hill, R. T., op. cit., p. 473.

The conditions in Somervell County approach those shown in the hypothetical section with the head at levels *BB′* and *CC′*. Because the highlands rise rather steeply above the major stream valleys the decline in artesian head has produced only the relatively small reduction in the width of the area of flow comparable to width *bC*+ *C′b′*, rather than a reduction equal to *ab*+*B′a′*, such as would have occurred had the surface sloped gently, as at *AB*.

The present area of flow is shown on plates 4 and 6. Plate 6 shows that the area of flow occupies a strip from a quarter of a mile to a mile in width along the valleys of Paluxy and Squaw Creeks and the Brazos River. This area is similar in shape to that in which flowing wells could be obtained years ago, when the artesian head was still at a high level.

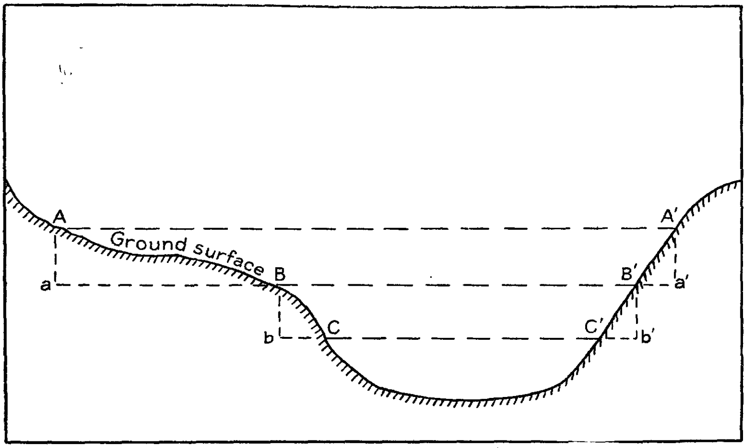


Figure 2.—Hypothetical section showing the relation of the decline in artesian head to the width of the area of artesian flow. *A–A′*, Width of area of artesian flow with head at level *AA′*. Decline in head *Aa* causes reduction in width of area of artesian flow equal to *aB*+*B′a′*. Further reduction in head *Bb*, equal to *Aa*, reduces width of area of artesian flow only by amount *bC*+*C′b′*.

The greatest reduction in the area of artesian flow due to the decline in head has occurred along the south side of Paluxy Creek and south of the Brazos River below the mouth of the creek. This area in which flowing wells can no longer be obtained lies parallel to the present area of artesian flow and ranges in width from a quarter of a mile to a mile. On the north bank of Paluxy Creek the land generally slopes more steeply up from the stream, and hence the area in which wells will no longer flow is only a relatively narrow strip parallel to the present area of flow. The general conditions are the same in the upper half of the valley of the Brazos River in Somervell County.

QUANTITY OF WATER DISCHARGED BY WELLS

TOTAL CAPACITY OF WELLS

During the present study a survey of the flowing wells was made to determine the total capacity of the wells. From this survey it is estimated that the total average daily capacity of all the flowing wells in Glen Rose and vicinity amounts to about 775 gallons a minute. The average daily capacity of all other flowing wells in the county is about 325 gallons a minute. Hence the total capacity of all the flowing wells in the county is about 1,100 gallons a minute.

The nonflowing wells that tap the artesian aquifers are pumped chiefly by suction pumps, force pumps, or windmills. Their average capacity is relatively small and probably does not exceed 3 gallons a minute. Their total capacity is estimated at about 1,000 gallons a minute.

DISCHARGE AT THE SURFACE

It is difficult to make an accurate determination of the quantity of water used for domestic purposes and for watering stock, as the draft from individual wells varies so widely. The population of Somervell County in 1930 according to the United States Census was 3,016, and, allowing for the number of visitors who spend from one day to several weeks or more within the county, it is estimated that the average population throughout the year is about 3,400.

The average consumption per capita per day in rural communities without water-supply systems and on farms is relatively low, and in this area it undoubtedly does not exceed 45 gallons. The average daily consumption for domestic use throughout the year would therefore amount to about 150,000 gallons. With a liberal estimate of 60,000 gallons a day for stock the total consumption for both domestic and stock use probably does not exceed 210,000 gallons a day. This quantity of water is equivalent to a discharge of 145 gallons a minute for 24 hours.

In addition to the water used for domestic purposes and for stock, several recreation pools are supplied by water from wells. The combined capacity of the wells supplying these pools is estimated to be about 170 gallons a minute during the period of low water in the summer. This discharge is equal to 245,000 gallons a day, or over 20 percent more than the amount used for domestic purposes and for stock in the whole county. Water for the recreation pools is supplied entirely by natural flow. The amount used for irrigation averages about 125 gallons a minute, or a daily flow of 180,000 gallons. Other discharge is estimated at 360,000 gallons a day; this is largely waste but does not include underground leakage, which is considered on pp. 35–42.

The total draft from wells in the county for all purposes during the summer is estimated to be about 1,000,000 gallons a day. This discharge is supplied by both flowing and pumped wells and includes the quantity wasted at the surface but does not include underground waste.

The draft during the winter is naturally not so great as during the summer. In winter the draft for irrigation is practically eliminated and the draft for recreation pools is reduced to about 55,000 gallons a day. Though the quantity used for domestic purposes and for stock is also less, the waste probably increases by at least an equivalent amount, owing largely to the seasonal recovery of the artesian head. The draft in winter is estimated to be about 370,000 gallons a day less than in summer, or a total of about 630,000 gallons a day.

An attempt to compute the total yearly draft would necessitate estimates of the time during which water was used for each of the various purposes, and information for such estimates is insufficient. The average daily discharge throughout the year, as calculated from the previous estimates, is about 800,000 gallons a day.

QUANTITY USED BENEFICIALLY

The average daily surface discharge of the wells has been estimated at about 1,000,000 gallons a day during the summer, or 694 gallons a minute. Of this quantity about 635,000 gallons a day is used for purposes that are considered more or less beneficial. The quantity for domestic use and for watering stock, estimated at 210,000 gallons a day, represents the highest use of water. The estimate for domestic use includes a reasonable allowance for the watering of gardens and lawns. The quantity used for irrigation is relatively small and at the time of this investigation averaged not more than 180,000 gallons a day. During the summer, of course, the consumption for this purpose on individual days may be considerably greater, but the estimate is based on an average daily quantity for the irrigation season. The remaining quantity of water used for purposes classed as beneficial is 250,000 gallons a day, supplied to recreation pools. Two of these are outdoor swimming pools operated in conjunction with tourist camps; a third is a private pond used largely for the propagation of fish. The use of water for swimming pools is generally regarded as a beneficial purpose, though under certain conditions a question may arise as to whether the water is devoted to the highest possible use.

One of the swimming pools is an artificial pool constructed of concrete and supplied by a flowing well that has an average flow during the summer of about 24 gallons a minute, or 34,600 gallons a day. The well flows almost continuously directly into the pool; the overflow from the pool is pumped through a series of filters, and the filtered water is then returned to the pool. In this manner the water is maintained in a sanitary condition, and frequent draining, with consequent waste of water, is avoided. The other swimming pool has been constructed by building a dam across a large natural depression along the bank of Paluxy Creek. The pool is supplied by three flowing wells that have an aggregate capacity during the summer of about 135 gallons a minute. In addition, it is reported that a large spring that is essentially a natural artesian well flows directly into the pool near its deepest part. It was impossible to determine the flow of this spring, if in fact it does exist, but because of the head of water on the spring opening when the pool is filled to its maximum level it is rather questionable if the yield is as great as reported, though it does appear that there is no reversal of flow or great loss through this supposed opening. Two of the flowing wells discharge directly into a pond used for the propagation of fish, and the overflow from this pond goes into the swimming pool. The average discharge during the summer of the three wells supplying the combined fish pond and swimming pool is 135 gallons a minute, which is equivalent to 194,500 gallons a day. At the time the area was visited, in June 1930, the waste water from the pools, which flowed into Paluxy Creek, was estimated at 45 gallons a minute, or 64,800 gallons a day. The remainder of the flow from the wells, about 130,000 gallons a day, was dissipated by evaporation or leakage from the pools.

The third recreation pool is a private pond used largely for the propagation of fish. It is supplied by a flowing well that discharges about 11 gallons a minute during the summer. This flow which is equivalent to 15,800 gallons a day, is largely dissipated through evaporation and seepage.

It should be noted that almost 40 percent of the water used beneficially in the entire county is used for these three recreation pools.

QUANTITY WASTED

SURFACE WASTE

No measurements are available to indicate the amount of artesian water that has been wasted at the surface in Somervell County in previous years, but according to the best information obtainable it would appear that there has always been a relatively large waste of water from the artesian wells. Periodic attempts have been made through the efforts of public-spirited citizens to have the well owners close their wells when they are not in use, but usually after a short period of control the wells are again opened and the water permitted to waste.

During a survey made in November 1929 and June 1930 more than 60 wells were examined in Somervell County which were wasting the artesian water either because the wells had no valves or because the valves were in such poor condition that the flow could not be fully controlled. The average discharge of wells in Somervell County that are not properly capped is estimated at 250 gallons a minute. This flow that serves no beneficial purpose is estimated at 370,000 gallons a day. The amount of water wasted is therefore nearly twice the amount used for domestic purposes and stock and more than half the amount used beneficially for all purposes during the summer. It represents a serious draft upon the artesian reservoir and is a major cause of the continued decline in pressure. The elimination of all surface waste will materially reduce the rate of decline and may prevent further decline altogether. The remedy is so simple and so easy of application in practically all wells that further surface waste of artesian water should not be tolerated.

UNDERGROUND WASTE

EVIDENCES OF UNDERGROUND LEAKAGE

Underground leakage in artesian wells is caused by insufficient casing, improperly seated casing, or casing that is defective. The methods most generally usable for determining whether an artesian well is wasting water underground into strata that contain no water or water under a lower pressure than that tapped by the well are the so-called "packer method", the meter method, and the pressure method. In Somervell County it has been possible to draw certain conclusions also from recovery of head in wells and from measurements of seepage from springs into Paluxy Creek.

Packer tests.—In the packer method a casing with a packer on the lower end is inserted in the well. If the well has been leaking, the casing and packer will shut off the leaks and consequently the water will rise higher and the discharge of the well will be increased. By making a number of trials the exact point of leakage can be determined. This method requires a well rig or a tripod with block and tackle for handling the casing and therefore is not adapted to general field use where many tests are to be made and the funds available for such work are limited. During the course of the leakage survey it was possible on one occasion to insert a short length of pipe with a packer on the end into a well that was in poor condition. Without the pipe and packer the well discharged about 2½ gallons a minute at the surface, but after the pipe was inserted the discharge increased to about 4 gallons a minute. This increase was undoubtedly due to water previously lost by underground leakage.

Current-meter tests.—The principles underlying the meter method are very simple. Water passing through a filled pipe or conductor of uniform cross section has a certain average velocity. If a portion of the water is diverted from the pipe or conductor through a leak into a permeable stratum, the velocity of the remaining water in the conductor will be less because less water is moving through the conductor above the leak than below it. Water passing upward through an artesian well that is in good condition has a comparatively uniform velocity at all points in the well where the cross section is the same. Hence, if a leak occurs in the casing, the water above that point will move at a slower rate than below it. It is the purpose of the leakage meter to determine the location of the points of marked change in the velocity and thereby determine the location of the leaks. The same principle is involved in the exploration of the uncased portion of the well to determine if the casing is properly seated or if the well is cased to a sufficient depth.

The deep-well current-meter equipment and method of operating it, as developed by the United States Geological Survey during the course of investigations in the artesian basins at Honolulu and in the Pecos Valley, New Mexico, are described in detail elsewhere.[10] The meter consists essentially of a turbine wheel mounted within a cylindrical brass base, which is suspended in a pipe and lowered and removed from the well by means of a cable. The meter is provided with a mechanism which makes and breaks an electric circuit at every revolution or every five revolutions of the turbine wheel, and by means of an insulated cable the electric impulse is transmitted to the surface and operates a telephone receiver. Each time the circuit is closed and opened a click is produced in the receiver, and by timing the number of clicks with a stop watch changes in velocity can be readily detected. In exploring a well observations of velocity are made at various depths to determine the presence of leaks. In a nonflowing well no current is recorded until a leak is passed; in a flowing well a leak will be indicated by an increase in velocity. As a reduction in the diameter of a well also causes an increase in velocity, check observations should be made above and below the point at which a well may be reduced in size and then compared with computations of discharge based on different standard sizes of well hole or casing in order to avoid misinterpreting such increase in velocity as being due to a leak.

The standard size of meter for use in wells of large diameter is 3 inches, but the meter used in Somervell County was 1½ inches in

[10] McCombs, John, Methods of exploring and repairing leaky artesian wells on the island of Oahu, Hawaii: U.S. Geol. Survey Water-Supply Paper 596, pp. 4–24, 1928. Fiedler, A. G., The Au deep-well current meter and its use in the Roswell artesian basin, New Mexico: Idem, pp. 24–32.

diameter and was built especially for use in small wells. Its operation is identical with that of the larger meter except that it was raised and lowered in the wells by means of a steel sucker rod three-eighths of an inch in diameter instead of by a cable.

The work of determining leakage by means of the meters was seriously handicapped by the way in which the wells were finished at the top. Most of the wells that seemed likely to furnish useful information on the problem of underground leakage were found to be plugged with material that had been thrown into the well, or the well hole had caved and hence it was impossible to lower the meter to the bottom of the well. In addition to these difficulties, it was found that the velocity in the wells of small yield was so low that it could not be reliably recorded by the leakage meter. Most of the wells are finished at the top with one or two joints of 5⅝-inch casing, and within this casing a short length of 1½- or 2-inch pipe is concreted. When the meter is within this small pipe a flow of 3 to 5 gallons a minute is ample to operate the meter satisfactorily, but when the meter drops through the small pipe and enters the large casing the velocity there is insufficient for a satisfactory test. In spite of these unfavorable conditions a number of wells were explored with the leakage meter during this investigation, and although the quantity of underground leakage and the location of the leaks could not be determined positively, the information obtained was sufficient to form a basis for certain conclusions.

The minimum velocity at which the meter operates satisfactorily was determined by laboratory tests to be 0.08 foot a second. A flow of water of lower velocity was insufficient to turn the turbine wheel of the meter. Most of the wells in which underground leakage is likely to occur are cased to depths of 20 to 40 feet with 4-, 5-, or 5⅝-inch casing. A velocity of 0.08 foot a second corresponds to a flow of about 3 gallons a minute in a 4-inch casing, 5 gallons a minute in a 5-inch casing, and 6 gallons a minute in a 5⅝-inch casing. As the equipment is not sensitive enough to record velocities of less than 0.08 foot a second leakage of the amounts stated previously is likely to be passed by unnoticed.

As far as possible wells that appeared to be in the poorest condition and were reported to be insufficiently cased were chosen for the exploration with the meter. In none of these wells was the current at any depth great enough to operate the meter; hence it is evident that no large amount of underground leakage was occurring from any individual wells, but the undetected leakage, though relatively small, can amount to a large percentage of the available flow, as many wells that apparently leak underground have an average discharge of only 3 to 5 gallons a minute.

Pressure tests.—The pressure method for determining leakage consists in obtaining the shut-in pressure of the well with a pressure gage. This pressure is compared with the pressure of other wells in the vicinity which are known to be in good condition and which tap the same water-bearing formations. In comparing the wells proper allowance must be made for difference in altitude. If a well free from marked interference is found to have a pressure considerably below the general pressure of the wells of the locality, the well undoubtedly leaks and requires further attention.

In Somervell County most flowing wells are subject to interference by surrounding wells, and many of them cannot be closed for lack of effective valves. Because the pressure of the wells is small, differences in pressure due to underground leakage are not likely to be great enough to indicate definitely that the well is leaking. After a number of preliminary trials had been made, the use of the pressure gage for testing was abandoned as being unsuited to this area.

Material evidence of underground leakage from the wells was afforded, however, by the action of some of the flowing wells, which showed a gradual increase in the shut-in pressure for some time after they were closed following extended periods of operation. The subjoined table shows the pressure at various times after the closing of a flowing well and the rate of recovery for the various periods.

Recovery in pressure of flowing well following period of operation

Time after closing of well (minutes)	Head (feet)	Rate of increase in pressure (feet per minute)
0	8.63	
1	9.21	0.58
4	10.13	.31
6	10.58	.22
8	10.92	.17
10	11.05	.06
25	11.28	.015

The recovery is at first rapid and then slows up gradually until the rate of increase becomes negligible—0.58 foot for the first minute after the well is closed, 0.06 foot a minute at the end of 10 minutes, and only 0.015 foot a minute at the end of 25 minutes. (See fig. 3.)

The gradual return of pressure after the closing of a well indicates that a cone of depression exists around a well for some time after the well has been closed. A cone of depression is evidence of a definite hydraulic gradient toward the well, and the presence of a hydraulic gradient always indicates a movement of water.

However, the cone of depression in the vicinity of a well tapping an artesian aquifer does not represent depletion of storage, as in a well tapping a water-bearing formation in which the water is not confined under artesian pressure; the artesian aquifer is filled with water, therefore the cone of depression in it represents only a reduction in pressure.

Several explanations of the persistence of the cone of depression may be given. The water removed from the aquifer may have been replaced by gas, but because gas is generally absent from the water issuing from wells in this area this theory does not appear valid. Meinzer [11] has advanced the theory that when water is with-

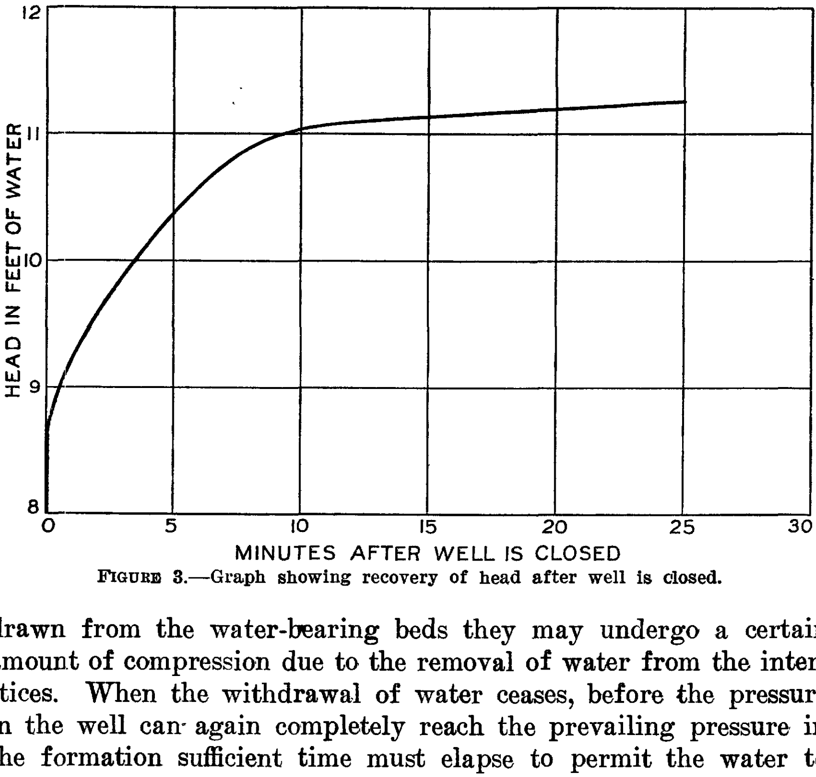


FIGURE 3.—Graph showing recovery of head after well is closed.

drawn from the water-bearing beds they may undergo a certain amount of compression due to the removal of water from the interstices. When the withdrawal of water ceases, before the pressure in the well can again completely reach the prevailing pressure in the formation sufficient time must elapse to permit the water to percolate into the depleted and compressed parts of the formation surrounding the well and to expand the interstices that have been previously compressed. In view of the character of the formations and the relatively low pressure of the wells and hence the small reduction in pressure in the aquifer when a well is permitted to

[11] Meinzer, O. E., and Hard, H. A., The Artesian water supply of the Dakota sandstone, with special reference to the Edgeley quadrangle: U.S. Geol. Survey Water-Supply Paper 520, pp. 73–95, 1925. Meinzer, O. E., Compressibility and elasticity of artesian aquifers: Econ. Geology, vol. 23, pp. 263–291, April 1928.

flow, this explanation does not appear to account fully for the very slow recovery of pressure.

Another explanation that may be offered to account for the slow recovery of pressure is that of underground leakage. In a well that leaks underground the water wasting out of the well may percolate into a formation that contains no water or into a formation that contains water under a lower head than that which is supplying the well. When a flowing well is closed the pressure should rise immediately to that which existed prior to the operation of the well, if the casing is tight and if there is no accumulation of gas or compression of the aquifers. But if the well leaks underground the pressure in the formation that contains no water or water under a lower head must be raised to that of the formation supplying the well, and the original pressure of the well will not be recovered until the pressure is equalized in all the formations. As theories of gas accumulation and of compressibility and elasticity of the artesian aquifers do not appear to be entirely applicable to the Somervell area, it is believed that the slow recovery of pressure here is indicative of underground leakage.

Seepage into Paluxy Creek.—A porous gravel stratum several feet in thickness is reported by the local well drillers to have been encountered within 20 to 30 feet of the surface in some wells in Glen Rose and vicinity. In such wells when water is first encountered it generally rises in the well to the level of this permeable stratum and no higher; but after the well is cased the water rises nearly to the surface or may even begin to flow, depending upon the altitude at the well site. This permeable stratum, therefore, undoubtedly permits underground leakage from wells that are not properly cased.

The hard limestone of the lower part of the Glen Rose formation is overlain in some places by gravel and other unconsolidated material. The channel of Paluxy Creek has been cut into this limestone. Along the banks of the creek in the vicinity of Glen Rose there is a line of small seepage springs. The discharge from the individual outlets is relatively small, and the location of many of them is concealed during the growing season by weeds and grasses; but during the winter, when freezing temperatures occur, the line of seepage is prominently marked by ice that forms along the banks of the stream. At least a part of the artesian water that leaks from the wells undoubtedly finds its way into the creek through these springs. As the individual flows were too small to be measured, an attempt was made to determine the total flow of all the outlets. Measurements were made June 30, 1930, of the flow of the creek at different points between the town of Paluxy and the mouth of the creek. All increase in flow in this stretch of the creek was due to the springs, and there was no underflow at the places where the measurements were made.

Gain or loss in several sections of Paluxy Creek from the town of Paluxy to the mouth, in gallons a minute

[Measurements made June 20, 1930]

Point of measurement	Discharge	Gain or loss from preceding point of measurement	Total gain
Highway bridge at Paluxy	900		
4 miles southeast of Paluxy	1,265	+365	365
5½ miles southeast of Paluxy	1,480	+215	580
2 miles west of Glen Rose	1,553	+73	653
1¼ miles west of Glen Rose	1,675	+122	775
Opposite Pecan Street, Glen Rose	1,572	−103	672
1 mile northeast of Glen Rose	1,689	+117	789

Within the part of Paluxy Creek covered by the measurements the channel has in most places been eroded into the limestone near the lower part of the Glen Rose formation, and most of the measurements were made at places where the limestone was clear of gravel and sand and hence there was no underflow. However, the sections were wide and the velocities were low, and conditions were not the best for measuring such small quantities of water. The surprising result of the measurements is the loss found in the section from a point of 1¼ miles west of Glen Rose to Pecan Street in Glen Rose. Check measurements made several days later gave 1,314 gallons a minute at the section 1¼ miles west of Glen Rose, 1,180 gallons a minute at Pecan Street, and 1,536 gallons a minute at the section 1 mile northeast of Glen Rose. The loss in the section west of Glen Rose on that day was therefore 134 gallons a minute, compared with 103 gallons a minute for the same section as noted in the table. The reason for this loss is not definitely known, but it would appear to be due chiefly to evaporation from the large shallow pools in this stretch of the stream and the absence of inflow. The gain of 117 gallons a minute in the last section is probably all derived from surface waste from wells at Glen Rose and seepage from the gravel stratum. This quantity is not very large, and it would indicate either that losses from wells are not excessive or that the gravel stratum does not drain freely into the creek because the stratum is not continuous. The evidence that there is some leakage into this stratum seems to be substantiated by the fact that drillers report that they encounter more water at this horizon now than they did years ago.

QUANTITY OF UNDERGROUND LEAKAGE

Though there is sufficient evidence to indicate that there is undoubtedly underground leakage from artesian wells in Somervell County, it is difficult to evaluate the total amount of such leakage, largely because the leakage from individual wells is too small to be reliably measured by any methods that have been developed thus far. In view of these conditions any determination of the total underground leakage from the artesian wells can be nothing more than an estimate based upon incomplete data and may accordingly be greatly in error. Until an opportunity is afforded to make a more detailed examination of many wells or to observe the action of test wells constructed especially for the purpose of obtaining information on the amount of underground leakage, it is considered inadvisable to attempt to make such estimates.

A study of all the information at hand indicates that the present leakage underground from wells is not excessive and is undoubtedly much less than is commonly believed by the average local resident. It was the opinion of a number of residents who were interviewed during the course of the study that the quantity of water being lost underground was as much as that which appears at the surface. The available information does not warrant such a conclusion.

PREVENTION OF WASTE

From a full consideration of both surface and underground waste it appears that surface waste is at present much the more pressing problem. The prevention of surface waste is feasible and may result in great benefit. Until the results of a constructive program of prevention of surface waste are fully determined or until more definite information on the amount of underground waste is obtained it is believed inadvisable to undertake an extensive program of plugging and recasing existing wells that are found to be wasting underground, except so far as this may be necessary to prevent pollution of the water supply. (See also p. 61.) However, all wells which may be abandoned in the future or replaced by new wells should be properly plugged. Improved methods of construction and of repair and plugging are described on pages 61–72.

RECHARGE

GENERAL CONDITIONS

The water-bearing sands of the Trinity group, which produce the artesian flows in Somervell County do not crop out anywhere within the county but are exposed along the valley of Paluxy Creek from Paluxy, in Hood County, to the town of Morgan Hill, in Erath County, and also in the northwest corner of Hood County. They are also exposed in Comanche, Eastland, Erath, and Parker Counties. The outcrop area is of irregular shape and varying width and extends both north and south beyond the boundary of the territory covered by plate 1. The water-bearing formations receive their water supply by downward percolation from the rain or snow that falls upon this outcrop area and from seepage losses from the streams that cross it.

All of this outcrop area contributes more or less to the artesian supply, but the part most beneficial to Somervell County is that along upper Paluxy Creek and northwest of this county. In considering the problem of recharge it is well to keep in mind the fact that Somervell County is but a very small part of the area underlain by the same artesian reservoir and that many wells in other counties east of the outcrop area derive their water supply from this artesian reservoir.

The geologic section across Somervell County (fig. 1) shows the relation of the formations to one another and the reason for the occurrence of flowing wells at Glen Rose and vicinity. The underlying Paleozoic rocks form the lower confining beds and prevent downward percolation; the more impervious beds in the lower part of the Glen Rose formation form the upper confining beds. The "basal sands" of the Trinity group are relatively permeable, and the elevated body of ground water in the outcrop of this formation furnishes the source of supply and the necessary source of pressure. Because the area including Glen Rose and vicinity lies below the static level of the water in the "basal sands", wells drilled in this area encounter water under artesian pressure and the wells yield flowing water.

METHOD OF ESTIMATING RECHARGE

The various methods available for determining the recharge to an artesian reservoir are, for several reasons, not entirely applicable to the area under consideration. Somervell County is but a small part of the area underlain by the same artesian reservoir, and the total draft by wells in other counties is doubtless much greater than the draft within Somervell County. The reservoir is so extensive and the unknown factors are so numerous that during the brief period of this investigation sufficient data could not be obtained to form a basis for a quantitative determination of the available ground-water supply in the county.

The safe yield of an aquifer has been defined by Meinzer [12] as the rate at which water can be withdrawn from it without depleting the supply to such an extent that withdrawal at this rate is no longer

[12] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, pp. 55–56, 1923.

economically feasible. Under artesian conditions draft in excess of safe yield may be indicated by a continued drop in storage of water in the reservoir, as shown by a lowering of the water level in wells in the intake area, where the water is not confined under artesian pressure, or by an increase in the hydraulic gradient in the area of withdrawal. As the ability of a water-bearing formation to yield water is also dependent on the rate at which the formation will transmit water under pressure, an increase in the hydraulic gradient in the area of withdrawal may indicate that the rate of withdrawal is greater than the capacity of the aquifer for transmittal. Eventually the reduction in head may be so great that the economic recovery of water is no longer feasible, because of the increased cost of pumping in the nonflowing wells or because the flowing wells no longer yield sufficient water.

Complete information regarding the water level in wells in the intake area is not available, but such information as was obtained indicates that there has been a noticeable lowering of the water level during the last 20 years. Information is too scanty to determine the rate of decline or to show whether the lowering of the water level has been more marked in recent years than formerly. The records of precipitation for this portion of Texas[13] indicate no great deficiency of precipitation from normal for extended periods that would account for a continued lowering of the water levels in wells in the intake area.

Unfortunately records are also deficient regarding the hydraulic gradient from the intake area to the area of withdrawal in Somervell County. Undoubtedly the hydraulic gradient has increased a certain amount with the increased withdrawal from the artesian reservoir, but this does not necessarily indicate that the withdrawal is in excess of the recharge or that the safe yield is exceeded.

The following meager information gives some idea of the present hydraulic gradient from points in or near the intake area to Glen Rose. At Thorp Springs, in Hood County, the altitude is about 765 feet above sea level and the water level in a well which is believed to enter the " basal sands " stands about 40 feet below the surface. The altitude of the water table is therefore 725 feet, which is 92 feet higher than that of well 158 at Glen Rose. As the distance between these two points is 17.6 miles, the hydraulic gradient is 5.2 feet to the mile. At Tolar, in Hood County, at an altitude of about 960 feet above sea level, the water table is reported to be about 200 feet below the surface. The water table is therefore 127 feet higher than the level in well 158 at Glen Rose. The distance from Tolar to Glen Rose is about 15.4 miles, and the hydraulic gradient is there-

[13] Williams, B. F., and Lowry, R. L., A Study of rainfall in Texas: Texas Reclamation Dept. Bull. 18, p. 15, 1929.

fore 8.2 feet to the mile. In a well near Lipan, Hood County, the water level was 14 feet below the surface. The altitude at this place is about 921 feet above sea level, and the water level was therefore 274 feet higher than at Glen Rose. The distance between the two points is 26.2 miles, and the hydraulic gradient is 10.4 feet to the mile.

According to the foregoing data the hydraulic gradient is greater toward the northwest than toward the north. This is to be expected and indicates that the greatest portion of the water withdrawn in the Glen Rose area is derived from the intake area lying along Paluxy Creek and to the northwest of Somervell County. It should also be noted that the general direction of the steepest slope of the hydraulic gradient is approximately at right angles to the intake area or outcrop of the "basal sands" of the Trinity group.

No streams of consequence cross the intake area from the southeast corner of Eastland County to the Brazos River, consequently the outcrop of the "basal sands" would receive in this stretch only minor contributions to the artesian reservoir from seepage losses from the run-off of streams. Therefore, most of the contributions to recharge here must be derived from precipitation which falls upon the intake area.

The precipitation over the area of intake that contributes most to the ground-water supply tapped by wells in Somervell County averages about 30 inches a year. On this basis each square mile of intake area receives about 521,000,000 gallons a year, or 1,400,000 gallons a day. The total estimated average daily draft of 800,000 gallons from wells in Somervell County is therefore only 57 percent of the average annual precipitation upon each square mile of the intake area. However, only a small percentage of the precipitation upon the intake area reaches the water table and augments the ground-water supply in the artesian reservoir; the rest is carried off by the main streams, evaporates, or is given off by plant growth.

The hydraulic gradient along various sections in the region of Glen Rose indicates that a marked cone of depression in the piezometric surface has been developed in this locality, and that the depression becomes less at points increasingly distant from the main center of draft. (See pl. 7.) The cone of depression in the vicinity of Glen Rose apparently is not so great during the winter as during the summer, but a marked hydraulic gradient from the intake area toward the area of withdrawal at Glen Rose persists throughout the year. This condition is to be expected. The artesian reservoir is not a tight basin available only to Somervell County, but drafts are made from it by municipalities to the east and north in other counties, and the draft at these places naturally continues throughout the year.

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In view of the lowering of the water level in wells in the intake area, the continued decline in head of the wells in the vicinity of Glen Rose, and the apparent increase in the hydraulic gradient in the vicinity of Glen Rose, the conclusion is drawn that the present draft in Somervell County has about reached the safe yield of the aquifers in this portion of the artesian reservoir.

PERMEABILITY OF AQUIFERS

TESTS ON SAND SAMPLES

The hydraulic permeability of a formation is defined by Meinzer [14] as its capacity for transmitting water under pressure. This capacity can be quantitatively defined as the rate of discharge of water through a unit cross-section area of the rock at right angles to the direction of flow if the hydraulic gradient is unity. It may also be expressed by a coefficient of permeability,[15] which is the rate of flow, in gallons a day, through a square foot of the cross section of the material, under a hydraulic gradient of 100 percent and at a temperature of 60° F. In field terms the coefficient of permeability may be expressed as the number of gallons of water a day at 60° F. conducted laterally through each mile of the water-bearing bed (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot to the mile of hydraulic gradient.

During the present investigation no deep wells were drilled that penetrated the lower aquifers of the Trinity reservoir in Somervell County. Samples of the water-bearing formations encountered by wells were therefore not obtainable. For determining the physical properties of the formation two samples for laboratory testing were taken from an outcrop of the "basal sands" on Robertson Creek, in Hood County, about 5 miles northwest of Thorp Springs. (See pl. 3, *A*.) One sample was a core of the sandstone in place; the other was loose, unconsolidated sand.

The physical properties [16] of the unconsolidated sample were found to be as follows:

Apparent specific gravity	1.52
Porosity ... percent	41.5
Moisture equivalent:	
By weight ... do	.9
by volume ... do	1.4
Permeability coefficient	437

[14] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U.S. Geol. Survey Water-Supply Paper 494, p. 44, 1923.

[15] For description of laboratory method of determining coefficient of permeability, see Stearns, N. D., Laboratory tests on physical properties of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 596, pp. 121–176, 1927.

[16] For definition of terms used in designating physical properties of materials, see Stearns, N. D., op. cit.

Mechanical analyses:

Gravel (greater than 1 millimeter)	percent	0.0
Coarse sand (1 to 0.5 millimeter	do	2.0
Medium sand (0.5 to 0.25 millimeter)	do	3.4
Fine sand (0.25 to 0.125 millimeter)	do	86.8
Very fine sand (0.125 to 0.062 millimeter)	do	5.4
Silt and clay (less than 0.062 millimeter)	do	2.2

The test made in the laboratory to determine the permeability of the consolidated sample of sandstone was not entirely satisfactory. Difficulty was experienced in forcing water through the sample, because the cementing material that held the sandstone together disintegrated on the application of water. A test with dilute hydrochloric acid showed that no lime was present and that the cementing material was probably clay. A test on the unconsolidated material resulting from the disintegration of the core was run for a period of 12 hours. At the start permeability coefficient was 122, and at the end it had increased to 185.

DETERMINATION OF PERMEABILITY BY FIELD TESTS

The method of determining the permeability of water-bearing formations by field tests on existing wells, developed by Thiem,[17] has a special advantage over the laboratory method in that it deals with water-bearing formations in the vicinity of a well undisturbed and in place. The method consists essentially in measuring the quantity of water discharged from a well and noting the amount of draw-down in nearby observation wells. With this information available the permeability is obtained by the application of a mathematical formula.

The original formula as given in Meinzer's translation [18] of the work done by Thiem has been modified by Wenzel [19] for more convenient use in the United States and is as follows:

$$P = \frac{527.7\, q \log_{10} \frac{a_1}{a}}{m\,(s - s_1)}$$

In this formula P is the coefficient of permeability; q is the rate of pumping, in gallons a minute; a and a^1 are the respective distances of the near and farther observation wells from the key well (in feet), m (for artesian conditions) is the thickness of the water-bearing bed (in feet); s and s^1 are the respective draw-downs at the nearer and farther observation wells (in feet).

[17] Thiem, G., Hydrologische Methoden, Leipzig, 1906.

[18] Meinzer, O. E., Dr. Thiem's method of determining permeability in the field by means of pumping tests and observation wells in which the resultant drawdown is measured (unpublished memorandum in files of U.S. Geological Survey, 1929).

[19] Wenzel, L. K., The Thiem method of determining permeability of water-bearing materials: U.S. Geol. Survey Water-Supply Paper (in preparation).

The work done by Wenzel has demonstrated that, though the method developed by Thiem is a very valuable one, satisfactory results cannot be expected unless proper recognition is given to the inherent limitations of the method.

The conditions in the Glen Rose region were not entirely satisfactory for making the necessary tests and observations. One series of tests was made on a group of wells that appeared to be adapted to the purpose, but the natural flow of the key well was not sufficient to produce a measurable draw-down in the surrounding observation wells, and it became necessary to install a pump to increase the flow. This proved to be unsatisfactory, for it was impossible to install in the well a suction pipe of sufficient length, and as soon as the pump was operated at normal speed the suction would be broken and the water discharged in heads. This attempt was therefore abandoned. Somewhat later in the season an opportunity was afforded for making some observations on the effect of closing a large flowing well (no. 142), which had been in operation continuously throughout the summer. It was not practicable to extend the observations into the winter in order to note the amount of draw-down on observation wells that would be produced by placing this key well in operation again after it had been closed for a period long enough to allow equilibrium to be established. The reverse process was therefore used observing the recovery in head on the observation wells after the key well was closed. Though this test was likewise not entirely satisfactory, it is believed that the results obtained are of some value and they are therefore presented herewith.

Observations were made on five wells (nos. 109, 111, 112, 139, 141) instead of only the two required by the Thiem method. This was done in order to have a check upon all observations and to make it possible to eliminate in a logical manner the various combinations of wells which were shown to be unsuitable for yielding reliable results. Wenzel determined during his work in Nebraska that the best results are obtained when the wells are in a straight line parallel to the hydraulic gradient. Furthermore, duplicate wells should be available down the slope of the water table at the same distance from the discharging well as the wells up the slope of the water table are from the key well.

If the proper arrangement of wells were available, the character of the water-bearing formation were uniform throughout the region, and all observations were of the same degree of accuracy the computed permeability should agree within close limits for all combinations of wells used. Actually, however, the permeability of the formation undoubtedly varies considerably from place to place, and errors of observation may be cumulative for any particular group of wells. Furthermore, as the tests were made under field conditions, it was naturally impossible to control or evaluate the effect of extraneous influences, such as the interference from distant wells, and it cannot be expected that the results obtained are as accurate as those that may be obtained in laboratory tests, where conditions can generally be rather closely controlled. The relations of the individual observation wells to the key well and to each other are shown by the table below and by figure 4.

Observation wells studied to determine coefficient of permeability in Somervell County, Tex.

Well	Distance from key well 142 (feet)	Draw-down (feet)
141	380	4.17
139	689	3.92
109	828	3.91
111	1,415	2.08
112	1,475	2.77

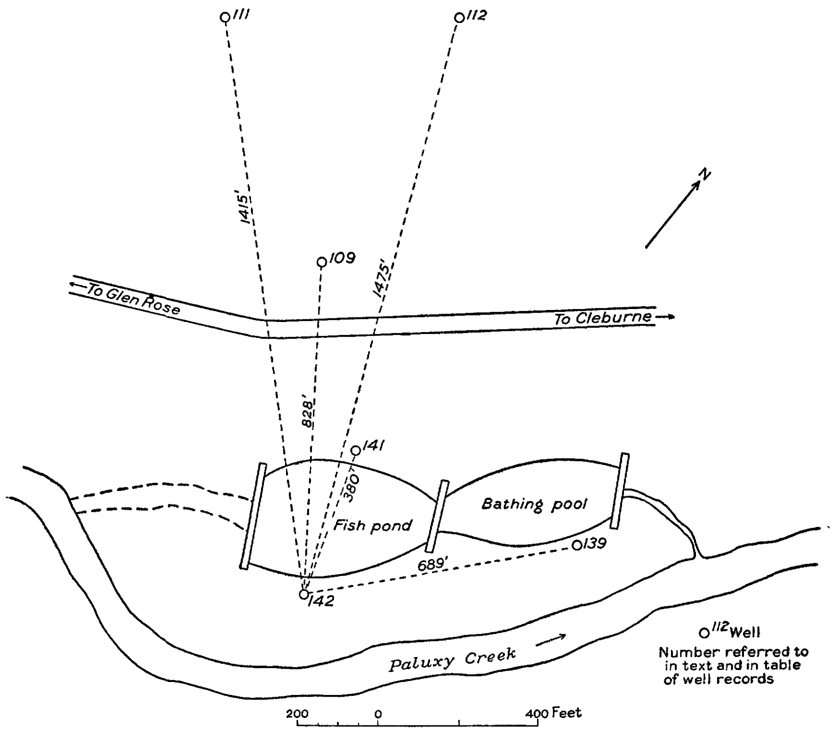

FIGURE 4.—Map showing location of wells used for determining permeability by Thiem method.

The following table summarizes the results noted from various combinations of two observation wells. The thickness of the water-bearing formation as given, 30 feet, represents an average of the thickness of the lower aquifer encountered in all the wells.

Permeability of water-bearing formations in Somervell County, Tex., as calculated from measurements of draw-down in groups of wells

[Calculations made according to Thiem's formula (see p. 47). Well 142 is the key well (see fig. 4); rate of flow, 40 gallons a minute; thickness of water-bearing formation, 30 feet]

	1	2	3	4	5
Well combination	139 and 141	139 and 109	139 and 112	139 and 111	141 and 109
Distance from key well:					
Farther well (a_1)...feet..	689	828	1,475	1,415	828
Nearer well (a)...feet..	380	689	689	689	380
Draw-down:					
Nearer well (s)...feet..	4.17	3.92	3.92	3.92	4.17
Farther well (s_1)...feet..	3.92	3.91	2.77	2.08	3.91
Permeability...gallons a day..	727	5,620	202	119	915

	6	7	8	9	10
Well combination	141 and 112	141 and 111	109 and 112	109 and 111	112 and 111
Distance from key well:					
Farther well (a_1)...feet..	1,475	1,415	1,475	1,415	1,475
Nearer well (a)...feet..	380	380	828	828	1,415
Draw-down:					
Nearer well (s)...feet..	4.17	4.17	3.91	3.91	2.08
Farther well (s_1)...feet..	2.77	2.08	2.77	2.08	2.77
Permeability...gallons a day..	296	192	155	89.5	−19.0

The table shows a wide variation in the computed coefficient of permeability. This condition was more or less to be expected.

The wells in group 2 (nos. 139 and 109) are not the same distance from the flowing well (no. 142), yet the draw-down observed is practically the same, and the coefficient of permeability as calculated, 5,620, is so extremely high in comparison with that of the other groups that it would appear to be unquestionably in error and is therefore disregarded. Furthermore, it may be seen by an inspection of the formula that, by reason of the fact that the denominator of the right-hand member of Thiem's equation is a difference of two quantities, when this difference is small a small error in the draw-down of either or both the wells may represent a large percentage of the total difference in draw-down and hence will be reflected as a major error in the permeability coefficient. The difference in draw-down for groups 1 and 5 is also small, and hence the computed coefficient is disregarded for both of these groups. The negative coefficient of permeability for group 10 is probably due to the fact that the observation wells are located upon almost the same circle of influence, to probable errors in measuring the draw-downs, and to interference from other wells.

It is admitted that factors which cannot be fully evaluated affect the draw-down in the various wells and hence introduce errors into the results obtained by the application of Thiem's formula. However, though a group of wells is disregarded in the computation of an average coefficient of permeability, the same wells when used in combination with other wells may (because of the reasons discussed previously) yield results that are reasonably accurate.

No apparent discrepancies are noted in groups 3, 4, 6, 7, 8, and 9, and it is considered that an average of their coefficients might be used. An average of the coefficients for these groups is 175.

As determined in the laboratory the coefficient of permeability of an unconsolidated sample of Trinity sandstone with water at 60° F. was 437. The temperature of the artesian water from wells in the Glen Rose region ranges from 69.5° to 70° F. and for the purpose of these studies was assumed to be 70° F. According to Slichter's coefficients [20] for determining the flow at temperatures other than 60° F., a factor of 1.15 must be applied to obtain the relative flow at 70° F. The permeability coefficient of the unconsolidated Trinity sandstone as thus corrected is 502.

The coefficient obtained at the beginning of the laboratory test run on a disintegrated core sample was 122, and the coefficient at the end was 185. The application of the same temperature factor of 1.15 gives corrected coefficients of 140 and 213, respectively, and the average of these is 176.

The remarkably close agreement of the average coefficient of 176 obtained by laboratory tests on the disintegrated core sample with the average coefficient of 175 obtained by the field-test method is interesting in view of the obvious likelihood of error in both methods. It is rather difficult to account for the much higher coefficient obtained by laboratory tests on the loose, unconsolidated sand, but it is believed that either some of the finer particles of the loose sand were lost in sampling and in transporting the sample to the laboratory or that the sand as arranged in the laboratory test was not as compact as it is in the field. The corrected coefficient of 502 for the sample of loose sand will therefore be disregarded, and 175 will be used as the coefficient of permeability for the "basal sands" of the Trinity group. According to the definition of the coefficient of permeability a water-bearing formation having a coefficient of permeability of 175 will transmit, when the head is 1 foot to the mile, 175 gallons of water a day, at 60° F., through a section of the formation 1 foot thick and 1 mile long at right angles to the direction of flow.

[20] Slichter, C. S., Field measurements of the rate of movement of underground water: U.S. Geol. Survey Water-Supply Paper 140, p. 13, 1905.

YIELD OF AQUIFERS AS ESTIMATED FROM PERMEABILITY TESTS

The average thickness of the water-bearing portions of the lower "basal sands" of the Trinity group is about 30 feet. Therefore, if the sand has an average coefficient of permeability of 175, a strip of the water-bearing formation 1 mile long will conduct 30 times 175 gallons, or 5,250 gallons a day, when the hydraulic gradient is 1 foot to the mile. The hydraulic gradient between Lipan and Glen Rose was estimated to be 10.4 feet to the mile. With an average hydraulic gradient of 10 feet to the mile, a strip of the water-bearing formation 1 mile long would therefore pass 10 times 5,250 gallons, or 52,500 gallons a day.

It has been estimated that the total draft throughout the year from wells in Somervell County amounts to about 800,000 gallons a day. If this quantity of water is supplied by the lower aquifer of the Trinity group under the assumed head the water must be drawn from a section over 15 miles wide. The distance across Somervell County from northeast to southwest through Glen Rose is about 15 miles, and this diagonal is practically perpendicular to the line drawn from Glen Rose to Lipan, which was used in determining the hydraulic gradient. Actually the water does not all come from one direction, but some water is undoubtedly drawn up the dip of the bed. Furthermore, some of the water used in Somervell County is supplied by the upper water-bearing portion of the "basal sands", which has not been included in the 30-foot thickness of aquifer used in the preceding computations. As the hydraulic gradient near the outcrop area is undoubtedly considerably less than the average slope from the intake area to the center of the region of greatest withdrawal, it is probable that the water moves along a section 15 miles or more in width to supply the estimated draft.

The hydraulic gradient in the Glen Rose area is also of interest in conjunction with a consideration of the permeability of the different aquifers of the "basal sands" of the Trinity group.

Plate 7 shows the hydraulic gradient along various sections in the vicinity of Glen Rose. Sections A–A′ and B–B′ are based on observations made on wells drawing from the lower aquifer of the artesian reservoir, and section C–C′ is based on observations on wells drawing from the upper aquifers. The gradient for section C–C′ is 16.15 feet to the mile, whereas the steepest gradient along section A–A′ is only 13.75 feet to the mile. This would indicate either that the hydraulic permeability of the upper aquifers is considerably less than that of the lower aquifer or that less water is being withdrawn from the upper aquifers. Without more complete information on the various factors involved a definite conclusion is not warranted, but from the fact that the most productive wells draw from the lower aquifer it would appear that the permeability of this aquifer is also somewhat greater than that of the upper aquifers.

In studies made in the Atlantic City region by Thompson [21] the permeability of the aquifers as determined by laboratory tests was used to predict the probable loss in head caused by increased draft upon the reservoir. Practically the same method is applicable to the conditions in Somervell County, though the basic data are not so complete as those for the Atlantic City region. The situation in Somervell County is complicated by the fact that some of the wells draw from one aquifer and others draw from several aquifers. Without reliable information on the depth of the well and the amount of casing in the hole it is impossible to estimate what part of the total estimated draft of 800,000 gallons a day is supplied by each aquifer. It is believed, however, that estimates based on the information available may be of interest in indicating the relative amounts of future decline in head that might occur.

With a permeability of 175 and a thickness of formation of 30 feet for the lower aquifer, each strip of formation 1 mile long will yield 5,250 gallons a day under a gradient of 1 foot to the mile. If the water withdrawn from the lower aquifer in the Glen Rose region comes from a strip about 3 miles wide, which is about the distance from Squaw Creek to the bridge across Paluxy Creek west of Glen Rose, this section will yield 15,750 gallons a day under a gradient of 1 foot to the mile. If 400,000 gallons a day is withdrawn from the lower aquifer in this region, this quantity could be supplied by the 3-mile strip if the gradient is equal to 400,000 divided by 15, 750, or 25.4 feet to the mile. If the water enters the region from two directions a gradient half as much, or 12.7 feet to the mile, would be required. The gradient along section A–A′, plate 7, is 13.75 feet to the mile for the steepest part and 12.50 feet to the mile for the upper part. A 50-percent increase in the draft from the sand, or a total of 600,000 gallons a minute, would require a gradient of 38.1 feet to the mile with the water coming from one direction or 19.0 feet to the mile with the water coming from two directions. It is therefore probable that a 50-percent increase in draft from the lower aquifer would produce a decline in head of over 6 feet to the mile if the water was coming from two directions.

The results of permeability tests by either laboratory or field test methods cannot yet be considered sufficiently reliable to form an accurate basis for a quantitative determination of recharge and safe yield of an artesian reservoir. Nevertheless, the results are valuable in indicating the probable productiveness of the artesian aquifers under conditions of increased draft. The present value of the

[21] Thompson, D. G., Ground-water supplies of the Atlantic City region: New Jersey Dept. Conservation and Development Bull. 30, pp. 93–96, 1928.

artesian waters in the Glen Rose region is to a great extent dependent upon the fact that a considerable portion of the water is obtained by natural flow. The present head available for producing flowing artesian water is rather low, and even a relatively small further decline will cause a number of wells to stop flowing. A probable decline in head of only 6 feet, as indicated for an increase in draft of 200,000 gallons a day, would undoubtedly be sufficient to cause a decrease in the number of flowing wells. Such an increase in draft could be caused by only one well of a capacity of 139 gallons a minute. Hence it is fortunate for the interests of the present water users that irrigation with artesian water has not assumed any great proportions, as the large quantities of water required for satisfactory irrigation would very soon make serious inroads on the present supply that is available by natural flow from existing wells.

QUALITY OF WATER

CHEMICAL QUALITY

Though the artesian waters of Glen Rose and vicinity are rather widely known in Texas and have been used medicinally, there has been some confusion as to their chemical composition and medicinal properties. This confusion is largely due to misunderstanding concerning their source. The Glen Rose formation derives its name from the town of Glen Rose, largely because the formation is exposed so characteristically in this locality, and its beds crop out in an almost complete succession along the bluffs of the valley of Paluxy Creek from its mouth nearly to the village of Paluxy. The waters from the Glen Rose formation, where this formation supplies water under artesian pressure, are comparatively highly mineralized sulphate waters; they are similar to the waters used at some well-known resorts but, as noted by Hill,[22] are unsuitable for ordinary domestic, industrial, or agricultural use. At Glen Rose and vicinity, however, by reason of the fact that the Glen Rose formation lies at the surface and is deeply incised by Paluxy Creek and the other streams of this area, it is not a water-bearing formation and does not yield water to wells. Some water in isolated wells appears to be derived from crevices and solution channels near the base of the Glen Rose formation, but this water is undoubtedly supplied by the upper aquifers of the underlying Trinity reservoir. Practically all the artesian waters at Glen Rose and vicinity are derived from the aquifers of the "basal sands" of the Trinity group, which yield water that differs greatly in character from the water of the Glen Rose formation and is vastly superior to it for general use.

During the course of the present study partial analyses were made of 17 samples of water from wells, 2 samples from springs, and 1

[22] Hill, R. T., op. cit., p. 448.

sample from Paluxy Creek. In addition, 6 complete analyses were made of samples of water from wells. The table on page 56 gives the results of the partial analyses made.

All the samples of well water except one contained varying amounts of hydrogen sulphide (H_2S). In the water from some of the wells the hydrogen sulphide is hardly evident; in that from others it is present in sufficient quantity to produce a very strong odor in the vicinity of the wells while the water is flowing. The water from well 169, at the Snyder Sanatorium, contains no noticeable amount of hydrogen sulphide. This is in marked contrast to the water from well 168, which supplies both the Snyder Sanatorium and the Glen Rose Hotel. The two wells are only about 300 feet apart; there is less than 10 feet difference in the depth; and as shown by the complete analyses (p. 57) there is no marked difference in the composition of their waters.

The results of the partial analyses of samples of water from the same well where the casing is presumed to separate the waters of different aquifers indicate no wide difference in the character of the waters. Well 168 is finished in this manner, and the two samples show practically the same characteristics with the exception of the somewhat higher content of hydrogen sulphide in the water from the shallow aquifer, which was noted at the time of sampling. In well 197, also, the water from the two aquifers is supposed to be separated, yet the water from the deeper aquifer is practically the same as that from uncased well 196, about 15 feet away, which is 60 feet shallower and presumably taps only the uppermost aquifer.

Because of the lack of accurate and detailed information on the amount of casing in the wells, the condition of the casing, and the horizons tapped by particular wells, it is rather difficult to draw reliable conclusions regarding the character of the water supplied by different aquifers. This is illustrated by a comparison of the analyses of water from wells 177, 169, and 10. Well 177 is only 53 deep, yet its water is essentially the same as that from well 169 which is 287 feet deep and located on ground of practically the same altitude about 1,500 feet away. The waters from the two wells are equally hard. At the time of sampling it was noted, however, that the water from well 177 contained a noticeable amount of iron (Fe), as indicated by the rust stain on the fittings at the well, and only a moderate amount of hydrogen sulphide, whereas the water from well 169 was in comparison relatively strong in hydrogen sulphide and showed less evidence of iron. Well 10 is about 700 feet from well 177 and yields calcium magnesium carbonate water ($CaMgC_2O_6$). Though both waters are moderately hard the water from well 10 contains more calcium than that from well 177.

Partial analyses of water from sources in and near Glen Rose, Somervell County, Tex.

[Parts per million. Analyses by W. L. Lamar, U.S. Geological Survey. The locations of wells 264, 276, 277, and 296 are shown on pl. 6, the other wells on pl. 4. See also table on pp. 76–84.]

Well no.	Owner or location	Date of collection (1929)	Depth (feet)	Total dissolved solids (calculated)	Iron (Fe)	Calcium (Ca) (by turbidity)	Sodium and potassium (Na+K) (calculated)	Bicarbonate (HCO_3)	Sulphate (SO_4) (by turbidity)	Chloride (Cl)	Nitrate (NO_3)	Total hardness as $CaCO_3$
10	John Anderson	Nov. 22	175	359	0.77	44	75	378	19	11	0.21	183
65	Near Cliff House	do	192	465	27	109	77	522	1.0	18	.08	286
128	Golden Gate Camp	do	142	374		20	106	395	18	12	.0	129
154	Lane & Sons' garage	do	285	373		30	105	405	9.0	14	.11	132
158	L. J. Wardlaw	do	290	374	1.8	36	111	410	6.0	15	.90	123
168	Snyder Sanatorium:											
	Lower flow [a]	do	295	370		24	99	394	14	14	.05	142
	Upper flow	do	125±	380		24	102	404	15	14	.0	144
169	Snyder Sanatorium	do	287	382		37	100	407	12	16	.05	152
177	Jack Morris	do	53	374		24	98	403	10	15	.05	148
193	Dr. Mitain	do		383		43	102	384	32	11	.60	142
196	T. K. Mathews	do	160	356		41	84	376	17	12	.0	160
197	T. K. Mathews:											
	Upper flow	do	100	395	.40	32	106	400	28	14	.0	147
	Lower flow	do	328	395		36	102	396	28	16	.0	154
264	Oil exploration well, 4 miles northeast of Glen Rose	do	1,500?	414		9.0	170	422	1.0	38	.05	32
276	Young's gas station, 2¾ miles northeast of Glen Rose	do	220	388		13	144	423	7.0	16	.05	64
277	Russel gas station, 2¾ miles northeast of Glen Rose	do		385		20	130	416	10	15	.50	90
296	Miss Daniels, 2¼ miles west of Glen Rose	do	285?	372		36	85	386	17	16	.57	172
A	Spring at Glen Rose-Cleburne highway bridge over Wheeler Branch	do		444		28	141	457	11	21	10	117
B	Paluxy Creek at Glen Rose	Nov. 23		323		51	43	295	32	20	.40	210
C	Porter Springs, 5½ miles northeast of Glen Rose	do		391		92	63	371	18	18	20	228

[a] Supplies also Glen Rose Hotel.

The water from the spring on Wheeler Branch (A in table, p. 56) is similar to the waters from the artesian wells in the vicinity. The water from Porter Springs (C), at the Glen Rose-Cleburne highway bridge across the Brazos River, is relatively hard. These springs issue from limestone crevices, and it is evident that they have taken up considerable calcium by solution of the limestone. The water from Paluxy Creek (B) is of like character, and its high calcium content is undoubtedly due to the fact that for most of the distance from the village of Paluxy to the mouth of the creek the stream flows over the limestone bed of the lower Glen Rose formation. The excessive amount of iron (Fe) in the water from well 65 is probably due to the corrosion of the well casing and pump fittings. The well had not been in use for some time, and it is probable that it was not pumped long enough before the sample was collected.

The following table gives the results of complete analyses of samples of water from eight wells. The analyses of the waters from the upper and lower aquifers tapped by well 141, as given in this table, show comparatively little difference in character. The water from the lower aquifer is less hard than that from the upper aquifer; it has less calcium and magnesium and also less hydrogen sulphide.

Analyses of water from wells in and near Glen Rose, Somervell County, Tex.

[Parts per million. Analyses by W. L. Lamar, U.S. Geological Survey, except as indicated. The location of well 274 is shown on pl. 6, the other wells on pl. 4. See also table on pp. 76-83.]

	10	71 [a]	141		158	168	169 [a]	274
			A	B				
Silica (SiO_2)	20	16	23	22	22	25	19	53
Iron (Fe)	.05	[b] 5	.04	.07	1.6	.08	[b] 3	.05
Calcium (Ca)	30	24	16	21	24	23	32	14
Magnesium (Mg)	24	20	12	16	19	18	22	6.8
Sodium (Na)	78	[c] 101	126	102	99	104	[c] 109	142
Potassium (K)	4.6		4.2	4.6	4.2	4.5		3.8
Bicarbonate (HCO_3)	376	412	413	398	412	410	407	389
Sulphate (SO_4)	35	9.7	19	16	12	19	41	44
Chloride (Cl)	12	9.8	19	14	16	17	21	16
Nitrate (NO_3)	0	--------	0	0	0	0	--------	1.3
Total dissolved solids	364	400	406	[d] 371	379	388	405	468
Total hardness as $CaCO_3$ (calculated)	173	140	89	118	138	131	167	63
Date of collection	June 19, 1930	-------	June 19, 1930	June 19, 1930	June 19, 1930	June 19, 1930	-------	June 19, 1930

[a] Analysis by Terrell Laboratories, Fort Worth, Tex.
[b] Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$).
[c] Calculated.
[d] Contained 1.0 part per million of hydrogen sulphide when analyzed.

10. Well 175 feet deep owned by John Anderson.
71. Well 298 feet deep owned by Somervell County.
141. Well 321 feet deep at Lakeview Park. A, Sample from depth of about 321 feet; B, sample from depth of about 125 feet.
158. Well 290 feet deep owned by L. J. Wardlaw.
168. Well 295 feet deep at Snyder Sanatorium.
169. Well 287 feet deep at Snyder Sanatorium.
274. Well 277 feet deep at Y.W.C.A. camp.

The water from all the wells in Glen Rose, regardless of the aquifers tapped, is slightly to moderately hard. No definite relation between the depth of the well and the hardness of the water is evident, but the analyses for wells 276 and 277 (p. 56) and 141 (p. 57) suggest that the artesian water may be softer east of Glen Rose than within the town proper. The water of well 264, about 1 mile north of wells 276 and 277, is the softest of all the samples analyzed. The well was reported to have been drilled to a depth of 1,500 feet as an oil exploration test, then plugged and abandoned. At the time of sampling less than half a gallon a minute was flowing from the casing. Information is not available regarding the depth of the aquifer that is supplying the water. In general, the water from the wells in Glen Rose, though moderately hard, is satisfactory for all uses. Some trouble is experienced with its use in boilers, as it shows a tendency to foam and precipitates a sludge that must be removed by washing in order to maintain the boiler at good efficiency.

It is probable that a greater difference in the character of the water from the different aquifers would be noted if uncontaminated samples from each aquifer could be obtained. It would appear, however, that the many uncased wells permit more or less free migration of the water from one aquifer to another and hence the true characteristics of the water from each aquifer are not fully evident in the samples.

SANITARY QUALITY

By Chester Cohen

In connection with the general ground-water investigations being conducted by the United States Geological Survey in cooperation with the Texas State Board of Water Engineers, the State Board of Health has made cooperative studies of the sanitary character of the waters of several of the areas under investigation.

Glen Rose has long been known as a health center, and a number of clinics and sanatoriums for massage treatment and rest cures are located in the city. A large part of the local prosperity is dependent upon the influx of persons who come to take the treatments and enjoy the recreational facilities of the region. It is obvious that the sanitary quality of the water is especially important, and a sanitary survey was therefore made during September, November, and December 1930.

Many of the wells are less than 175 feet in depth and are cased with only 20 to 40 feet of casing. A number of the wells had no casing that was properly seated in the hole but were kept flowing simply by having one or at the most two joints of 1½- to 2-inch pipe inserted into the hole. The deeper wells are generally cased from about 200 to 265 feet.

The problem at Glen Rose was to determine the relative safety of the water supply from the numerous privately owned wells. Unfortunately, the city is without a sewer system, and each home employs an individual septic tank or a cesspool as a method of sewage disposal. These cesspools and septic tanks are dug into the gravel that underlies the town at depths of 10 to 20 feet from the surface. It is, therefore, possible that the upper materials at Glen Rose are generally polluted. This conclusion is partly borne out by bacterial analyses that were made on November 11, 1930, of samples of water from two springs in this area, which indicated a high proportion of undesirable gas-forming organisms with evidence of the presence of *Bacillus coli.* One of the springs is in the rear of the Walter Davis home, and the other is on the Glen Rose-Cleburne highway at the downstream side of the highway bridge across Wheeler Branch. The water from this spring on the highway contains no apparent hydrogen sulphide, in marked contrast to most of the artesian waters, but a partial chemical analysis (p. 56) showed it to be relatively high in nitrates in comparison with the artesian water. The presence of high nitrates may be evidence of past pollution. This conclusion was substantiated by further partial analyses made in the field by the writer.

In order to determine whether the water is these artesian aquifers is of satisfactory quality at the source, examination was made of three wells completed during 1929 that are considered representative of the methods of construction being used.

Well 177, belonging to Jack Norris, was finished at a depth of 53 feet and is probably cased with about 20 feet of 4¼-inch casing. This well is supplied by water that apparently comes from the crevices and solution channels at the base of the limestone in the lower part of the Glen Rose formation. Well 10, belonging to John Anderson, was finished at a depth of 175 feet and cased with 20 feet of 5⅝-inch casing. The depth to the water-bearing bed is given by the driller as 108 to 150 feet. A little water was encountered in the limestone at about 50 feet, as in the Morris well, but the main water supply comes from the second water-bearing zone. Well 158, owned by L. J. Wardlaw, was completed to a depth of 290 feet and is cased with 212 feet of casing. Practically no water was encountered at the 50-foot horizon. The other two aquifers were encountered at 125 and 250 feet. The water from the 125-foot horizon was cased off by means of 212 feet of casing, and the well is supplied largely by 30 feet of water-bearing sand between the depths of 250 and 290 feet.

Six samples of water were taken from the three wells. None of these six samples showed any trace of pollutional bacteria, and in each sample the water at the time of sampling was entirely satisfactory for all domestic uses. The available evidence, therefore, indicates that the deeper waters have not been contaminated by the shallow ground water of unsatisfactory sanitary quality contained in the surficial deposits. The purity of the artesian water may be attributed in part to the natural purification that occurs in ground-water supplies during the period of storage and filtration through the sand strata, but it is due chiefly to the artesian pressure, which tends to prevent the downward percolation of polluted water through the overlying strata or its entrance into the artesian wells. The abandoned wells in the Glen Rose area may nevertheless in the future present a serious obstacle to maintaining the sanitary quality of the water of the artesian aquifers, inasmuch as they are not generally properly plugged to prevent the entrance of surface pollution. The fact that many of the wells in the area have insufficient pressure to flow at the surface creates a condition which should not be overlooked in any consideration of the maintenance of the purity of the artesian waters.

In order to determine the present condition of the older wells in the area, samples were taken from 23 such wells situated in different parts of the town, and 26 bacteriologic analyses were made of water from these wells during the period of the study. The samples from two of the wells showed evidence of pollution. One of these samples, however, was improperly collected, in that the faucet from which the water was taken was not sterilized prior to obtaining the sample, and therefore the results may be disregarded. The well from which the other sample was collected was equipped with a windmill; its water level had been drawn down considerably below the ground surface, and during the survey it was noted that water was standing around the well head, which was not properly constructed. Thus the surface conditions, the lack of a sealed casing head, and the lowered static level of the water are probably responsible for the pollution. The samples from all the other wells were free from any evidences of pollution.

The bacteriologic analyses were made chiefly in the State Hygienic Laboratories at Austin, Tex., on samples sent in to the laboratories by the writer. All the tests were made in accordance with the procedure recommended by the American Public Health Association in analyzing water for domestic use. In evaluating the sanitary quality of the water two terms have been used, "satisfactory" and "unsatisfactory." A well considered satisfactory is one that furnishes a supply which is free from any gas-producing organisms after 48 hours of incubation and which meets the standards of the United States Public Health Service. An unsatisfactory well is one that does not meet the standards of the American Public Health Association for a drinking-water supply.

On the basis of the sanitary survey that was made the following conclusions and recommendations are presented:

1. The water supplies at present obtained at depths below 50 feet are satisfactory for domestic uses.
2. The shallow ground water in the area—that is, the water originating in the shallow gravel—is at least in part polluted and is not satisfactory for drinking or culinary purposes.
3. Any further decreases in the artesian head increases the possibility of the entrance of polluted water from the surface or from the upper gravel.
4. A program should be undertaken immediately for abolishing all surface privies, cesspools, and septic tanks and substituting therefor a modern method for disposal of sewage through a system of tight pipes.
5. As far as possible all abandoned wells should be located and plugged to prevent the entrance of surface water into them.

CONSTRUCTION AND REPAIR OF WELLS

PRESENT METHODS OF CONSTRUCTION

In Somerville County all artesian wells are constructed by the solid or cable tool percussion method. In the northwestern part of the county, where in some small areas the water table is relatively near the surface, a few shallow wells furnish small supplies for farm use.

The dug wells are constructed by excavating a square or circular hole in the ground with hand tools. Such wells are generally about 4 feet in diameter. If the formations penetrated are sufficiently consolidated to stand without caving while the hole is being dug no curbing is used until the water table is encountered. The hole is then curbed with wood, rock, cement, or tile, after which excavation is continued a short distance below the water table, the depth being more or less determined by the amount of water encountered and the rapidity with which the water percolates into the well. If caving occurs while the well is being excavated the walls are cribbed with wood in order that the excavation can be carried deeper. Because the curbing and the well cover cannot generally be kept in a water-tight condition, it is difficult to keep such a well in a sanitary condition so that the water will be suitable for domestic use. The modern drilled well is so far superior in respect to sanitary quality that the dug well is not to be recommended even for isolated farm supplies.

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As few of the artesian wells in Somervell County exceed 325 feet in depth, all wells of this type are constructed by the cable-tool percussion method with portable drilling rigs. The essential operation of drilling consists in raising a blunt-edge clublike drilling tool and permitting it to fall of its own weight. For maximum efficiency in drilling, the features of the drill bit are varied according to the nature of the material to be penetrated. The percussive action of the bit breaks off, crushes, or penetrates the formations, and the action of the tool as it operates up and down in the drill hole mixes the drill cuttings with water, which is poured into the hole if sufficient fluid is not encountered in the formations. A complete string of tools consists of the drilling bit, stem, jars, sinker, and rope socket. On the shallow work in this area the sinker is never used, and the jars are also sometimes omitted. The stem is a heavy bar attached to the drilling bit; it provides additional weight to the blows struck by the bit and by increasing the length of the drill helps to keep the hole straight. The drilling jars are a pair of linked steel bars which assist in raising the bit from the bottom of the hole and prevent it from being stuck by affording a means for striking a sharp upward blow on the drilling bit. The sinker bar is similar to the stem; its purpose is to add weight and length to the tools and assist in sinking the drilling line and in keeping the hole straight. The rope socket furnishes the means for attaching the drilling rope or wire cable to the tools.

The portable rigs used in this area are built in compact form upon a frame mounted on wheels. The entire outfit can readily be moved from place to place by a tractor or a motor truck. The machine consists essentially of several drums upon which are spooled the drilling cable and sand line, a spudder for supplying the up and down motion to the tools, and a small A-frame which supports the cable sheave that is centered over the spot where the well is to be drilled. The power for operating the rig is supplied by means of a belt from a small gas engine.

In drilling a hole by the solid or cable tool percussion method, a small hole is first excavated by hand tools at the spot where the well is to be drilled. Drilling is then started with the tools, and after a quantity of cuttings has been drilled loose, the bit is removed and the hole cleaned out with a baler. Water is added from the surface if sufficient fluid is not encountered in the hole, and the drilling action of the bit mixes the cuttings with the water to form a sludge, which is bailed out. The bailer consists of a section of tubing from 10 to 20 feet in length and somewhat smaller in diameter than the well. It has a valve at the lower end, of either the flat type or the ball and tongue type. After the hole is bailed the drilling operation is continued until additional cuttings accumulate, which in turn are bailed from the hole.

Where the formation is unconsolidated and the hole caves, it is necessary to follow the bit with casing, and in some places the casing is put down ahead of the drill by driving. When the hole has reached a sufficient depth for setting the casing, the drill hole is cleaned and the casing is lowered into the well by the hoist and seated into a solid formation by driving. Drilling then proceeds to the final depth.

In Somervell County practically all artesian wells less than 150 to 175 feet deep are cased with only 20 to 40 feet of casing at the upper end, as the hole remains open without serious caving below the bottom of the casing. Wells that penetrate the lower aquifers are generally cased to a depth of 200 to 250 feet, and the remainder of the hole is left uncased. This lower casing is in addition to the short length of 20 to 40 feet of casing at the top. The bottom end of the main casing in some wells is fitted with an improvised packer consisting of several circular disks of fabric belting, which are attached to the casing between metal washers and nuts that are screwed over a short threaded section of the casing at its lower end. The purpose of this packer is to provide a watertight seal between the casing and the sides of the drill hole, thereby preventing the loss of artesian water on the outside of the casing and the subsequent reduction in the artesian head. In some wells the deep inner casing is not inserted into the hole until after the well has been drilled to its final depth. If the completed well yields flowing water, a short length of 1½- or 2-inch pipe is usually cemented into the top of the casing and a suitable valve placed thereon to control the flow. In several deep wells the water from the upper aquifers issues from a pipe between the two casings, and the water from the deep aquifer issues from the inner casing. Figure 5 shows the method of casing and finishing some of the deep wells in which the water from the two main aquifers is separated.

SUGGESTIONS FOR IMPROVEMENTS IN CASING AND FINISHING

Considerable improvement can be made in the methods of casing and finishing the wells drilled in Somervell County, especially in the matter of using more casing and in seating the casing more effectually.

Most of the so-called shallow wells, which range in depth from 50 to 175 feet, are cased with only one or two 20-foot joints of casing 5⅝ inches in diameter. In view of the marked similarity between the pressure of water encountered in the crevices of the limestone at about 50 feet in most of the wells and the pressure of the water in the first water-bearing sand encountered at 140 to 170 feet, it appears that this water-bearing sand is feeding the limestone crevices and that some of the artesian pressure is thereby dissipated. For wells utilizing the water in the base of the limestone, two joints of casing

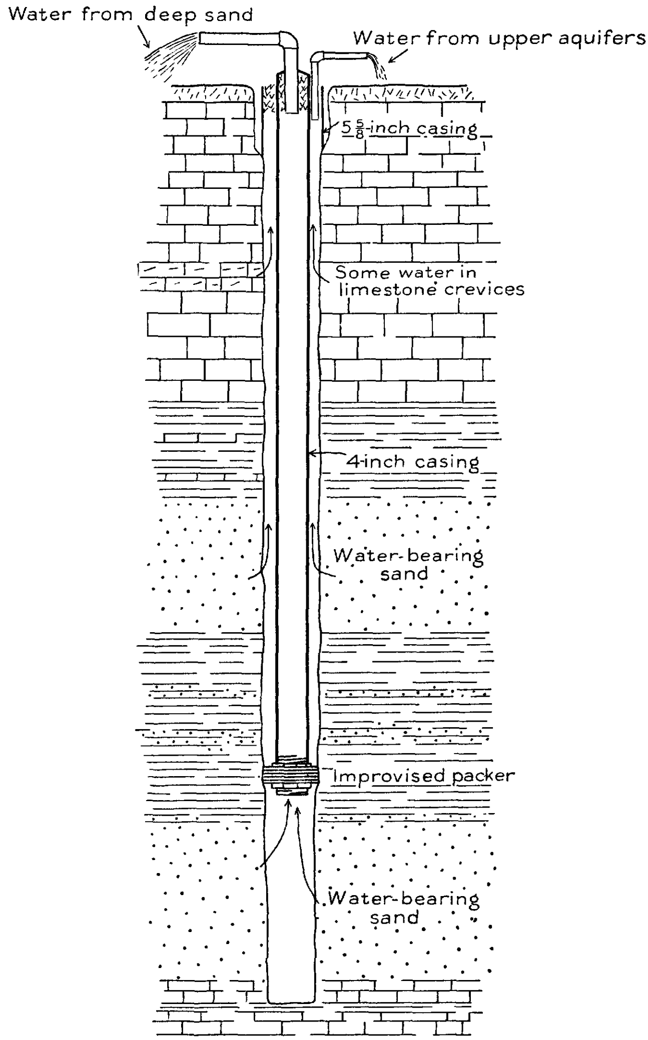

FIGURE 5.—Method of casing and finishing wells to separate the water of different aquifers.

may be sufficient if properly seated, but it is believed that the artesian supply and pressure will be better conserved if all wells that draw from the uppermost water-bearing sand (encountered at about 125 to 175 feet in wells at Glen Rose) are cased to a depth of about 100 to 125 feet. Drive shoes should also be used on the lower end of the casing in order to obtain a seat that will effectually prevent leakage between the outside of the casing and the walls of the hole. If the casing is not carried along while drilling but is seated in one string after the hole has been drilled, the bottom portion of the hole should be reduced slightly in diameter by using a smaller bit. The casing, with a drive shoe at its lower end, should then be securely seated in the reduced hole section by light driving to insure a watertight seat.

The practice of seating the inner string of casing by means of an improvised packer in wells in which the water from two aquifers is to be separated is believed to permit leakage from the lower aquifer and a resultant loss of pressure. This is indicated by the change of pressure of the water of the upper aquifer when the valve on the casing supplied by water from the lower aquifer is opened or closed. The casing in such wells should be securely seated in the red clay beds in a hole of slightly smaller diameter before the well is drilled to the deeper water-bearing sand, otherwise the formation in contact with the packer may be eroded by any slight leakage and eventually permit considerable loss of water from the lower aquifer and a resultant loss of pressure.

A number of wells in Glen Rose and vicinity have been completed without the use of any casing whatever by merely inserting a pipe in the upper end of the hole in order to keep the opening from caving in. Such makeshift methods of construction should not be tolerated; they result in a gross waste of water at the surface, because the flow is not controlled, and they also increase materially the underground leakage. Although most of the wells that have been drilled recently are supplied with valves to control the flow while the well is not in use, several wells, more particularly those of small capacity, have been completed without providing a satisfactory means of controlling the flow when the water is not required.

One of the most satisfactory methods of securing a satisfactory seal in the formation is to cement the casing around the lower joint or, preferably, throughout its length. Satisfactory methods of cementing casing have been developed in oil-well drilling, and in recent years these methods have been adapted to water-well construction with excellent results.[23] The method of cementing casing by the use of the dump bailer is especially applicable to the construction of artesion wells in Somervell County. In cementing a well by this process the liquid cement is lowered in a dump bailer, which discharges its load on reaching the bottom of the hole. A dump bailer

[23] For a detailed discussion of cementing methods see Fiedler, A. G., Use of cement in well construction: Water Works Engineering, vol. 82, pp. 587, 588, 620, 623, 1929; Tough, F. B., Methods of shutting off water in oil and gas wells: U.S. Bur. Mines Bull. 163, 1918.

is similar to a regular bailer except that means are provided to keep the bailer valve open when the bailer reaches the bottom of the hole in order to insure the complete dumping of the load of cement. After the necessary amount of cement has been placed in the well the casing is pulled 10 to 25 feet off the bottom, or far enough to bring the shoe above the level of the cement. The casing is then filled with water, sealed at the top, and again lowered to the bottom. Because the water is practically incompressible and there is no outlet at the top the cement cannot enter the casing and is forced up on the outside, where it is permitted to set before the well is uncapped.

In places where the water level in the well is low and the addition of water from the surface will not fill the casing because of leakage into formations containing no water or water under a lower head than that which would be built up in the casing, it is necessary to provide a means for sealing the lower end of the casing. If this is not done the entrained air above the water will be compressed after the well is capped and the casing is lowered to the bottom, and the cement will come up inside the casing instead of being forced up outside. To overcome this difficulty several types of cement plugs have been devised to seal the bottom of the casing and serve the same purpose as the column of water in the pipe.

The two plugs most generally used are the "sure-shot" cement plug and the Hall cement plug. The sure-shot plug is lowered on the bailer and may be readily raised or lowered in the pipe. It does not set until it passes outside of the casing, when a set of slips are released. When the bailer is picked up the slips will pull up firmly against the shoe and the plug will seal the casing, which is then lowered to the bottom, displacing the liquid cement. The Hall plug accomplishes the same purpose but is set in the pipe a short distance above the shoe by means of an upward pull on the bailer. Both plugs have appropriate valves which open to permit the water to flow through the plug while it is being lowered into place. If the sure-shot plug is properly seated below the shoe, very little cement will normally enter the casing. If the Hall plug is used, about 5 feet of cement must generally be drilled out after the cement has set, because it is generally inadvisable to try to set the plug nearer than 5 feet from the end of the casing, owing to the risk of getting the plug below the shoe. After the casing has been reseated and the cement has had an opportunity to set thoroughly the cement plugs are drilled out and the hole continued into the water-bearing sand.

The method of cementing with a dump bailer is particularly applicable for use in Glen Rose. It involves little additional expense, as in most places the cement can be forced out of the casings by filling the well with water and capping the top of the casing before it is lowered. Some additional expense will be involved if cement plugs have to be used.

Where wells of especially good construction are desired the casing should be cemented throughout its length by tubing or casing methods.[24] These methods are relatively more expensive than the dump-bailer method, and their use would add materially to the cost of a well. Under the circumstances they are not recommended for general use, for it is realized that methods of improving the construction of the wells must be economical to be adopted.

Attention is also called to the danger of pollution in wells that have only one or two joints of casing and are ineffectively sealed in the formation. The mere fact that the wells yield water by natural flow is no guaranty that the water may not be polluted, for abandoned nonflowing wells that are not properly plugged may permit surface waste to enter the water-bearing formation, thereby contaminating the supply. It is especially important, therefore, that the wells that utilize water from the uppermost aquifer, which is encountered at Glen Rose and vicinity at a depth of about 50 feet, be cased with at least 40 feet of casing, and wherever the casing cannot be tightly seated it should be properly cemented by one of the methods described. Though the Glen Rose community has apparently had a very satisfactory record so far as typhoid and other water-borne diseases are concerned, some of the pumped wells undoubtedly yield water of questionable sanitary quality because they are not effectively sealed at the top to prevent the entrance of surface waste and consequent contamination. It is therefore recommended that greater attention be devoted to the matter of constructing the wells with a view to preventing pollution, and that they be finished in accordance with the methods approved by the State board of health.

REPAIR OF WELLS

Comparatively little attention has been given to the repair of old wells in Somervell County, as the usual practice seems to have been to abandon an old well when it became no longer satisfactory for use and drill a new one nearby. According to the best information available it appears that only a few wells have been abandoned within the present area of artesian flow. In the belt which formerly yielded flowing water but in which the reduction in artesian head has caused the wells to cease flowing, probably many wells have been abandoned. The number and condition of such wells are not known, hence it is impossible to estimate accurately the amount of water that may be lost from them by underground leakage. However, as pointed out by Cohen on page 60, the abandoned wells

[24] Fiedler, A. G., op. cit., pp. 588, 620, 623; Tough, F. B., op. cit., pp. 32–54.

may in the future present a serious obstacle to maintaining the sanitary quality of the water of the artesian aquifers. Even if it were possible to locate most of the abandoned wells, a general program of repair would not be warranted at present. The problem is largely one of plugging these old wells to prevent avoidable underground leakage and pollution of the artesian supply. Methods of plugging are described on pages 69–72.

Although the available information is not sufficient for a reliable estimate of the amount of underground leakage from wells that are now in use, the evidence indicates that considerable improvement might be made in the condition of some of the wells by making suitable repairs.

During the present investigation a number of wells were found which were reported as having no casing, the hole being kept open by a piece of 1½- or 2-inch pipe about 20 feet long that had been placed in the well. Unfortunately the wells were in such poor condition that an examination with the leakage meter could not be made. As all these wells undoubtedly penetrate some formations that contain no water or water under a lower artesian pressure than the aquifer supplying the well, it is evident that some underground leakage must occur. This leakage can largely be prevented by casing the hole below all permeable strata and sealing the casing in a tight formation.

The most satisfactory method of casing a hole finished in this manner is to remove the small-diameter pipe and rotate a pipe of larger diameter into the hole. However, the hydraulic rotary system of drilling is not used in Somervell County, and hence the necessary machinery for rotating a casing is not available. Another method is to clean out the old hole to its original size and set a string of casing with a cable-tool rig. Though there is some danger of the surficial deposits caving, it is believed that no serious difficulty would be experienced in using cable-tool equipment in making the repairs, provided that care is used in carrying on the work. Some caving will probably occur in the superficial deposits, but as the limestone is relatively near the surface in most of the present area of artesian flow the surficial deposits that may cause trouble are not very thick. After the original hole in the limestone has been entered no further difficulty should normally occur, as the limestone is relatively hard and does not cave if left uncased.

To insure that the hole is tightly cased it is generally advisable to ream the hole to accommodate a casing one size larger than could have been used in the original hole. This will provide a seat for the new casing, and by using a casing shoe on the lower end the casing can be driven securely into the impervious formation and a tight seal made.

A relatively large number of wells are wasting water at the surface. (See table, pp. 76–84.) In many wells this waste is due to the absence of proper valves on the discharge pipes or to valves that cannot be completely closed because of worn or damaged parts. The repairs needed are relatively simple and inexpensive, and there is no justification for further waste of water from such causes. The waste is also a menace to health, for much of the water is permitted to collect in shallow pools or ditches that furnish excellent breeding places for mosquitoes.

PLUGGING OF WELLS

Various methods have been devised for plugging wells that leak underground, and the work done in other artesian areas has thoroughly demonstrated the wisdom of preventing underground leakage from artesian wells. In Honolulu [25] an effective program of plugging leaky artesian wells has been carried on for several years under the supervision of the United States Geological Survey in cooperation with the Territorial government. This work has proved the practicability and effectiveness of the methods developed, but it has shown that the plugging of a well is not an inexpensive undertaking. On the island of Oahu a population of over 100,000 is practically dependent upon the artesian waters for domestic and industrial supply. The prosperity of Glen Rose and vicinity is to a large extent dependent upon the permanence of the artesian supply, but the water cannot be considered nearly so valuable as in Honolulu. Hence, any program of conservation that involves the plugging of many wells would, of necessity, be limited by the value of the water that might be conserved. It should also be remember that Somervell County is but a very small part of the area underlain by the Trinity reservoir, which furnishes the supply of water, and that development of artesian water from the same reservoir in other counties cannot be prevented under the present laws of the State. Though it is not probable that any great development of artesian water will be made in the near future in areas adjacent to Somervell County, the fact should not be overlooked that a continued decline in head could result from such development regardless of any conservation measures that might be in effect within this county.

One of the most effective methods of plugging an artesian well that is leaking underground is to clean out the hole to its original depth and fill the well with impervious material so as to prevent the circulation of artesian water from one horizon to another. Leakage to a stratum that contains no water or water under a lower head than that of the aquifer supplying the well is thereby prevented.

[25] McCombs, John, Methods of exploring and repairing leaky artesian wells on the island of Oahu, Hawaii: U.S. Geol. Survey Water-Supply Paper 596, pp. 4–24, 1928.

In order that a well may be plugged effectively it is essential that the hole be opened, preferably to the bottom of the original well or at least for some distance into the lowermost aquifer penetrated. Plugging the hole near the top to prevent the water from wasting at the surface does not prevent the possible waste of water underground, and such methods of abandonment should not be tolerated under any circumstances. Some casing will probably be needed in most wells to prevent the caving of the surficial deposits while the well is being cleaned and plugged. This casing is only temporary and may be removed after plugging has been carried to such a point that there is no further danger from caving. After the well has been cleaned iron lathe turnings, iron filings, or lead wool should be placed in the hole and tamped solidly in place with a blunt bit until the well is filled above the top of the aquifer and the movement of the water is overcome. It is evident that if the water is yet moving the cement cap used to complete the plug will not set, for the mortar will be so diluted with water that the cement will have no bonding power. After all flow has been stopped by the addition of iron turnings or similar material a plug of cement is placed with the dump bailer. Cement grout is used for this purpose, and after it has set thoroughly the hole is filled with crushed rock and the temporary casing is removed. Where the flow is strong it is desirable to ascertain by tests with the leakage meter that all flow has been stopped before the concrete is placed. However, in view of the relatively low permeability of the artesian aquifers and the comparatively low head of the water, it is believed that no difficulty will be experienced in completely stopping the flow of water, and if the plug of iron turnings has been properly placed by the driller to a level above the top of the aquifer the concrete plug can be safely placed without previous tests with a leakage meter. More complete information on this method of plugging artesian wells is given in the report covering work done in Honolulu.[26]

The use of cement under pressure in conjunction with mud-laden fluid, as used in oil-well practice, is particularly adapted to plugging wells that are partly obstructed and cannot be cleaned out to the bottom. If water is issuing at the surface from around the casing, such leakage is first confined by placing several sections of large pipe and thoroughly cementing the pipe in place by the usual methods. Proper fittings are then attached to this section of casing, and heavy mud-laden fluid is circulated in the well. Cement is then pumped into the well under pressure through tubing and forced out of the well into the aquifers. The pressure is then maintained on the well for several days to permit the cement to set thoroughly. There are

[26] McCombs, John, op. cit.

several patented processes for introducing the cement into the well, and the process selected for any particular well would be governed by the existing conditions.

Under certain conditions mud-laden fluid, if properly applied, is an effective sealing agent that will prevent the circulation of artesian water from one aquifer to another or to porous beds that contain no water. This method is generally the most economical one that can be used. In order to be effective the mud must be free from sand and other coarse material that will tend to settle out. The effectiveness of the mud in overcoming the water pressure depends largely upon its specific gravity. According to Swigart and Beecher [27] the specific gravity of the average oil-field mud fluid ranges from 1.05 to 1.30, about 8.75 to 11.0 pounds to the gallon, or 66 to 82 pounds to the cubic foot. When used for plugging, the mud should normally be as heavy as can be handled satisfactorily by the pumps, but it must be a fluid and not a pasty clay.

Mud-laden fluid can be applied most effectively by the use of pumps. The well should preferably be opened to the bottom of the original hole after which mud-laden fluid under pressure should be thoroughly circulated in the hole. The mud not only seals the interstices of the water-bearing formations, but the column of mud of high specific gravity counterbalances the pressure of the water, thereby preventing circulation.

Nonflowing wells can be sealed by introducing the mud fluid into the hole with a dump bailer if mud-hog pumps are not available. Flowing wells can be sealed most satisfactorily by inserting the mud under pressure through tubing or by the lubricator method, as described by Lewis and McMurray.[28] After the fluid has been thoroughly circulated in the hole the hole should be filled completely with clean mud of high specific gravity.

During the investigation several methods of plugging leaky wells were suggested to the writer by interested local people. The suggestion that was made most frequently was to plug the well with sand. This suggestion was based on the fact that wells have been known to cease flowing when caving occurs in the aquifer and that newly drilled wells have started flowing when the drilling water, which contained a large amount of suspended sand, was bailed from the hole. A most serious objection to this method of plugging is that sand is not impervious, and though a well might no longer flow because the available pressure was counterbalanced by a column of fluid of higher specific gravity than water, leakage could still continue.

[27] Swigart, L. W., and Beecher, C. E., Manual for oil and gas operations: U.S. Bur. Mines Bull. 232, p. 33, 1923.

[28] Lewis, J. O., and McMurray, W. F., The use of mud-laden fluid in oil and gas wells: U.S. Bur. Mines Bull. 134, pp. 19–23, 1916.

Heavy mud-laden fluid applied in accordance with the methods described is a much more effective material to use and will accomplish better results.

RECOMMENDATIONS FOR CONSERVATION OF ARTESIAN WATER

The development that has taken place in Glen Rose and vicinity is due more or less to the very favorable location of the town in relation to the procurement of flowing artesian wells. Without this asset it is probable that much of the development might never have occurred and Glen Rose would have remained a typical small farming community. Because of the tourist resorts large numbers of people come each year for rest and recreation, and a large part of the business of the community during the summer is concerned with satisfying the needs of this group of people. As the flowing artesian water is an asset of considerable value, its conservation is especially important.

In any program for the reduction of the present underground waste by recasing and plugging existing wells it should be borne in mind that such work is expensive. The fact should not be overlooked that the value of the flowing water to an individual well owner may be insufficient to warrant any great expenditure by him to prevent underground waste, though the small quantities of water wasted from individual wells may in the aggregate assume considerable proportions and under certain conditions may warrant constructive action by the whole community.

From the results of the investigation as a whole it is evident that a general program of conservation must be followed faithfully in Somervell County if the residents expect to prevent further shrinkage in the area of artesian flow and the loss of additional flowing wells. The decline in artesian head and the resultant reduction of the flow of the wells is still in progress, though fortunately the rate of decline is not alarming and certainly is much less than it probably was some years ago.

Recasing and repair of wells.—After full consideration of all the information available regarding the problem of repair of wells, particularly with reference to recasing old wells, it is not considered desirable at this time to recommend a general program of recasing and repair. However, as the surface waste of water is excessive, it is recommended that valves be placed on all wells that are wasting water at the surface, so that the useless draft on the artesian basin can be stopped. For wells that have no casing or casing in such condition that a valve cannot be attached, the necessary repairs should include the placing of casing to such a depth as will prevent all underground leakage.

Plugging abandoned wells.—Without more complete information on the total quantity of underground leakage no recommendation is being made for a general program of plugging abandoned wells and wells that are probably leaking underground by reason of insufficient or defective casing. In order to prevent a further progressive increase in underground waste and to protect the ground-water supply from pollution it is recommended that no new wells be permitted to be drilled unless all existing wells on the property are properly repaired, recased, or plugged. Wells that are to be abandoned should be plugged by an approved method, such as has been outlined. Makeshift methods, such as pouring sand into the well, should not be permitted.

Draft of large wells.—As far as the residents of Glen Rose are concerned, one of the most serious aspects of the situation is the rather heavy draft of a few wells of large capacity located on relatively low land. By reason of the use to which these wells are placed, they are permitted to flow continuously during the summer, and hence they tend to produce a regional cone of depression which includes a large number of the other flowing wells. Some reduction in head and flow is naturally to be expected during the summer, as the draft upon the artesian reservoir is greatest at that season. However, as the draft from the large wells is continuous, the head is lowered progressively until an essential condition of equilibrium is reached, after which further decline during the summer is only seasonal and proceeds at a relatively slow rate.

It is not within the province of this report to decide upon the rights of the respective water users supplied by the artesian basin, as such rights have never been adequately defined by court decisions or statute in this State. In view of the marked trend of judicial opinion in other States to define the rights of ground-water users on the basis of either the doctrine of correlative rights or the doctrine of prior appropriation, it appears probable that the wells of large capacity are diverting from the artesian basin more than their proportionate share of the available supply of water.

Enforcement of existing statutes.—Ground water is now generally regarded in practically all States as a natural resource subject to supervision by the State so that it may be developed along the lines that will yield the greatest good to the greatest number. As such, it has been repeatedly ruled in numerous court decisions that the prevention of waste of ground water properly falls within the police powers of the State. Obviously this is a wise and progressive policy, for otherwise a valuable natural resource that might be developed to promote the prosperity and welfare of the people could be completely dissipated and wasted. Statutes have already been enacted in Texas for the purpose of preventing the misuse of ground water, and though they have not been enforced heretofore because of the lack of necessary enforcement machinery they appear to be adequate to cover the present situation in Somervell County. Considerable benefit would be derived from the complete checking of existing surface waste within the area, and though it cannot be stated definitely that further decline in head can be completely halted by this means, such a program is so inexpensive to apply that its execution should not be delayed longer. The residents of the area for their own benefit and welfare should therefore exert their best efforts to effect the strict enforcement of the following statutes:[29]

ART. 7600. *Artesian well defined.*—An artesian well is defined, for the purposes of this chapter, to be an artificial well in which, if properly cased, the waters will rise by natural pressure above the first impervious stratum below the surface of the ground. (Acts 1917, p. 232, sec. 90.)

ART. 7601. *When artesian well declared a public nuisance.*—Any artesian well which is not tightly cased, capped, and furnished with such mechanical appliances as will readily and effectively arrest and prevent the flow from such well, either over the surface of the ground about the well or wasting from the well through strata through which it passes, is hereby declared a public nuisance and subject to be abated as such upon the order of the board. (Idem, sec. 91.)

ART. 7602. *Waste defined.*—Waste is defined for the purposes of this act, in relation to artesian wells, to be the causing, suffering, or permitting the waters of an artesian well to run into any river, creek, or other natural watercourse or drain, superficial or underground channel, bayou, or into any sewer, street, road, highway, or upon the land of any other person than that of the owner of such well, or upon the public lands or to run or percolate through the strata above that in which the water is found, unless it be used for the purposes and in the manner in which it may be lawfully used on the premises of the owner of such well. (Idem, p. 233, sec. 92.)

ART. 7603. *Proper irrigation of trees, etc.*—Nothing in the preceding article shall be construed to prevent the use of such water, if suitable, for proper irrigation of trees standing along or upon any street, road, or highway, or for ornamental ponds or fountains, or for the propagation of fish or for the purposes authorized by this chapter. (Idem, p. 233, sec. 92.)

ART. 7604. *Well properly cased.*—Whenever any person desires to drill a well upon his own land for domestic purposes or use for stock-raising purposes or use that comes within the definition of artesian well, as defined in this chapter, he shall have the right to do so without subjecting himself to the provisions of this chapter, provided that said well shall be properly and securely cased and whenever water is reached containing mineral or other substances injurious to vegetation or agriculture it shall be the duty of the owner of said well to securely cap same or to control its flow so as not to injure the land of any other person or to fill it up so as to prevent the water of said well to rise above the first impervious stratum below the surface of the ground. (Idem, sec. 93.)

ART. 7605. *Accurate record kept.*—Any person boring or causing to be bored any artesian well shall keep a complete and accurate record of the depth

[29] Texas Revised Civil Statutes, 1925, vol. 2, pp. 2198–2200.

and thickness and character of the different strata penetrated, and when such well is completed shall transmit by registered mail to the Board of Water Engineers a copy of such record. (Idem, sec. 94.)

* * * * * * *

ART. 7613. *Penalty for permitting waste.*—Whoever wilfully causes or knowingly permits waste, as defined in this chapter, shall be fined in any sum not exceeding $500, or shall be imprisoned in jail not more than 90 days, or by both such fine and imprisonment. (Idem, p. 234, sec. 101.)

ART. 7614. *Sworn statement.*—Any person, association of persons, corporation, or water improvement or irrigation district owning or operating any artesian well, as defined for the purposes of this chapter at the time of its taking effect shall, within 1 year thereafter, transmit to the Board of Water Engineers a sworn statement showing the result of such test, together with a declaration of the use or uses to which the newly developed supply will be devoted, and the contemplated extent of such use. (Idem, p. 235, sec. 102.)

ART. 7615. *Detailed statement furnished.*—On or before the 1st day of March of each year, every person, association of persons, corporation, water improvement or irrigation district who, during any part of the preceding calendar year, owned or operated any artesian well for any purpose other than that of domestic use, shall furnish, under oath, to the Board of Water Engineers, upon blanks to be furnished by the Board, a detailed statement showing the quantity of water which has been derived from such well and the character of use to which same has been applied, together with the change in level of water table of said well, and if used in irrigation, the acreage and yield of each crop, together with such additional information as the Board may require. (Idem, sec. 103.)

WELL RECORDS

The information concerning individual wells obtained during the study of artesian conditions in Somervell County is presented in the following table:

Records of wells in Somervell County, Tex.

[An asterisk (*) in front of the well number indicates a flowing well. Blanks in a column indicate that information was not obtained or is not available. Discharge largely estimated. Under "Waste", a cipher (0) indicates no waste at the surface. Symbols indicating use: A, Abandoned; B, bathing pool; D, domestic; I, irrigation; M, medicinal; S, stock. Symbols indicating type of pumping equipment: E, Electric motor-driven pump; En, internal-combustion engine; FP, force or lift pump (indicates water table generally beyond suction lift); P, hand pump (type not known); PP, pitcher pump (indicates water table within suction lift of surface, usually 18 feet or less); W, windmill]

Glen Rose and vicinity

[For locations of wells see pl. 4]

Well no.	Owner	Year drilled	Diameter (inches)	Depth (feet)	Casing		Discharge (gallons a minute)	Head above or below surface (feet)	Date of measurement	Use	Waste (gallons a minute)	Pumping equipment	Remarks
					Length (feet)	Size (inches)							
*1	Dr. Earp	1929		128						D			
2	Mrs. G. P. Lantz	1927		140	120					D	0	W	
3	Herman Shields						Few			D	0	PP	
4	—— Flowers						Few			D			
*5	D. M. Boone	1916	5½	176	30		3	+10		S, D			
*6	—— Davis		5½	165	28		5			D	0		
*7	—— Bridges		4	170			4			D	0		
*8	—— Kirk		5	145	30		3			D	3		
9	—— Knight		4	160									
*10	John Anderson	1929	4	175	20	5⅝	10	+13.3	June 14, 1930	D	0		Water at 108 and 150 feet.
*11	Floyd Davis	1924	5	175	90		4			D	4		
*12	—— Parsons			150			10	+7.0	June 14, 1930	D	0		
13										D	0	PP	
*14	A. L. Robinson			150			5			D	0		
*15	Chas. Connolly						5			D	0		
*16	do		3	286			3			D	0		
17	Herbert Thomas		2¾	295									
18	Ed. Edmiston		4½	141	20								
19	J. M. Wales	1927	3½	301	271								
20	A. J. Price		3	302	298								
21	Price and Otey		3¾	248	160					D	0	P	
22	R. P. Campbell			206						D	0	FP	
23	do									D		P	
24	A. J. Price		5⅝	177									
25				165						D	0	PP	
26										D	0	PP	
27	Ed. Martin									D	0	FP	
28										D	0	PP	
29	J. L. Collings									D	0	P	
30										D	0	FP	
31	E. B. Earp		5	176	18					D	0	FP	

32	Tom Cruce		5½	178						D	0	FP	
33	Tom O'Neal		5	180						D	0	W	
34	B. F. Newton									D	0	P	
35	—— Childress			72				−60.5	June 19, 1930	D	0	FP	
36	J. L. Collings		5⅝	144				−80.6	June 17, 1930	A	0		
37			6	72	5	6		−60.5	Nov. 9, 1929	A	0		
38										D	0	FP	
39	J. D. Walker											P	
40	Ed Embree									A	0		
41	Glen Rose Bank			60						D	0	FP	
*42	E. W. Small	1928	4½	173	30		5			D	0	E	
43	L. L. Dioson		4½	68			0			A	0		
44	—— Shields		3½	175						D	0	FP	
45	Mrs. Ruark									D	0	FP	
46	Billy Woods		4½	170						D	0	PP	
47	—— Rodin									D	0	FP	
48	W. P. Hattler									D	0	FP	
49	Watt Cousin									D	0	PP	
50	E. W. Small			173						D	0	FP	
51	—— Adams									D	0	PP	
52	John West									D	0	PP	
53	—— Franklin									D	0	PP	
*54	F. L. Echols		2½	308			5			D	0		Serves 5 families.
*55	do						3			D	0		
*56	Fred Gaither			298			4	+7		D	0		
57	Snyder Sanatorium	1927	3	316	260 20	3 5⅝				D	0	E	
58	do			260						D			
59	A. H. Roden									D	0	FP	
60	Glen Rose Golf Club									D, I	0	W	
61	—— Gilmore		4	222						D	0	W	
62	C. A. Milain		4½	165						D	0	E	
63	Cliff House									D	0	W	
64	do						0			A	0		
65	George Knott	1908		192						D	0	FP	
*66	M. E. Church				20	5⅝	5			D	0	FP	
*67	N. J. Otey		4⅝	287			3			D	3		
68	Fred Gaither	1904		298						D	0	P	
*69	A. J. Price		2½	217						D			
70	Somervell County		3¾	291		3¾	0			A	0		
*71	Somervell County Courthouse			291		3¾	40	+19.7	Nov. 8, 1929	D	0		
*72							6			D	0		
*73	T. Johnson	1927	4	272			8			D	0		
74	Baptist Parsonage									D	0	P	
75	G. C. Gibbs									A			
*76	J. G. Daniels		3¾	308			5			D	0		
77	C. A. Bridges									D	0	W	
78	Lilly Airs									D	0	W	
79	Goffield place									D	0	W	
80	Ed Davis									D	0	W	
81	—— Gresham									D	0	P	
82	O. J. Cory									D	0	W	

Records of wells in Somervell County, Tex.—Continued

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Glen Rose and vicinity—Continued

[For locations of wells see pl. 4]

Well no.	Owner	Year drilled	Diameter (inches)	Depth (feet)	Casing Length (feet)	Casing Size (inches)	Discharge (gallons a minute)	Head above or below surface (feet)	Date of measurement	Use	Waste (gallons a minute)	Pumping equipment	Remarks
83	F. C. Finley									D	0	PP	
84	Glen Rose High School	1911		152						D	0	E	
85	F. C. Finley		5	110						D	0	FP	
86	—— Pruitt	1930		128				−22		D	0	P	
87	J. W. Riddle									D	0	P	
88	Martin Rhodes			135						D	0	P	
89	Sullivan			129						D	0	P	
90	R. L. Leach									D	0	FP	
91	—— Parker									D	0	PP	
92	Mrs. Ned Sullivan	1924	4½	129						D	0	FP	
93	Lee Lane	1911		196						D	0	FP	
94										D	0	FP	
*95	Clinton Gaither	1912		328			15			D	4		Serves 3 families.
*96	Vincent Wright	1921		159			2			D	2		
*97	Con Marchbank	1905		213			2			D	2		
*98	R. E. McDonald	1911	5	300			3			D	3		
99	Fred Gaither		3½	316									
*100	Perry Embree	1904					18	+7		D, I	3		Original flow 60 gallons a minute. Original head estimated at +18 feet.
*101	—— Buzan	1930		65	22	5	Few			D	½	E	
102	Dr. Milling	1911		318						D	0		
103	—— Gibbs									D	0	PP	
*104	J. R. Buzou						5			D	0		
*105	—— Ward			125			Few			D	0	W	
106	Dr. West		4⅜	145						D	0	PP	
*107	H. J. Cox	1890					½			D	½		
*108	do		4⅝		20		4				4		
*109	do	1924	4½	341	280 60	4½ 3	25	+9.8	June 16, 1930				Supplies outdoor swimming pool.

*110	do	1924	5	368			10	+14.9	Nov. 25, 1930	D			Flowed 8 gallons a minute in 1925. Supplies bathhouse at tourist camp.
*111	R. L. McAllister			332	12 200	5⅝ 3	4	+5.4	June 14, 1930	D	1½		
*112	do		4	310	150 275	4 2⅝	1½ 0	+5.5 +9.5	do do	D I			Upper flow. Lower flow.
*113	—— Caselman		2½	312			6			A	3		
*114							3			D	1½		
*115	—— McCowin			150			3			D	0		
*116	John Adams estate						2	+0.8		A	2		
*117	Mrs. Beryl Reeves				10	1¾	10	+4.6		D	10		
*118							2			D	0		
*119	English place						4			D	2		
120	A. D. McCowen		3½	312									
121	J. L. Lilly									D			
122	Dr. Gibbs									D	0	PP	
123	—— Reeves									D	0	FP	
124	O. R. Archie									D	0	FP	
*125	—— Mullins						5			D	5		
*126	J. C. Peterson	1924					5				0		
127	J. R. Mitain									A	0		
*128	Golden Gate Camp	1920	5⅝	142	30	5⅝	5	+2		D	5		
129	—— Gillespie		5	281									
*130	Pickney Taylor						¾			A	¾		
*131	Sam Martin	1923		325			7	+11.5		D	2½		
*132	R. S. Darnaby		5⅝	312			2			D	2		
*133	R. H. Roden						1			A	1		
*134	—— Johnson						1			A	1		
*135	Ed. Ward	1926		187	20		5			D	4		
*136	Tom Darnaby		5⅝	150			2½				2½		
*137	Sam Darnaby						1				1		
*138	G. I. Daniels						3	+6.1	June 14, 1930	D	2		
*139	do			305			50	+9.2	do	B	10		Supplies swimming pool and bass pond.
*140	do		5	195			20			B			Do.
*141	do			321	125 225		2 60	+6.3 +20.9	June 26, 1930 do	 B			Upper flow. Lower flow.
*142	do		3	311			60	+18.6	Nov. 30, 1929	B			Supplies swimming pool and bass pond.
*143	Sam Martin			140			5			D	2		Supplies gas station.
*144	—— Gresham						8	+10.9	Nov. 8, 1929	D	6		
*145							6			D	0		
146	F. S. Williams		2¾	324									
*147							8	+7.5		D	3		
148										D	0		
149	—— Hill									D	0		
150	Williams Lumber Co			305						D	0		
151	J. G. Daniels			308									
152	J. D. Tankersly									D	0		Supplies 4 houses.
*153	R. L. Bryant			92			5			D	0		
*154	Lane & Sons garage	1925		296	260	3	35	+20.2	June 14, 1930		0		

Records of wells in Somervell County, Tex.—Continued

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Glen Rose and vicinity—Continued

[For locations of wells see pl. 4]

Well no.	Owner	Year drilled	Diameter (inches)	Depth (feet)	Casing		Discharge (gallons a minute)	Head above or below surface (feet)	Date of measurement	Use	Waste (gallons a minute)	Pumping equipment	Remarks
					Length (feet)	Size (inches)							
*155	—— Campbell						½	+.5		D	0		
156	Lillie Campbell			135				+.2		D	0		
*157	L. J. Wardlaw						3	+3.3		I	0		
*158	do	1929	5⅝	290	212		25	+21	June 13, 1930	D	0		Water at 125 and 250 feet.
*159	R. L. McAllister		4½	146			2½			D	2½		
160	—— Campbell	1901		397						A	0		
*161	do	1902	5⅝	283			5	+7.0		D	0		
*162	—— Couts		4	287			2	+6		D	2		
163										A	0		
*164	Glen Rose Laundry		3¼	320	271		30	+23		I	0		
165										A	0		
*166	E. A. Davis		2¼	316			4			D	0		
167	W. D. Felder		4¾	277									
*168	George Snyder	1925	3¾	295			25	23.5	June 13, 1930	D,M	0		Utilizes 2 flows.
*169	do		3¾	287			18	+20.0	do	D,M	0		
170	Perry Kugel									A	0		
171	O. E. Winslow		4	163						A	0		
172	Price Bros.		2¾	289									
*173							Few			D			
*174	L. B. Odom			124	21		6			D	3		Water at 115 feet.
*175	R. L. Nickels		5½	135	16		40	+8.2	June 14, 1930	I,D	0		
*176	D. N. Boone		2¾	174			4			D	0		
*177	Jack Morris	1929	4¼	53	20+		9	+9.6	June 14, 1930	D			
*178	—— Pruitt						9	+11.2	do	D	4		Serves tourist park.
*179	do						3	+4.8		D	2		
*180	Grandy Moss						5			D	2½		Do.
181	—— Booker									D	0	W	
*182	E. B. Earp	1930	5	128	24		40						
183	Fred Ernst	1929	4¼	170						S			
184	do	1929	5	166	21			−20		D		PP	Water at 150 feet.
185	do									A			

186	L. P. Gibbs		4¼	146									
187	G. P. Bessint		5¼	141									
188	W. D. Hudson		4¼	148							1		Serves tourist park.
189	Fred Ernst	1924								D		E	Serves 2 houses and tourist park.
190	Fairy Land Park	1929	4¼	172						S			
191	H. E. Logan		5⅝	132						D	0	W	
192	Joe Beck									D	0	PP	
193	Dr. Mitain									D	0	W	
194	C. W. Campbell		4½	156						D	0	PP	
195	T. K. Mathews									D	0	PP	
*196	do			160	0		3	+4.3	June 14, 1930	Park	3		Water at 140 feet. Serves tourist park.
*197	do			328	280		2 6	+1.0 +6.9	do do	 Park	2 4½		Upper flow at 140 feet. Serves tourist park. Lower flow. Serves tourist park.
198	do	1904		150				−12				PP	Flowed originally at altitude of 3 feet above ground.
199	Joe Sandlin									D	0	W	
200	John Taylor									D	0	P	
201	Mrs. Couts			287						D	0	P	
202	Mrs. W. W. Young									D	0	W	
203	George Hurell									D	0	W	
204	W. W. Hudson		4¼	172						D	0	E	Supplies 3 houses.
205	C. D. Span		5¼	136						D	0	W	
206	Lee Owens									D	0	W	
207	John Fox									D	0	PP	
208	do									D	0	PP	
209	F. S. Williams and Smith	1911	2¾	324				−15		D	0	W	
210	J. W. Jackson		5½	146						D	0	P	Serves 2 families.
211	—— Pruitt									D	0	W	
*212	—— Porter	1917			20 20	5⅝ ¾	½			D	½		
*213	W. Nowlin	1911	4	307			25			D, I	0		
214	U. Gilmore									D	0	PP	
215	do									D	0	P	Do.
216	Mrs. Loper									D	0	PP	
217	Lee Taylor		5⅝	146						D	0	PP	
218	J. F. Dempsey	1914		300						D	0	WP	
219	Bill Woods									D	0	FP	
220	Louis West									D	0	P	
221	W. H. Kuglen	1918		140				−2.0		D	0	PP	
222	Wm. McVickers									D	0	P	
223	J. F. Dempsey									D	0	FP	

Records of wells in Somervell County, Tex.—Continued

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Somervell County outside of Glen Rose and vicinity

[For locations of wells, see pl. 6]

Well no.	Owner	Year drilled	Diameter (inches)	Depth (feet)	Casing		Discharge (gallons a minute)	Head above or below surface (feet)	Date of measurement	Use	Waste (gallons a minute)	Pumping equipment	Remarks
					Length (feet)	Size (inches)							
224	Jim Collins			125						D	0		
225	—— Williamson	1907		81									Well supplied by Paluxy formation.
226	Gid White	1906		128						D			Do.
227	Tod Mullian	1907		81						D			Do.
228	Sam White	1906		96									Do.
229	Lee Evans	1905		70									
230	—— Wisdom	1906		62						D			Do.
231	J. W. Kensey		4	300									
232	Clark Hedrick	1906		91						D			Do.
233	Tom West	1907		400									
234	George Sandlein	1919	2¼	426									
235	John MacVickers	1894		326						D			
236	William Kennedy			248						D	0		
237	—— Wardlaw			347									
238	Albert Tankersly	1922		420									
239	Herman Kinder			243									
240	John Hawkins	1894		335									
241	—— Schackleford									D	0	P	Flowed originally.
242	—— Grafer									D	0	P	
243	—— Marsh									D	0	W	Do.
244	Mrs. L. W. House									D	0	W	Do.
245	Dewitt Barnet									D	0	W	
246	Bert McKinney									D	0	P	
247	Mrs. Barnet												
248	Mrs. Pruitt									D	0	W	
249	Rainbow school	1922		249						D	0	W	
250	W. H. O'Nell	1893		484	40 200	6 3		−60		D	0	En	Flowed originally about 9 gallons a minute; ceased flowing about 1905.

251	John Barber	1894		336						D	0		
252	—— Tankersly			375						D	0	PP	Flowed until about 1925.
253	W. C. Woodard									D	0	PP	
254	Leslie Elliott									D	0		
255	Clem Elliott									D	0	W	
256	Walter Stewart									D	0	W	
257	Ivan Davis									D	0	W	
258	W. F. Lewis									D	0	W	Never flowed.
259	J. B. Bunch									D, S	0	W	
260	Charles Bostick			135									Water at 135 feet.
261	Sid Mitchell	1894		132									
262	Mrs. Hodge	1911		387									
263	L. W. Woodward		4¼	201						D	0		
*264				1,500			½			S	½		Oil exploration test.
265	S. W. Stewart		3							A	0		
266	do									A	0		
*267	do			350			½	+8.9	June 19, 1930	D	0		
268	J. R. Mitain			375						D	0	PP	Flowed until about 1918.
*269	do	1898	5⅝	332			25			I	25		
270	—— Mitchell	1930	4½	169	33							PP	
271	Tim Stewart	1928		200	20			−18		D		W	Serves gas station. Water at 75 feet.
272	Ben Nock	1929	5¼	196½	34							PP	Water at 20 feet.
*273	R. S. Darnaby	1926	4½	163	20	4½	6			D, Park			
*274	Y.W.C.A	1924	3	277			60	+19.5	June 19, 1930	D	0		Serves small swimming pool.
*275							4				4		
*276	——Young			220			9	+8.2		D	3		Serves gas station.
277	——Russell									D	0	E	Do.
*278	J. R. Mitain		5⅝				5			D, S	5		
*279	George Snyder	1919	5½	320	20	5½	10			D	10	E, W	Supplies bass pond.
*280							2			S	2		
*281							2½			S	2½		
282	Ed. Martin		5⅝	280									
283	Bowin English			316									
284				206									
285	Sam Young	1899		296									
286	Mrs. Fulfer			119				−90		D, S	0	W	
287	Will Chuks									D, S	0	W	
288	—— Parvin									D, S	0	W	
289	William Wilson	1900		277									
290			3					−84		D, S			
291				120						D, S		W	
292	L. J. Ward		4½	248									
293	Edgar Ware			120									
294	William Rives			364									
295			5	280									
*296	Miss Daniels			285			75	+13.4	June 14, 1930	I	0		
297		1898		295						D	0		
*298	Miss Daniels		5	200			35			A	35		
299	Jim Tate		5⅝	165									
300	John Hamberly		4½	267									
*301	—— Tabernacle						8			S	8		

Records of wells in Somervell County, Tex.—Continued

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Somervell County outside of Glen Rose and vicinity—Continued

[For locations of wells see pl. 6]

Well no.	Owner	Year drilled	Diameter (inches)	Depth (feet)	Casing: Length (feet)	Casing: Size (inches)	Discharge [a] (gallons a minute)	Head above or below surface (feet)	Date of measurement	Use	Waste (gallons a minute)	Pumping equipment	Remarks
302	W. B. Ellis		4½	277									
*303			4½	143			15				15		
*304	Jim Wess			175	15		6				6		
*305	—— Muse						20				3		
306	I. N. May	1915		300+				−19		A			
*307	C. J. Gravitt	1905		300			1			D	1		
*308	do	1929		375			1	+1		D			
*309	—— Muse						3	+3		A	3		
*310	I. H. Daniels		3½	176			2				2		
*311	G. W. Wilson			297	250		2½	+2.5	Nov. 11, 1929		2½		
312	Chris Roland	1915						−6	do			PP	Flowed originally.
313	R. L. Wess		6	268				−148	June 21, 1930	D, S			
314	C. B. Wheeler			280						D, S		FP	
315	Jess Hobson			328				−70	June 21, 1930	D, S		W	
316	Arthur Davis			315						D, S		W	
317	W. L. Howard	1930		350						D		W	Water at 320 feet.
318	Lew Parham			336						D, S		W	
319	B. A. Collins		6	244				−216	June 21, 1930	D, S		W	
320	John Goldsmith			220									

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