TEXAS WATER COMMISSION



BULLETIN 6309

# RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE TRINITY RIVER BASIN, TEXAS



By

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## FOREWORD

The ground-water reconnaissance study is the first phase of the State's water-resources planning concerning ground water as outlined in the progress report to the Fifty-Sixth Legislature entitled "Texas Water Resources Planning at the End of the Year 1958." Before an adequate planning program for the development of the State's water resources can be prepared, it is necessary to determine the general chemical quality of the water, the order of magnitude of ground-water supplies potentially available from the principal water-bearing formations of the State, and how much of the supply is presently being used. To provide the data necessary to evaluate the ground-water resources of Texas, reconnaissance investigations were conducted throughout the State under a cooperative agreement with the U. S. Geological Survey. The ground-water reconnaissance investigations were conducted by river basins so that the results could be integrated with information on surface water in planning the development of the State's water resources. The river basins of the State were divided between the Ground Water Division of the Texas Water Commission and the U. S. Geological Survey for the purpose of conducting and reporting the results of the ground-water investigations.

This bulletin presents the results of the Trinity River Basin ground-water reconnaissance investigation. It provides a generalized evaluation of the ground-water conditions in the basin and points out areas where detailed studies and continuing observations are necessary. The additional studies will be required to provide estimates of the quantity of ground water available for development in smaller areas, to provide more information on changes in chemical quality that may affect the quantity of fresh water available for development, and to better determine the affects of present and future pumpage. This report was prepared by personnel of the Texas Water Commission.

TEXAS WATER COMMISSION

Joe D. Carter

Joe D. Carter, Chairman

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# RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE TRINITY RIVER BASIN, TEXAS

## ABSTRACT

The reconnaissance investigation of the Trinity River Basin was undertaken as part of a statewide program designed to provide the general order of magnitude of ground-water supplies potentially available from the principal water-bearing formations of Texas. The Trinity River Basin is in the eastern part of the State and covers approximately 17,930 square miles. The area of study includes all or parts of 37 counties and represents about 6.8 percent of the total area of Texas.

The physiographic expression of the Trinity River Basin ranges from treeless prairies to rolling timbered hills with altitudes ranging from sea level at the mouth of the Trinity River to about 1,400 feet above mean sea level in the upper reaches of the basin. The average annual precipitation ranges from approximately 27 inches at the upper end of the basin to about 50 inches near the coast. The population within the Trinity River Basin in 1960 was approximately 1,905,900 which represents nearly 20 percent of the State's population. The economy of the basin ranges principally from light industries in the urban areas to varying forms of agriculture in the rural areas. Oil and gas production scattered throughout the basin also contributes to the economy.

The Trinity Group, the Carrizo Formation and Wilcox Group, the Sparta Formation, and the formations that constitute the Gulf Coast aquifer of this report are primary aquifers and are capable of supplying large quantities of water over large areas of the Trinity River Basin. The Woodbine Formation and Queen City Formation are classified as secondary aquifers because they are capable of supplying small quantities of water over large areas of the basin. In addition to the primary and secondary aquifers, rocks of Pennsylvanian age, the Nacatoch Formation of the Navarro Group, the Cook Mountain Formation, the Yegua Formation, the Jackson Group, and alluvium yield small to moderate quantities of water locally, but have limited potential.

On the order of 300,000 acre-feet of ground water of a chemical quality suitable for most municipal, industrial, and irrigation uses is estimated to be available annually from the primary and secondary aquifers of the Trinity River Basin. The estimate is based on pumpage under idealized conditions in each of the aquifers and is related primarily to the ability of the aquifer to transmit

water and on the availability of recharge in the outcrop areas of the aquifers. It is assumed that the effect of pumping is such that the static water level is drawn down to the top of the aquifer where the top is 400 feet below land surface. An estimated 50,000 to 55,000 acre-feet of water is available perennially from the Trinity Group aquifer; approximately 12,000 acre-feet from the Woodbine aquifer; 70,000 to 80,000 acre-feet from the Carrizo-Wilcox aquifer; 50,000 to 60,000 acre-feet from the Sparta aquifer; 20,000 to 30,000 acre-feet from the Queen City aquifer; and approximately 66,000 acre-feet from the Gulf Coast aquifer. In addition, large quantities of water can be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed. However, this source of water is available only during the development of assumed conditions and should not be considered as water available for development on a sustained basis.

In 1960, approximately 66,000 acre-feet of ground water was pumped from the aquifers of the Trinity River Basin for municipal, industrial, and irrigation purposes. Most of the pumpage, 34,222 acre-feet, was from the Trinity Group aquifer with additional withdrawals of 5,739 acre-feet from the Woodbine aquifer, 4,506 acre-feet from the Carrizo-Wilcox aquifer, 1,255 acre-feet from the Sparta aquifer, 107 acre-feet from the Queen City aquifer, 19,343 acre-feet from the Gulf Coast aquifer, and 974 acre-feet from the other aquifers of the basin.

Large quantities of water of good quality are available for additional development in all the primary and secondary aquifers of the Trinity River Basin. About 25,000 acre-feet in addition to that presently being pumped is available for development from the Trinity Group and Woodbine aquifers in the northern third of the basin. The most favorable area for additional development of these two aquifers is north of Dallas and Tarrant Counties. South of these two counties, considerable additional quantities of ground water are also available for development. The largest withdrawal from the Trinity Group and Woodbine aquifers is in the Dallas and Tarrant Counties area and this area is not considered favorable for development of any additional large quantities of ground water. From the Carrizo-Wilcox, Sparta, and Queen City aquifers in the central part of the basin, approximately 150,000 acre-feet of water annually is available for additional development. Pumpage from these three aquifers is small, and conditions are favorable for additional development throughout the extent of the aquifers. From the Gulf Coast aquifer in the southern part of the Trinity River Basin, about 45,000 acre-feet of ground water is perennially available for additional development. During the time water levels are being lowered to a depth of 400 feet along the line of discharge, on the order of 8,500,000 acre-feet also will be obtained from storage in the Gulf Coast aquifer. Although a moderate amount of development has already taken place in the Gulf Coast aquifer, conditions are favorable for additional development throughout its geographic extent in the Trinity River Basin.

For detailed water planning or for planning individual water supplies, more detailed information than is contained in the present report is needed. Detailed ground-water investigations, as outlined in the progress report to the Fifty-Sixth Legislature entitled "Texas Water Resources Planning at the End of the Year 1958," should be made on the six primary and secondary aquifers of the Trinity River Basin to better define the geologic and water-bearing characteristics of the aquifers and to refine the estimates presented in the present report of ground water available for development.

# RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE TRINITY RIVER BASIN, TEXAS

## INTRODUCTION

### Purpose and Scope

The reconnaissance investigation of the Trinity River Basin was made as part of a statewide program to determine the order of magnitude of ground-water supplies potentially available from principal water-bearing formations of the State.

The approach to water planning in Texas is by river basins; thus, the ground-water reconnaissance investigations were conducted by river basins so that the results could be integrated with information on surface water by agencies and groups concerned with planning the development of the State's water resources. For purposes of reconnaissance ground-water studies, the State was divided into 13 major river basin areas and a coastal region which includes all or parts of several river basins and their intervening coastal areas. In planning the development of the State's water resources to meet present and future needs, the quantities of ground water and surface water that can be developed must be known and considered. Because adequate information was lacking for determining the total quantity of ground water available for development in much of the State, the Texas Water Commission recommended in a report to the Fifty-Sixth Legislature that ground-water reconnaissance studies be made.

The reconnaissance investigation of the Trinity River Basin included determinations of the location and extent of the principal water-bearing formations within the basin, the general chemical quality of ground water available, the order of magnitude of ground-water supplies potentially available for development, and the quantity of ground water being utilized. The results of the Trinity River Basin reconnaissance investigation provide a generalized evaluation of ground-water conditions over large areas. The amount of water available for development in the Trinity River Basin determined during this study probably is correct in its order of magnitude but cannot be considered an exact figure. Results of the investigation are not sufficiently specific for detailed water planning or for the planning of individual water supplies. This report points out areas where detailed studies and continuing observations are necessary to determine the quantity of ground water available for development in specific areas, to provide more information on changes in chemical quality that may affect the quantity of fresh ground water available for development, and to better determine the effects of present and future pumpage.

## Location and Extent

The Trinity River Basin is located in the eastern part of the State, as shown by Figure 1. It extends from the Gulf Coast on the south to the Red River Basin on the north and is drained by the Trinity River and its tributaries. The total land area within the Trinity River Basin, which includes all or parts of 37 counties, is approximately 17,930 square miles. This represents about 6.8 percent of the State's total area.

Because of the basin's large areal extent and the differences in geography and geology, the Trinity River Basin has been divided into three regions to facilitate discussion. Each region contains a series of principal water-bearing formations and, in most instances, a different type of geologic, topographic, and economic conditions. The boundaries of the regions coincide with the topographic limits of the Trinity River Basin and the topographic limits of smaller drainage subdivisions which have been defined by the Planning Division of the Texas Water Commission. Locations of the three regions into which the Trinity River Basin has been divided for report purposes are shown on Figure 1.

## Methods of Investigation

The investigation for this report was begun in September 1959. The fieldwork was concluded in September 1961. During the course of the study special emphasis was placed on the following items:

1. Collection and compilation of readily available logs of wells and preparation of generalized cross sections and maps showing other subsurface geologic data.

2. Inventory of large wells and springs, and major pumpage.

3. Compilation of existing chemical analyses and sampling of water from selected wells for additional analysis.

4. Determination of areas of recharge and discharge of the principal water-bearing formations.

5. Obtaining pumping-test data for selected wells to determine the water-bearing characteristics of the principal water-bearing formations.

6. Correlation and analysis of all data to determine the order of magnitude of ground-water supplies available and the general effects of future pumping.

The basic data used in the preparation of this report have been compiled in a tabulation of basic data. These data are in the files of the Texas Water Commission at Austin, Texas.

## Previous Investigations

Ground-water investigations have been conducted in all or parts of 14 counties of the Trinity River Basin. However, only the published reports on Tarrant

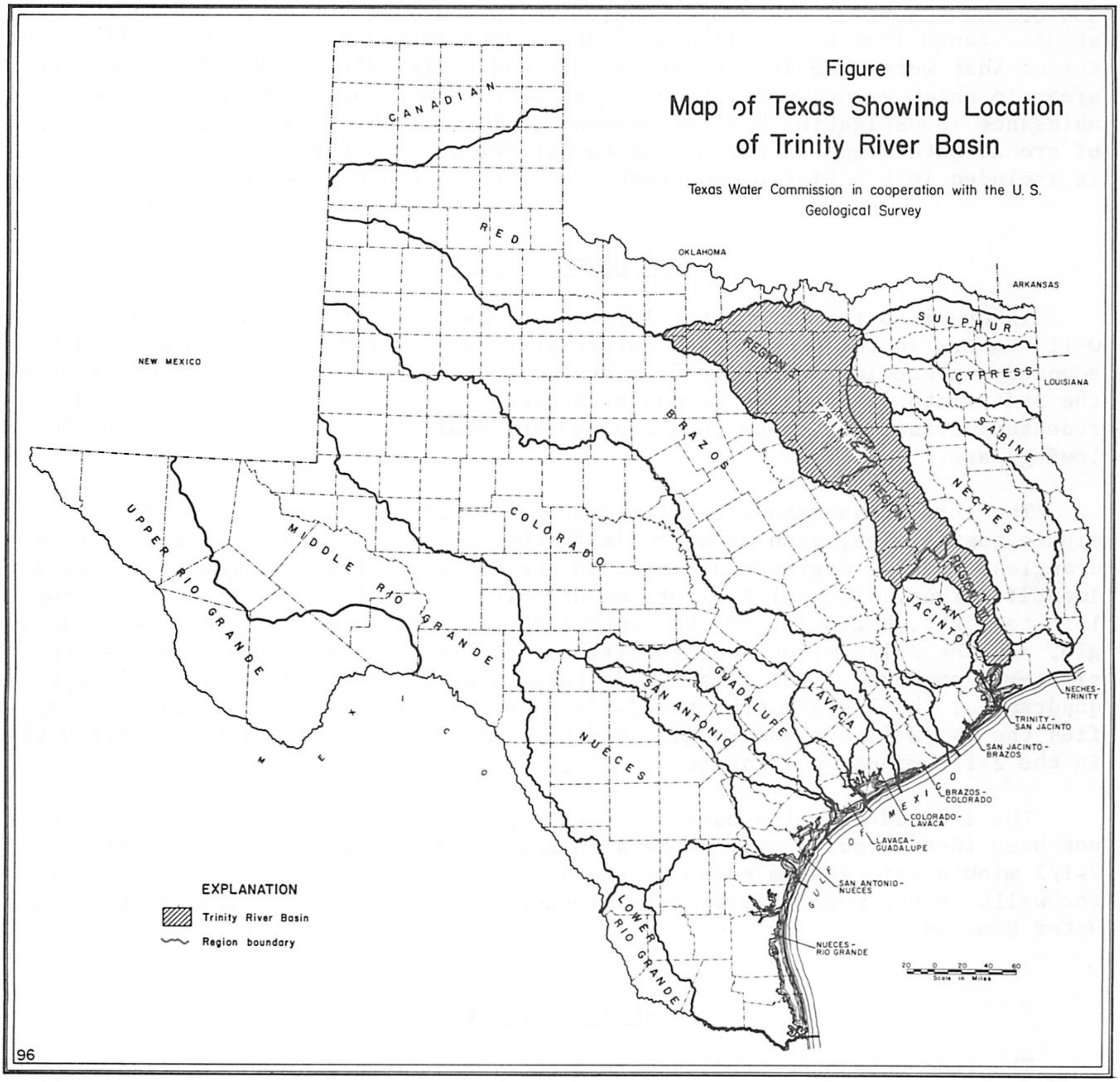



Figure 1

Map of Texas Showing Location of Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

and Grayson Counties are comprehensive and up-to-date. The results of the other studies range from generalized and out-of-date information to water-well inventories that were made in the late 1930's and early 1940's. Figure 2 shows the areas in which ground-water studies had been made prior to the present reconnaissance investigation and the general quality of the data. A complete list of ground-water reports pertaining to earlier work in the Trinity River Basin is included in the list of references at the end of this report.

## Well-Numbering System

In order to facilitate the location of wells and to avoid duplication of well numbers in the present and future studies, the Texas Water Commission has adopted a statewide well-numbering system. This system is based on division of the State into quadrangles formed by degrees of latitude and longitude and the repeated division of these quadrangles into smaller ones, as shown on the following page.

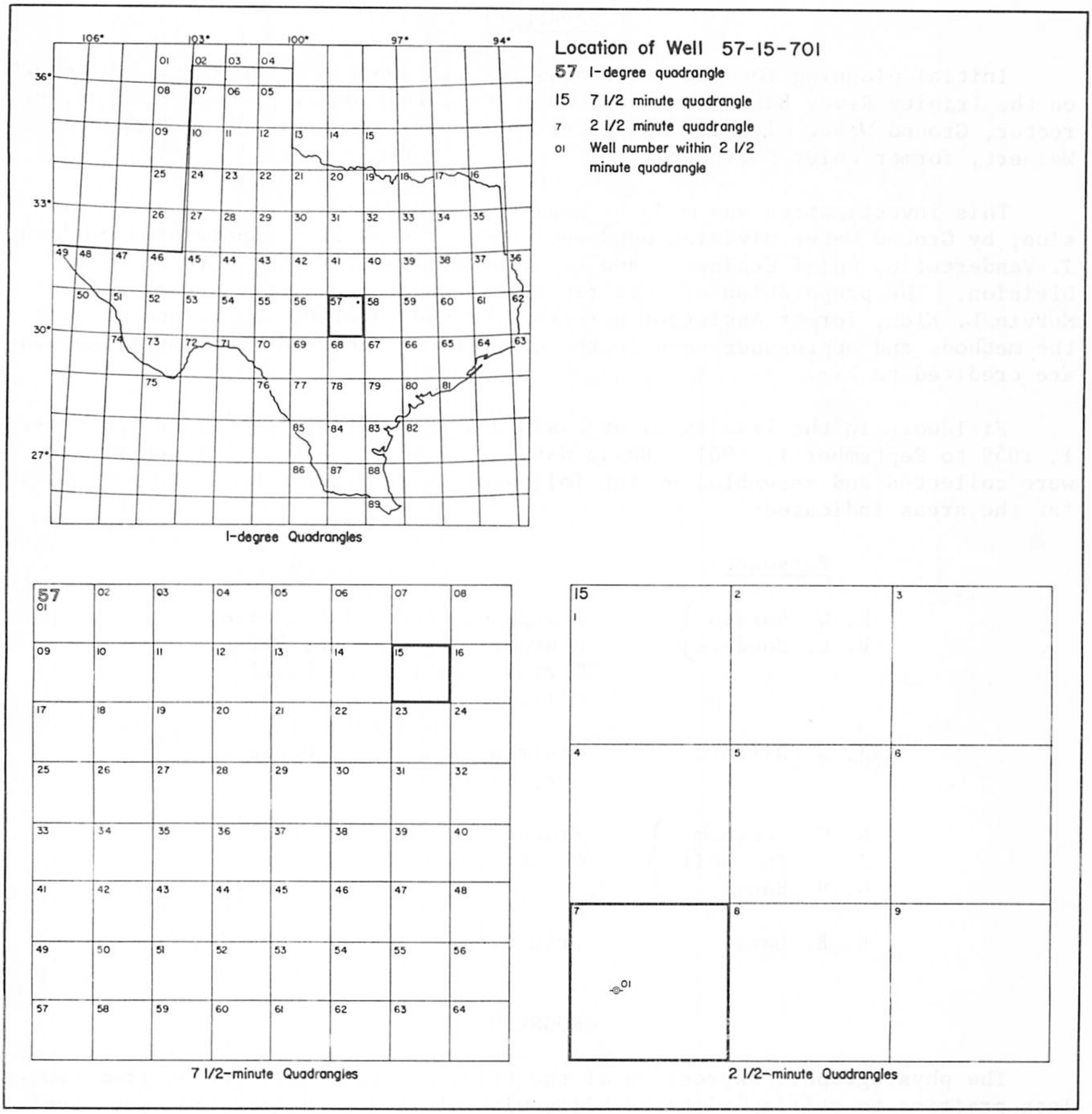
The largest quadrangle, a 1-degree quadrangle, is divided into 64 7-1/2 minute quadrangles, each of which is further divided into 9 2-1/2 minute quadrangles. Each 1-degree quadrangle in the State has been assigned a number for identification. The 7-1/2 minute quadrangles are numbered consecutively from left to right, beginning in the upper left-hand corner of the 1-degree quadrangle, and the 2-1/2 minute quadrangles within the 7-1/2 minute quadrangle are similarly numbered. The first 2 digits of a well number identify the 1-degree quadrangle; the 3rd and 4th, the 7-1/2 minute quadrangle; the 5th digit identifies the 2-1/2 minute quadrangle; and the last 2 digits identify the well within the 2-1/2 minute quadrangle.

The individual wells used as control points on various illustrations have not been identified by well numbers in this report. However, by utilizing the 7-1/2 minute grid system shown on the maps, the reader can adequately identify the wells in the event additional information is needed from files of the Texas Water Commission.

## Acknowledgments

The reconnaissance studies were greatly facilitated by the aid and cooperation given by many individuals and organizations. Appreciation is expressed to the well drillers, consultants, officials of many municipalities, industries, governmental agencies, water improvement and conservation districts, geological societies, and well owners for their cooperation and contribution of data. Appreciation is also expressed to the many oil companies who not only supplied data on their water supplies, but also permitted the use of numerous electrical logs from their files which otherwise were not available.

Special acknowledgment is made to members of the U. S. Geological Survey for the data they furnished on parts of the Trinity River Basin. Grateful acknowledgment is expressed to William F. Guyton and Associates, consulting ground-water hydrologists, for their review and comments on this report.


Location of Well 57-15-701
57 1-degree quadrangle
15 7 1/2 minute quadrangle
7 2 1/2 minute quadrangle
01 Well number within 2 1/2 minute quadrangle
106°
103°
100°
97°
94°
36°
33°
30°
27°
1-degree Quadrangles
7 1/2-minute Quadrangles
2 1/2-minute Quadrangles

## Personnel

Initial planning for the reconnaissance fieldwork and the resulting report on the Trinity River Basin was done under the direction of L. G. McMillion, Director, Ground Water Division and under the general supervision of McDonald D. Weinert, former Chief Engineer.

This investigation was made by Engineering Services, Texas Water Commission, by Ground Water Division personnel under the general supervision of John J. Vandertulip, Chief Engineer, and L. G. McMillion, Director, Ground Water Division. The preparation of this report was under the direct supervision of Mervin L. Klug, former Assistant Director, Ground Water Division, and many of the methods and approaches used in the quantitative phase of the investigation are credited to him.

Fieldwork in the Trinity River Basin was done during the period September 1, 1959 to September 1, 1961. Basic data, from which this report was written, were collected and assembled by the following Texas Water Commission personnel for the areas indicated:

| Personnel | Counties worked |
|---|---|
| R. W. Harden<br>V. L. Souders | Montague, Cooke, Jack, Wise, Denton, Collin, Hunt, Parker, Tarrant, Dallas, Rockwall, Ellis |
| J. W. Dillard | Kaufman, Van Zandt, Henderson, Navarro |
| R. C. Peckham<br>J. T. Thornhill<br>G. H. Baum | Freestone, Anderson, Leon, Houston, Madison, Walker |
| B. B. Baker | Trinity |

## GEOGRAPHY

The physiographic expression of the Trinity River Basin ranges from treeless prairies to rolling timbered hills with altitudes ranging from sea level at the mouth of the Trinity River to about 1,400 feet in the upper reaches of the basin. The Planning Division of the Texas Water Commission has subdivided the Trinity River Basin into smaller drainage areas for water-resources planning. These subdivisions, which are numbered in accordance with numbers assigned by the Planning Division, are shown on Plates 1, 2, and 3.

The climate of the Trinity River Basin is characterized by hot summers and mild winters. Precipitation ranges from approximately 27 inches at the upper end of the basin to about 52 inches near the coast. Conversely, evaporation rates are lower near the coast and higher in the northwestern part of the basin. The average monthly rainfall for the period of record at selected stations in the Trinity River Basin is shown on Figure 3. Precipitation during the spring and summer months generally is in the form of scattered thunderstorms.

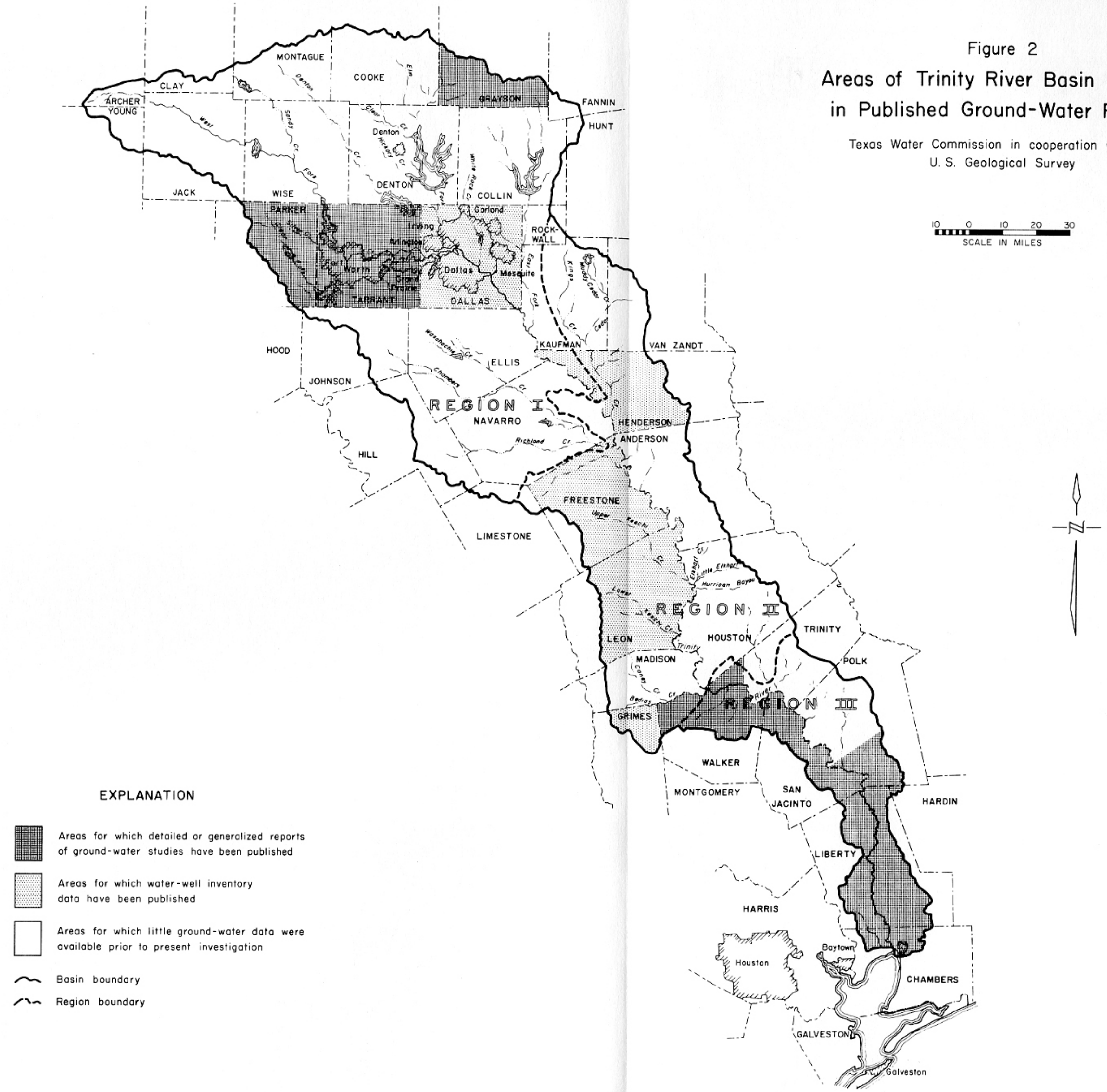



Figure 2
Areas of Trinity River Basin Included in Published Ground-Water Reports

Texas Water Commission in cooperation with the U. S. Geological Survey

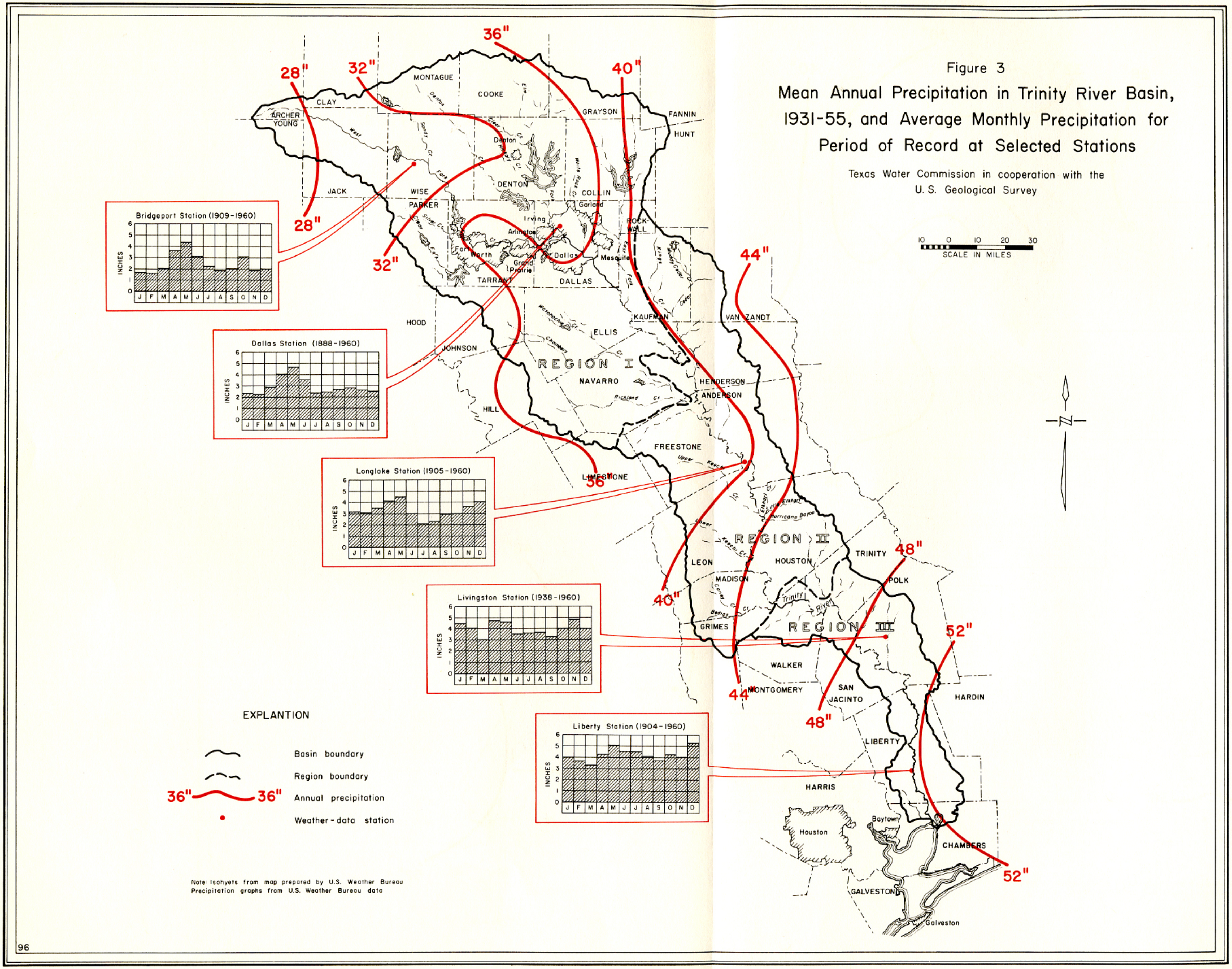



Figure 3

Mean Annual Precipitation in Trinity River Basin, 1931-55, and Average Monthly Precipitation for Period of Record at Selected Stations

Texas Water Commission in cooperation with the U. S. Geological Survey

During the fall and winter months, rainfall is more widespread and generally of longer duration. The highest rates of evaporation occur between March and October.

The population of the Trinity River Basin in 1960 was approximately 1,905,900 and represents nearly 20 percent of the State's total population. Eighty-four percent of the people lived in urban areas, which are defined as towns or concentrated areas of 2,500 or more inhabitants. The remainder of the population is classified as rural. Fifty-five cities with populations of 2,500 or more lie within or partly within the basin. The economy of the basin ranges principally from light industries in the urban areas to varying forms of agriculture in the rural areas. Oil and gas production scattered throughout the basin also contributes to the economy of the area.

The geography of each of the three regions of the Trinity River Basin, shown on Figure 1, is discussed at greater length in the following paragraphs.

## Region I

The physiographic expression of Region I is controlled chiefly by the types of rock appearing at the surface. These rocks crop out in a series of north-trending linear belts of alternating treeless prairies and rolling timbered hills. The prairies are smooth to slightly rolling, and the timbered hills are characterized by low rounded sandy hills and knobs, vegetated by post oak. The topography is more rugged and varied in the western part of the region with resistant rocks forming prominent westward-facing escarpments in some areas. The 10,388 square miles of Region I are dissected by numerous streams and tributaries of the Trinity River. The Trinity River and its major tributaries and the major drainage subdivisions in Region I are shown on Plate 1.

The average annual precipitation from 1931 to 1955 ranged from about 27 inches in the western part of the region to 41 inches in the eastern part. Figure 4 shows the average annual precipitation at Bridgeport from 1909 to 1960 and the average precipitation at Dallas from 1888 to 1960. The average monthly distribution of precipitation for the periods of record at the Bridgeport and Dallas weather stations are shown on Figure 3. The maximum rainfall in Region I occurs generally during the months of April, May, and June. Rainfall during the remainder of the year is fairly evenly distributed.

Approximately 1,763,000 people, or slightly more than 92 percent of the total population of the Trinity River Basin, reside in Region I. Of this amount, 88 percent live in urban areas having populations of more than 2,500. Most of the urban population is concentrated in the Dallas-Fort Worth metropolitan area.

The region has a diverse and productive economy and it comprises one of the more important economic sections of the State. The Dallas-Fort Worth area is highly industrialized and features a wide variety of products. It specializes particularly in light manufacturing and serves as a large wholesale and retail distribution center for the Southwest. Light industries are also located in many cities outside of the Dallas-Fort Worth metropolitan area. Agricultural products also are of primary importance to Region I. Numerous meat-packing plants are associated with the Fort Worth stockyards, which are the largest in

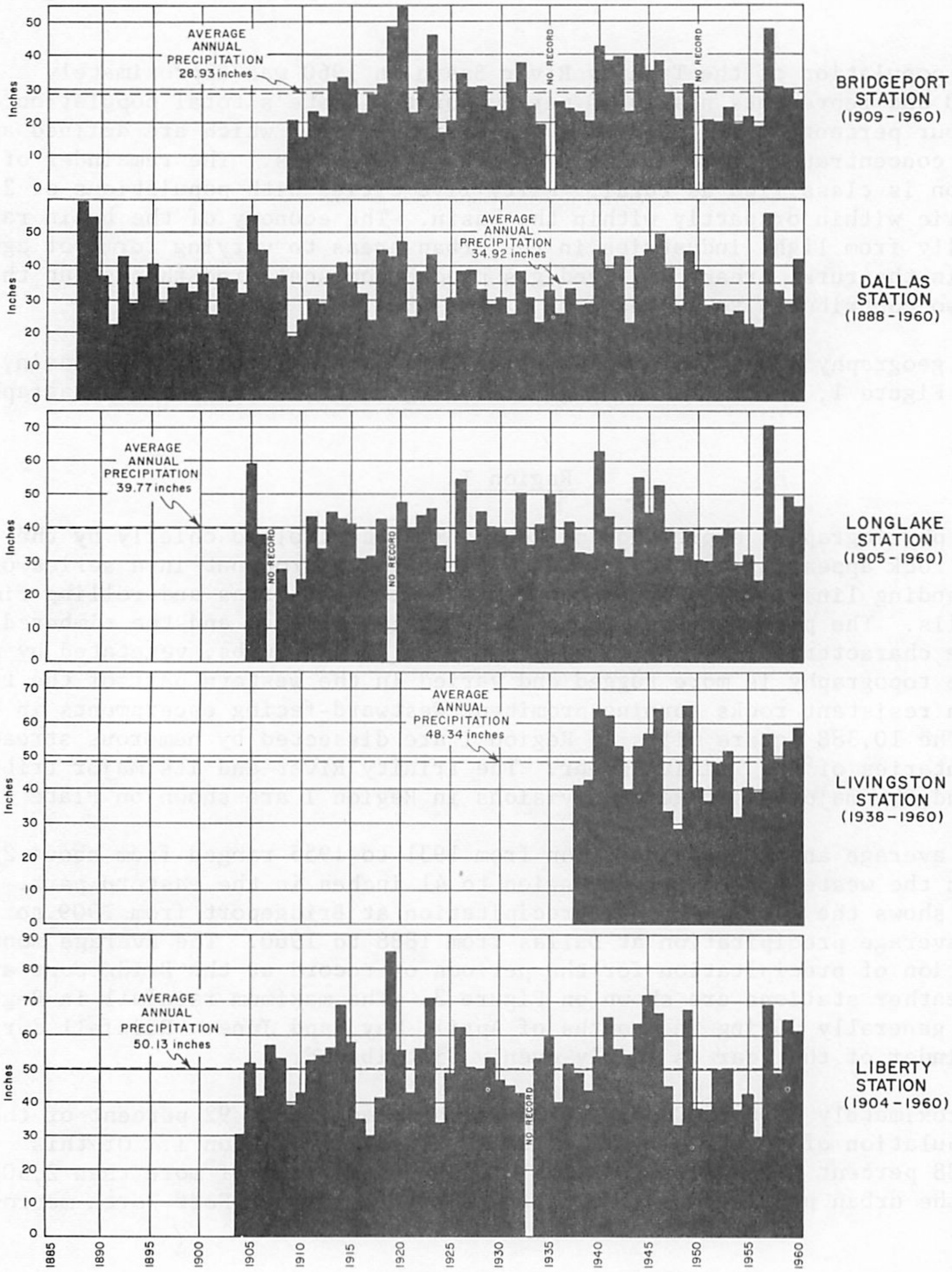



Figure 4

Annual Precipitation for Period of Record at Selected Stations in Trinity River Basin

(From U. S. Weather Bureau data)

Texas Water Commission in cooperation with the U. S. Geological Survey

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the State. The blackland prairie, one of the richest agricultural sections of the State, occupies the eastern third of the region. Agricultural products of the region include cotton, corn, sorghum, small grains, hay, livestock, poultry, and dairy products. The economy in sections of the region is generally derived from general farming, livestock raising, ranching, grain farming, and fruit and vegetable raising. Oil and gas production is important in the northwestern part of the region and in Navarro County.

## Region II

The extreme northern part of Region II, Kaufman and Van Zandt Counties and part of Henderson County, lies within the blackland prairie. The topography in this part of the region is flat to gently rolling. The remainder of the region lies principally in the East Texas timberland area, which is characterized by gently rolling to hilly topography. Small areas of prairie land occur in the southwest corner of the region. The 5,155 square mile area of Region II is drained by numerous streams and major tributaries of the Trinity River. The location of the Trinity River and its major tributaries in Region II is shown on Plate 2, together with the major drainage subdivisions.

The average annual precipitation from 1931 to 1955 ranged from about 38 inches in Freestone County to about 46 inches in Trinity County. Figure 4 shows the annual precipitation at the Long Lake Station from 1905 through 1960. Rainfall in Region II is fairly evenly distributed throughout the year. The wettest months are April, May, and December, and the driest are July and August. Distribution of precipitation is illustrated by the graph of average monthly precipitation at the Long Lake Station shown on Figure 3.

Only 5 percent of the basin's population, or about 95,100 inhabitants, reside in Region II. Nearly 70 percent of the region's population live in rural areas reflecting an agricultural type economy. The remaining 30 percent live in urban areas scattered throughout the region.

Agriculture and the oil and gas industry form the two most important segments of the region's economy. The blackland prairie in the northern part of the region supports general farming which produces cotton, grain, hay, livestock, poultry, and dairy products. The remainder of Region II is in the East Texas timberlands area. About 90 percent of this area is either pasture or woodland. The remaining 10 percent is devoted to general farming and other miscellaneous activities. The uplands produce timber, pasture, truck crops, corn, hay, and forage crops. The bottomlands are used for pastures, meadows, timber, corn, and cotton. Oil and gas production is scattered throughout Region II, and along with it are associated industries such as refineries and compressor stations. Only minor amounts of light manufacturing occur in the urban areas of the region.

## Region III

Most of Region III is in the East Texas timberlands area, which is characterized by gently rolling to hilly topography and heavily forested land. Chambers County and the lower part of Liberty County are in the coastal prairie area, where the land is flatter. The 2,387 square miles of Region III is drained by the Trinity River and its tributaries. The Trinity River and its major tributaries in Region III are shown on Plate 3 together with the region's major drainage subdivisions.

The average annual precipitation from 1931 to 1955 ranged from approximately 45 inches in Walker County to about 52 inches in Chambers County. Figure 4 shows the annual precipitation at the Livingston station for the years 1938 through 1960 and at the Liberty station for the years 1904 through 1960. The distribution of rainfall throughout the year is fairly even. Graphs showing average monthly precipitation for the period of record at the Livingston and Liberty stations are presented on Figure 3.

Region III has approximately 47,700 inhabitants, or slightly less than 3 percent of the total population of the Trinity Basin. About 60 percent of the people live in rural areas, and about 40 percent live in urban areas.

The economy of Region III is dependent principally on lumbering and pulpwood industries. In addition, oil, gas, and sulfur are produced in the lower part of the region. There are minor amounts of general farming, livestock raising, ranching, and grain farming. Truck crops, poultry, and dairy products also are associated with agricultural activities.

## GENERAL GEOLOGY

The present-day geology in the Trinity River Basin reflects the various depositional phases and environments that have taken place through geologic time. Those depositional phases most directly related to ground water in the basin occurred during Pennsylvanian, Cretaceous, Tertiary, and Quaternary geologic times.

During Pennsylvanian time, deposition of sediments in a large sea produced a sequence of marine and nearshore sand, shale, and limestone. Rocks of this age crops out at the surface in the northwestern part of the Trinity River Basin and have a general regional dip to the northwest.

After the deposition of Pennsylvanian sediments, uplifting occurred and the rocks were subjected to erosion. During Cretaceous time, typical nearshore sand and marine shale and limestone were deposited in the area now occupied by the Trinity River Basin on truncated rocks of pre-Cretaceous age. Sedimentary rocks of Cretaceous age are exposed at the surface in the northern part of the Trinity River Basin and dip in a generally eastward direction.

After the Cretaceous Period, which closed with uplifting of the area where Cretaceous rocks are now exposed and with continued subsidence of the Coastal Plain and Gulf of Mexico areas, sediments of Tertiary and Quaternary age were deposited. During the Tertiary and Quaternary Periods, an alternating sequence of marine and continental deposits was formed as a result of repeated transgression and regression of the sea. The marine sediments are characterized by clay, shale, and marl, with minor amounts of sand. Continental and nearshore deposits consist of sand and lesser amounts of clay, shale, and lignite. Rocks of Tertiary and Quaternary age crop out at the surface in most of Regions II and III, and dip generally southeast. Since the beginning of the Tertiary

Period, rocks in the Trinity River Basin have been eroded and modified by ancestral and present-day streams to produce the basin's present topographic expressions.

## Stratigraphy

The nomenclature of rock-stratigraphic units used in this report is in accordance with usage by The University of Texas Bureau of Economic Geology. The geographic names of the rock-stratigraphic units are in agreement with those recorded by the Geologic Names Committee of the United States Geological Survey, Washington, D. C.

The fresh water-bearing part of the stratigraphic section in the Trinity River Basin is composed of rocks ranging in age from Pennsylvanian to Recent. Table 1 shows the geologic units of this section from youngest to oldest, their approximate thickness, a brief description of their lithology, and a brief summary of their water-bearing properties. The location of the outcrop areas of various stratigraphic units listed in the table are shown on Plates 1, 2, and 3. Plate 4, a geologic section drawn generally along the axis of the Trinity River Basin, shows the stratigraphic position of these rocks in the subsurface.

## Structure

Rocks of Pennsylvanian age dip regionally toward the north and west. Within the Trinity River Basin, oil and gas in commercial quantities have accumulated along small structural features. The small structures, the generally low rock permeabilities, the lateral sedimentary changes, and the general dip in the opposite direction of the slope of the land surface have restricted the amount of water entering and moving through the Pennsylvanian rocks. The general lack of favorable hydrogeologic conditions limits their potential for ground-water development.

Cretaceous rocks dip east-southeast with the rate of dip increasing Gulfward. The land surface also slopes toward the Gulf of Mexico but at a lesser rate. This has facilitated the flushing of permeable beds deposited in brackish waters through the movement of fresh water entering the outcrop areas and being discharging at lower elevations downdip. The structural features of the Cretaceous rocks are shown by the various geologic sections presented on Figures 5 and 6 and on Plate 4.

At the time Eocene sediments were deposited, the area now occupied by Van Zandt, Henderson, Navarro, Freestone, and Leon Counties lay on the western edge of a structural feature known as the East Texas embayment. The axis of the embayment forms a gradually eastward curving arc extending northward from the mouth of the embayment in the north-central part of Houston County. The features of the structure as it exists in the Trinity River Basin are best illustrated by the contour lines on Plate 10 showing the top of the Carrizo Formation.

Rocks in the northern part of Region II dip eastward towards the East Texas embayment. In the southern part of Region II and in Region III the rocks dip southeastward toward the Gulf of Mexico. Continued subsidence and deposition of sediments in these areas caused the structural flexure and faulting commonly

Table 1.--Geologic units and their water-bearing characteristics, Trinity River Basin

| System | Series | Group | Stratigraphic unit | Approximate thickness (feet) | Character of rocks | Water-bearing characteristics |
|---|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | | Alluvium | 0- 50 | Unconsolidated, sand, silt, clay and gravel. | Yields small amounts of water in isolated areas of stream valleys. |
| | Pleistocene | | Beaumont Clay | 0-1,500 | Unconsolidated, sand, silt, and clay in upper part; thick basal sand, and clay with thin sand lenses in lower part. | Yields moderate to large amounts of water in Region III. |
| | | | Lissie Formation | 0-1,600 | Alternating thin to thick beds of sand, gravel, sandy clay, and clay. | Yields large amounts of water in Region III. |
| Tertiary | Pliocene(?) | | Willis Sand | 0- 400 | Sand and gravel interbedded with silt and clay. | Do. |
| | Pliocene | | Goliad Sand | 0- 500 | Sand, gravel, and lime-cemented sandstone interbedded with variegated clay; over-lapped by younger formations and does not crop out in the Trinity River Basin. | Do. |
| | Miocene(?) | | Lagarto Clay | 0-1,000 | Predominantly massive clay and sandy clay interbedded with sand and sandstone. | Yields moderate to large amounts of water in Region III. |
| | Miocene | | Oakville Sandstone | 0-1,650 | Predominantly sand and sandstone inter-bedded with clay and silt. | Do. |
| | Miocene(?) | | Catahoula Sandstone | 0-1,500 | Sand and clay; some volcanic ash and fuller's earth. | Do. |
| | Eocene | Jackson | | 0-1,200 | Sand, sandy shale, shale, and a few thin beds of limestone. | Yields small to moderate amounts of water on and near the outcrop. |
| | | Claiborne | Yegua Formation | 0-1,500 | Sand, sandy shale, shale, a few beds of limestone and lignite. | Do. |
| | | | Cook Mountain Formation | 0- 500 | Predominantly shale with some sand. | Yields small amounts of water from the sand sections on and near the outcrop. |
| | | | Sparta Formation | 0- 380 | Massive, poorly cemented sand in lower part; sands in upper part interbedded with clay and shale. | Yields moderate to large amounts of water in Region II. |
| | | | Mount Selman: Weches Formation | 0- 240 | Glauconitic sandstone and shale. | Not known to yield usable water in the basin. |
| | | | Mount Selman: Queen City Formation | 0- 460 | Micaceous sand with shale and sandy shale lenses and thin glauconitic sand layers. | Yields moderate amounts of water in Region II. |
| | | | Mount Selman: Reklaw Formation | 0- 310 | Shale with thin sand layers in upper part; yellow friable sandstone with glauconi-tic sandstone layers in lower part. | Yields only small amounts of water from the sands in and near the outcrop. |
| | | | Carrizo Formation | 0- 220 | Clean, fine to medium-grained sand with some thin interbedded shale. | Yields large amounts of water in Region II. |
| | | Wilcox | | 0-3,500+ | Interbedded sand and shale, and lignite beds. | Do. |

(Continued on next page)

Table 1.--Geologic units and their water-bearing characteristics, Trinity River Basin--Continued

| System | Series | Group | Stratigraphic unit | Approximate thickness (feet) | Character of rocks | Water-bearing characteristics |
|---|---|---|---|---|---|---|
| Tertiary | Eocene | Midway | | 0- 900+ | Massive shale with a few thin sand streaks and limestone beds. | Yields only small amounts of water from a limestone lentil in Limestone County. |
| Cretaceous | Gulf | Navarro | Kemp Formation | 0- 500 | Clay. | Not known to yield usable water in the basin. |
| | | | Nacatoch Formation | 0- 200 | Fine-grained sand and sandy clay. | Yields small to moderate amounts of water in and near the outcrop. |
| | | | Neylandville Formation | 0- 300 | Limestone, marl, and clay. | Not known to yield usable water in the basin. |
| | | Taylor | | 0-1,200 | Clay, marl, and chalk, with some sand and sandy marl. | Yields only small amounts of water in the outcrop. |
| | | Austin | | 0- 800 | Chalk, marl, and limestone. | Not known to yield usable water in the basin. |
| | | Eagle Ford | | 0- 640 | Shale with thin laminated beds of sandstone and limestone. | Yields only small amounts of poor quality water in the outcrop. |
| | | Woodbine | | 0- 500 | Ferruginous sand, sandstone, clay, and some lignite. | Yields moderate to large amounts of water in Region I. |
| | Comanche | Washita | | 0- 690 | Alternating shale, limestone, clay, and some sand. | Yields only small amounts of water in the outcrop. |
| | | Fredericks-burg | | 0- 370 | Shale, clay, marl, limestone, and shell agglomerate. | Not known to yield usable water in the basin. |
| | | Trinity | Trinity Group, undifferentiated | 0-1,200 | Coarse to fine-grained sand, shale, clay, and some gravel. | Yields moderate to large amounts of water in Region I. |
| | | | Paluxy Formation | 0- 450 | Fine-grained sand, sandy shale, shale, sand lenses, and anhydrite. | Yields moderate amounts of water in Region I. |
| | | | Glen Rose Formation | 0-1,000 | Dense to marly limestone, marl, shale, sand lenses, and anhydrite. | Yields small amounts of water in localized areas of Region I. |
| | | | Travis Peak Formation | 200-900 | Coarse-to fine-grained sand, shaly sand, and sandy shale; shale; varicolored shale and clay with some thin limestone lentils. | Yields large amounts of water in Region I. |
| Pennsyl-vanian | undifferentiated | | | | Shale, limestone, sandstone, and conglomerate. | Yields small to moderate amounts of water in localized areas of Region I. |

called the Luling-Mexia-Talco fault zone. This fault zone, which generally coincides with the common boundary of Region I and Region II, is shown on the geologic maps, Plates 1 and 2. Large oil and gas fields have been discovered along the faults.

The regional dip of all Tertiary and Quaternary rocks south of Leon County is to the southeast, with the rate of dip approximately 50 feet per mile near the outcrop. The rate of dip and thickness of the rock units increase downdip. The land surface also slopes Gulfward but at a lesser rate, resulting in older beds cropping out to the northwest of younger beds at progressively higher elevations. This provides favorable hydrologic conditions that permit flushing of the permeable beds of the Tertiary and Quaternary rocks, enabling them to contain fresh water for some distance downdip from their outcrop areas.

In addition to the Luling-Mexia-Talco fault zone, numerous smaller faults occurring throughout the basin and salt domes in Anderson, Freestone, and Leon Counties and in the lower Gulf Coast area reflect structural features of lesser areal extent that may affect the availability of fresh ground water. These minor features provide traps for oil and gas, which are produced at various points throughout the area.

The geologic section along the axis of the Trinity River Basin, shown on Plate 4, illustrates the general structural features of the various rock units along the axis of the basin.

## Fresh-Water Aquifers

An aquifer is defined as a geologic formation, a group of formations, or a part of a formation that is water bearing, and use of the term is usually restricted to those water-bearing units capable of yielding water in sufficient quantity as to constitute a usable supply. An impermeable formation, a geologic formation which is incapable of transmitting significant quantities of water, is called an aquiclude. Because of their varying abilities for supplying ground water, the aquifers of the State have been classified as major and minor water-bearing formations on a statewide basis.

A major water-bearing formation has been defined by the Texas Board of Water Engineers (1958, p. 33) as one which yields large quantities of water in large areas of the State. Five of the State's major water-bearing formations occur in the Trinity River Basin. They are the Trinity sands, the Carrizo-Wilcox sands, the Catahoula-Oakville-Lagarto sands, the Goliad-Willis-Lissie sands, and the Beaumont sands. A minor water-bearing formation has been defined as one which yields large quantities of water in small areas or relatively small quantities of water in large areas of the State. Three water-bearing formations of this classification occur in the Trinity River Basin. They are the Woodbine sands, Mount Selman sands, and the Sparta sands. In addition to the major and minor water-bearing formations of the State there are many water-bearing formations which yield small or moderate quantities of water and are of great importance locally.

Aquifers that are important on a statewide basis may or may not be of equal importance as a source of ground water in an individual river basin. Their importance in a river basin depends in large part on the amount of water they can

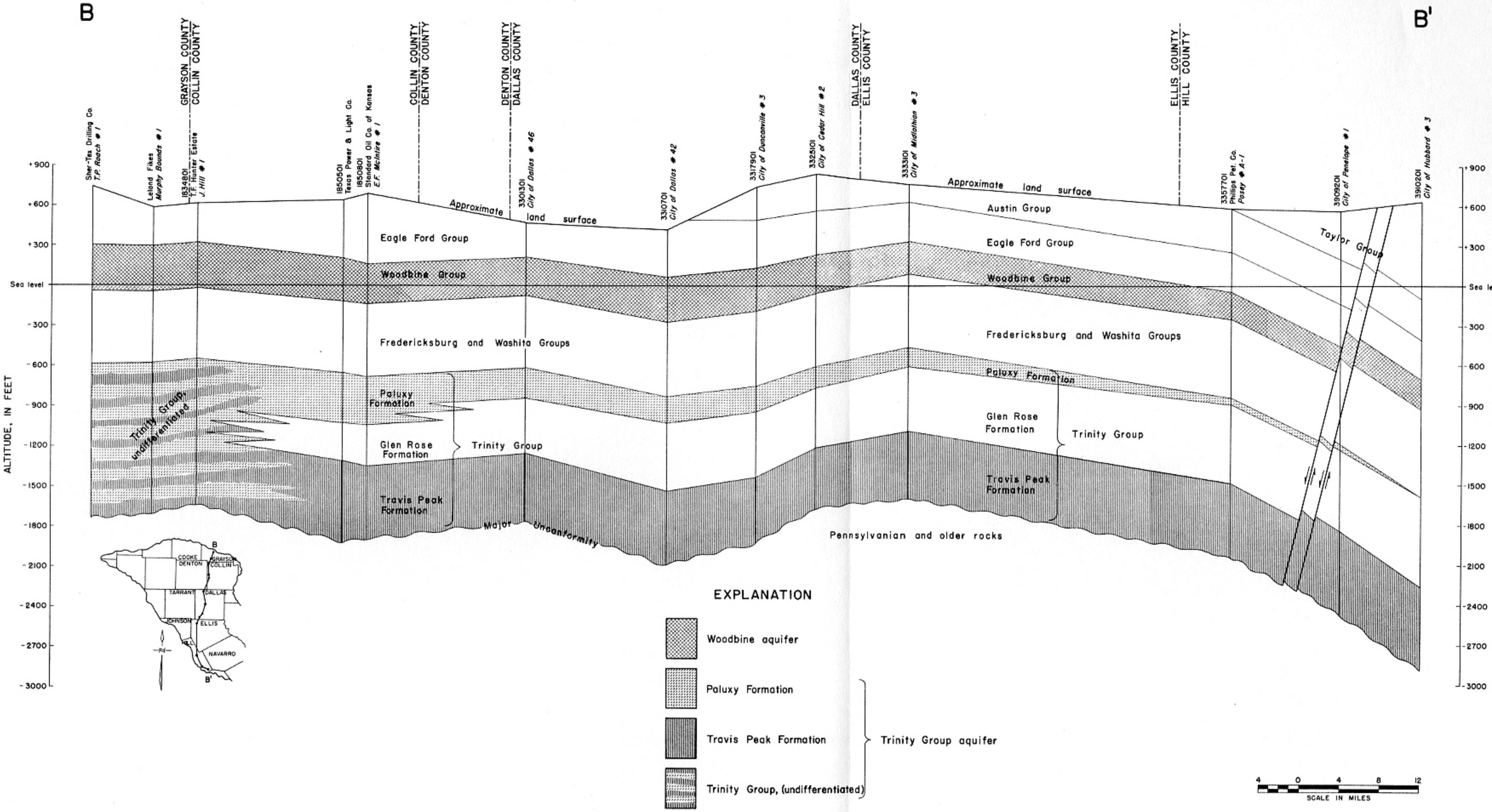


Figure 5

## Geologic Section B-B', Region I, Trinity River Basin

Texas Water Commission in cooperation with the U.S. Geological Survey

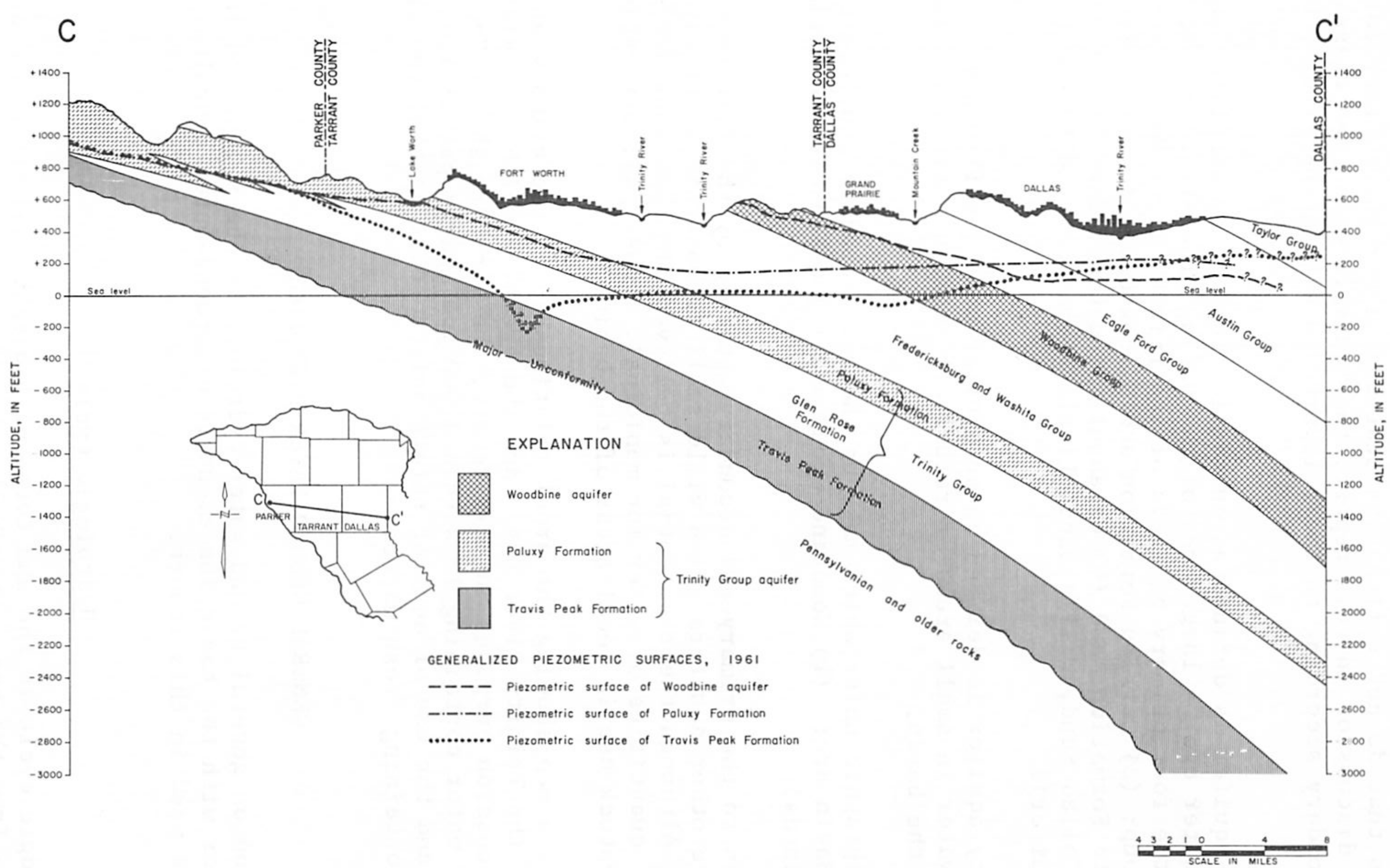


Figure 6

**Generalized Geologic Section C-C', Region I, Trinity River Basin**

Texas Water Commission in cooperation with the U.S. Geological Survey

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supply in relation to the total amount of available ground water that can be developed in the basin. An aquifer that is important on a statewide basis may have within a river basin, limited areal extent or unfavorable hydrogeologic characteristics that do not reflect its statewide importance. Therefore, for the purpose of discussion in this report, the aquifers have been classified as primary or secondary according to their importance within the Trinity River Basin.

A primary aquifer is defined as an aquifer capable of supplying large quantities of water over a large area of the basin. The stratigraphic units which make up the four primary aquifers of the Trinity River Basin are: (1) Trinity Group; (2) Carrizo Formation and Wilcox Group (Carrizo-Wilcox aquifer); (3) Sparta Formation; and (4) Catahoula Sandstone, Oakville Sandstone, Lagarto Clay; Goliad Sand, Willis Sand, Lissie Formation; and Beaumont Clay (Gulf Coast aquifer).

A secondary aquifer is defined as an aquifer capable of supplying large quantities of water in small areas or relatively small quantities of water in large areas of the basin.

The stratigraphic units which make up the two secondary aquifers of the Trinity River Basin are: (1) Woodbine Group and (2) Queen City Formation (Mount Selman sands).

In addition to the primary and secondary aquifers of the Trinity River Basin, there are other aquifers which yield small to moderate quantities of water locally. Although their potential is believed limited, they are currently supplying small quantities of water for municipal, industrial, irrigation, domestic and livestock use in local areas of the basin.

Figure 7 is a map showing the areal relationship of the primary and secondary aquifers of the Trinity River Basin and the areas in which they yield fresh water. For discussion purposes in this report, the term "fresh" or "usable" water refers to water containing less than 3,000 ppm (parts per million) dissolved solids, and the use of aquifer refers only to that part of the stratigraphic units containing fresh water.

## GENERAL GROUND-WATER HYDROLOGY

This section on general ground-water hydrology has been included to acquaint the reader with the basic fundamentals of ground-water hydrology and to define the terms used in this report.

### Hydrologic Cycle

The hydrologic cycle is the sum total of processes and movements of the earth's moisture from the sea, through the atmosphere, to the land, and eventually, with numerable delays en route, back to the sea. Figure 8 illustrates a number of the courses which the water may take in completing the cycle. All water occurring in the Trinity River Basin, whether surface water or ground water, is derived from precipitation. Moreover, precipitation in this area is derived for the most part from water vapor carried inland from the Gulf of Mexico.

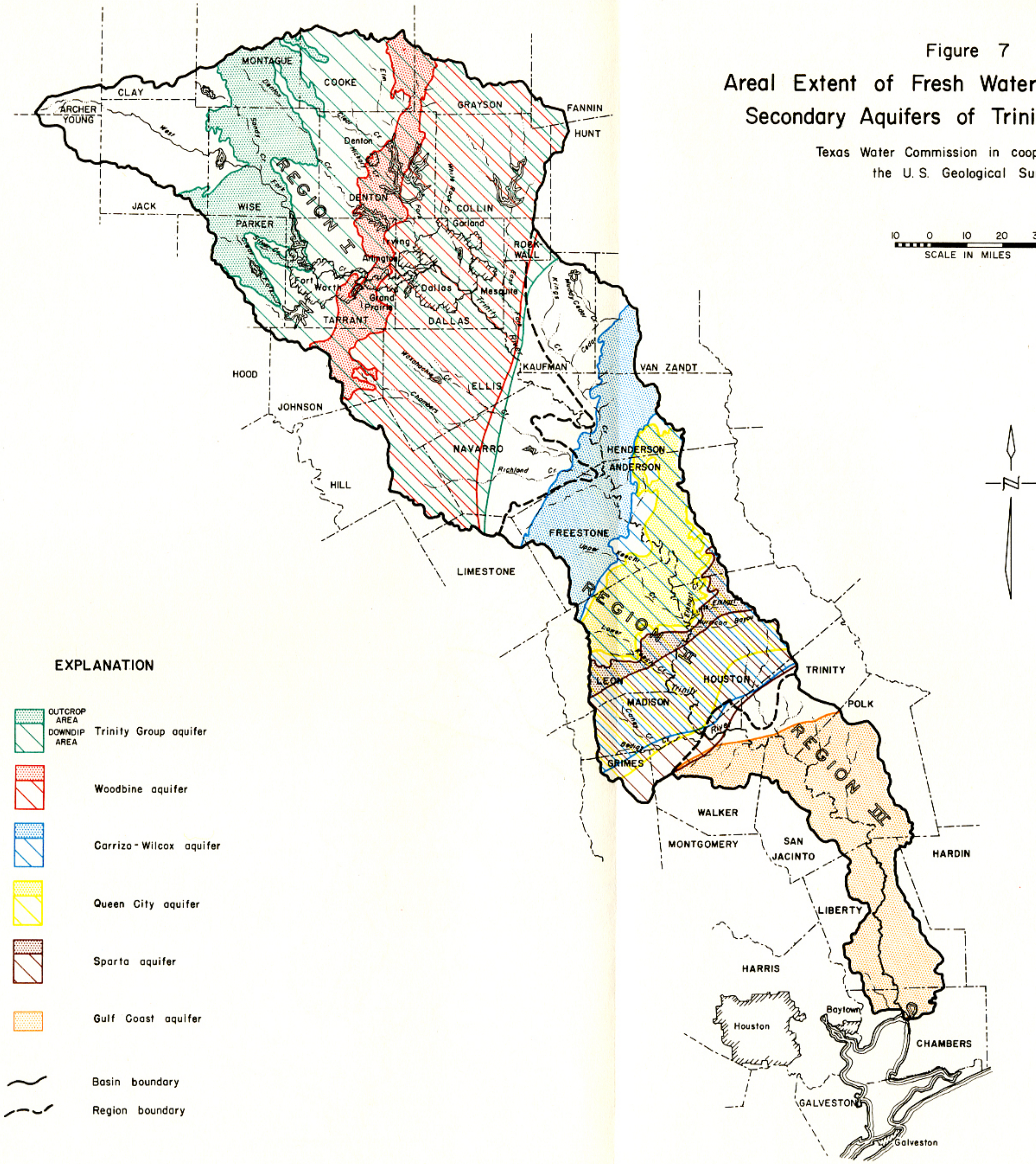


Figure 7

Areal Extent of Fresh Water in Primary and Secondary Aquifers of Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

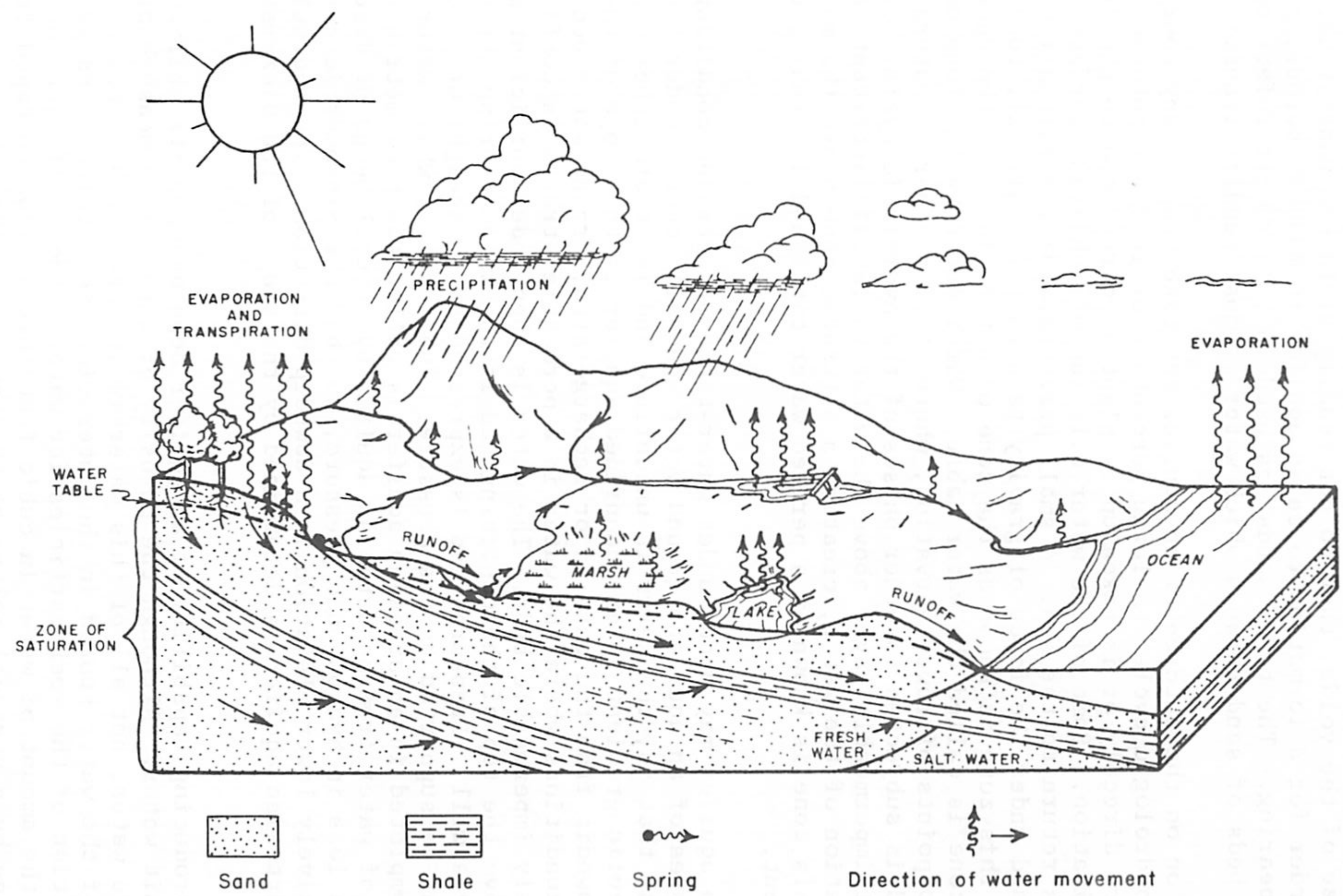


Figure 8

The Hydrologic Cycle in the Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

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## Occurrence and General Hydraulics

Ground water is contained in the interstices or voids of pervious strata. Two rock characteristics of fundamental importance in the occurrence of ground water are porosity, the amount of open space contained in the rock, and permeability, which is the ability of the porous material to transmit water. Fine-grained sediments, such as clay and silt, commonly have high porosity, but owing to the small size of the voids, they do not readily yield or transmit water. Therefore, in order for a formation to be an aquifer it must be porous, permeable, and water-bearing. The term "sands" as used in this report refers to distinct layers or beds of sand through which water is most readily transmitted.

Precipitation on the outcrop of an aquifer may take one of many courses in completing the hydrologic cycle. A large percentage of it is evaporated back to the atmosphere directly or is taken up by plants and returned to the atmosphere by transpiration. Some of the water will run off the land surface into streams and thus return to the sea. A small percentage of the rainfall will percolate downward under the force of gravity to a zone in which all rock voids are saturated. This zone is known as the zone of saturation, and the upper surface of the zone is called the water table. Water entering the zone of saturation moves to points of lower elevation, where it is discharged naturally or artificially and is subjected to other phases of the hydrologic cycle. Occasionally a local impermeable layer above the water table will intercept the downward percolation of the water, creating a saturated zone above the main water table. This zone is known as a perched water table and is usually of small areal extent.

Water in an aquifer may occur under water-table or artesian conditions. In the outcrop area of an aquifer, ground water generally occurs under water-table conditions; that is, the water is unconfined and is at atmospheric pressure. The hydraulic gradient in an unconfined aquifer is the slope of the water table. Downdip from the outcrop or recharge area, ground water occurs under artesian conditions where the water in a permeable stratum is confined between relatively impermeable beds. The water is then under sufficient pressure to rise above the top of the confining bed if the water-bearing stratum is penetrated by a well. Pressure head is expressed as the height of a column of water that can be supported by the pressure. The level to which water will rise in wells completed in an artesian aquifer is called the piezometric surface. The loss of water from an artesian aquifer by natural means of discharge downdip causes a loss in hydrostatic pressure, so that the piezometric surface is at a progressively lower elevation in a downdip direction. The hydraulic gradient of an artesian aquifer is determined by the slope of the piezometric surface.

The water-producing capability of an aquifer depends upon its ability to store and transmit water. Although the porosity of a rock is a measure of its capacity to store water, not all of this water in storage may be recovered by pumping. Some of the water stored in the interstices is retained because of molecular attraction of the rock particles for water. The coefficient of storage is equal to the amount of water in cubic feet that will be released from or taken into storage by a vertical column of the aquifer having a base 1 foot square when the water level or hydrostatic pressure is lowered or raised 1 foot. In an aquifer under water-table conditions, the coefficient of storage is essentially equal to the specific yield, which is the ratio of the volume of water a saturated material will yield under the force of gravity to the total volume of material drained. In an artesian aquifer, ground water is withdrawn from storage without draining the water-bearing rocks. As water is pumped from the artesian aquifer the hydrostatic pressure is lowered. The weight of the overlying sediments, which were partially supported by the hydrostatic pressure, compresses the water-bearing material and the confining media, and the water expands, causing some water to be released from storage.

The quantity of water the aquifer receives as recharge and the ability of the aquifer to transmit water to the areas of discharge are the principal factors that must be considered in determining the amount of water available for withdrawal on a sustained basis. The coefficient of transmissibility provides an index of an aquifer's ability to transmit water. It is defined as the amount of water in gallons per day that will pass through a vertical strip of the aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot. By using the coefficient of transmissibility, the amount of water that will pass through an aquifer under various hydraulic gradients can be determined. The coefficient of permeability is defined as the quantity of water in gallons per day that will pass through a section of the aquifer 1 foot square under a hydraulic gradient of 1 foot per foot. It may be determined by dividing the coefficient of transmissibility by the thickness of the aquifer, in feet.

The coefficients of storage and transmissibility are determined from pumping tests of wells which screen a water-bearing formation. The term "screen" is used to define the zone or zones in the casing that are open to the aquifer by means of well screens or other similar openings through which water enters the well. A pumping test consists of pumping a well at a constant rate for a period of time and making periodic measurements of water levels in the pumping well and, if possible, in one or more observation wells. The recovery of the water level is also measured after pumping stops. From the data obtained, the coefficients of transmissibility and storage can be calculated by means of certain formulas. In general, the coefficient of storage can be determined if data are obtained from one or more observation wells. The coefficients of transmissibility and storage may be used in computing the effects that pumping from a well will have on water levels in the aquifer at various times and at various distances from the pumped well. The coefficients also can be used in computing the quantity of water that will flow through a given section of the aquifer and in estimating the availability of water from storage. A general indication of the hydraulic characteristics of an aquifer is provided by the specific capacity of a well. The specific capacity of a well is defined as the gallons per minute a well will yield for each foot of water-level drawdown that has occurred at the end of a period of time during which the well has been pumped at a constant pumping rate. However, the type of well construction and the thoroughness of well development also have an effect on the well's specific capacity that is not directly related to the aquifer's hydraulic characteristics.

## Recharge, Discharge, and Movement

Recharge is the addition of water to an aquifer. The principal source of ground-water recharge in the Trinity River Basin is precipitation which falls on the outcrop of the various aquifers. In addition, seepage from streams and lakes located on the outcrop and possibly interformational leakage are sources of ground-water recharge. Recharge is a limiting factor in the amount of water that can be developed from an aquifer, as it must balance discharge over a long period of time or the water in storage in the aquifer will eventually be depleted. Among the factors which influence the amount of recharge received by an aquifer are: the amount and frequency of precipitation; the areal extent of the outcrop or intake area; topography, type and amount of vegetation, and the condition of soil cover in the outcrop area; and the ability of the aquifer to accept recharge and transmit it to areas of discharge.

Discharge is the loss of water from an aquifer. The discharge may be either artificial or natural. Artificial discharge takes place from flowing and pumped water wells, drainage ditches, gravel pits, and other forms of excavations that intersect the water table. Natural discharge occurs as effluent seepage, springs, evaporation, transpiration, and interformational leakage.

Ground water moves from the areas of recharge to areas of discharge or from points of higher hydraulic head to points of lower hydraulic head. Movement is in the direction of the hydraulic gradient just as in the case of surface-water flow. Under normal artesian conditions, movement of ground water usually is in the direction of the aquifer's regional dip. Under water-table conditions, the slope of the water table and consequently the direction of ground-water movement usually is closely related to the slope of the land surface. However, in the case of both artesian and water-table conditions, local anomalies are developed in areas of pumping and some water moves toward the point of artificial discharge. The rate of ground-water movement in an aquifer is usually very slow, being in the magnitude of a few feet to a few hundred feet per year.

## Fluctuations of Water Levels

Changes in water levels are due to many causes. Some are of regional significance whereas others are extremely local. The more significant causes of water-level fluctuations are changes in recharge and discharge. When recharge is reduced, as in the case of a drought, some of the water discharged from the aquifer must be withdrawn from storage and water levels decline. However, when adequate rainfall resumes, the volume of water drained from storage in the aquifer during the drought may be replaced and water levels will rise accordingly. When a water well is pumped, water levels in the vicinity are drawn down in the shape of an inverted cone with its apex at the pumped well. The development or growth of this cone depends on the aquifer's coefficients of transmissibility and storage, and on the rate of pumping. As pumping continues the cone expands and continues to do so until it intercepts a source of replenishment capable of supplying sufficient water to satisfy the pumping demand. This source of replenishment can be either intercepted natural discharge or induced recharge. If the quantity of water received from these sources is sufficient to compensate for the water pumped, the growth of the cone will cease and new balances between recharge and discharge are achieved. In areas where recharge or salvagable natural discharge is less than the amount of water pumped from wells, water is removed from storage in the aquifer to supply the deficiency and water levels will continue to decline.

Where intensive development has taken place in ground-water reservoirs, each well superimposes its own individual cone of depression on that for the neighboring well. This results in the development of a regional cone of depression. When the cone of one well overlaps the cone of another, interference occurs and an additional lowering of water levels occurs as the wells compete for water by expanding their cones of depression. The amount or extent of interference between cones of depression depends on the rate of pumping from each well, the spacing between wells, and the hydraulic characteristics of the aquifer in which the wells are completed.

Water levels in some wells, especially those completed in artesian aquifers, have been known to fluctuate in response to such phenomna as changes in barometric pressure, tidal force, and earthquakes. However, the magnitude of the fluctuations are usually very small.

## GENERAL CHEMICAL QUALITY OF GROUND WATER

All ground water contains dissolved minerals. The kind and concentration of these depend upon the environment, movement, and source of the ground water. Water has considerable solvent power which dissolves mineral matter from the soil and the component rocks of the aquifer as it passes through them. The amount that is dissolved depends on the solubility of the minerals which are present, the length of time the water is in contact with the rocks, and the amount of dissolved carbon dioxide contained in the water. The concentrations of dissolved minerals in water generally increase with depth and are greater in stratigraphic units where ground-water circulation is restricted. In most stratigraphic units whose sediments were deposited in brackish water, the flushing action of fresh water moving through the aquifers has not been complete throughout the strata. Therefore, at some distance downdip and in some cases in limited areas, highly mineralized water is encountered.

In addition to natural mineralization of water, the quality of water also can be affected by man. Contamination can occur from the disposal of industrial waste into improperly completed or faulty disposal pits and disposal wells. Inadequate plugging of test holes and severe corrosion of well casing permits highly mineralized water to enter and contaminate fresh-water aquifers. The quality of water in an individual water well can be affected by the well's construction through improper casing or cementing, which allows water of poor quality to enter the well or move into a fresh-water aquifer having a lower hydrostatic head. Contamination also can occur through the improper disposal of wastes either into the ground or into surface streams which may provide recharge to ground-water aquifers.

The chemical quality of uncontaminated ground water, unlike that of surface water, remains relatively constant at all times. This, in addition to its relatively constant year-round temperature, makes ground-water supplies highly desirable for many uses.

### Standards

The principal mineral constituents found in ground water are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, silica, iron, manganese, nitrate, fluoride, and boron. Water used for municipal supplies should be colorless, odorless, palatable, and wherever possible be within the limits set by the U. S. Public Health Service (1962, p. 2152-2155) for drinking water used on interstate carriers. Some of these standards, in parts per million, are as follows:

| | |
|---|---|
| Chloride (Cl) | 250 |
| Fluoride (F) | (*) |
| Iron (Fe) | 0.3 |
| Manganese (Mn) | 0.05 |
| Nitrate ($NO_3$) | 45 |
| Sulfate ($SO_4$) | 250 |
| Total dissolved solids | 500 |

* When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit in the following table.

| Annual average of maximum daily air temperatures (°F) | Recommended control limits (Fluoride concentrations in ppm) | | |
|---|---|---|---|
| | Lower | Optimum | Upper |
| 50.0 - 53.7 | 0.9 | 1.2 | 1.7 |
| 53.8 - 58.3 | .8 | 1.1 | 1.5 |
| 58.4 - 63.8 | .8 | 1.0 | 1.3 |
| 63.9 - 70.6 | .7 | .9 | 1.2 |
| 70.7 - 79.2 | .7 | .8 | 1.0 |
| 79.3 - 90.5 | .6 | .7 | .8 |

The above limits are desirable for municipal use, but it is realized that many supplies which cannot meet these standards must be used for the lack of a more suitable supply. Many supplies failing to meet all these standards have been in use for long periods of time without any apparent ill effects on the user. Maxey (1950, page 271) states that water having a nitrate content in excess of 45 ppm should be regarded as unsafe for infant feeding. The presence of large quantities of nitrate may indicate pollution. Water containing more than 0.3 ppm iron and manganese combined is likely to cause objectionable staining of laundered clothes and plumbing fixtures.

Hardness of water is an important factor in domestic, municipal, and industrial supplies. The principal constituents causing hardness of water are calcium and magnesium. Water hardness is expressed in parts per million as calcium carbonate. An increase in hardness causes an increase of soap consumption in washing and laundering processes, and the formation of scale in boilers and other equipment. A generalized classification for hardness, which is useful as an index to the analyses of water, is as follows: less than 60 ppm, soft; 61 to 120 ppm, moderately hard; 121 to 200 ppm, hard; and more than 200 ppm, very hard.

The tolerance in chemical quality of water for industrial use differs widely for different industries and different processes. One of the major items of concern to most industries is the development of water supplies which do not contain corrosive or scale-forming constituents that affect the efficiency of their boilers and cooling systems. Hardness, along with excessive amounts of silica and iron, cause scale deposits which clog lines and reduce efficiency of heat-exchange apparatus. Suggested water-quality tolerances for a number of industries (Moore, 1940, page 271) are presented by Hem (1959, page 253).

There are a number of factors involved in determining the suitability of water for irrigation purposes. The type of soil, adequacy of drainage, types of crops, climatic conditions, and the quantity of water used all have an important bearing on the continued productivity of irrigated acreages. According to a report by the U. S. Salinity Laboratory Staff (1954, page 69), the characteristics of water that are important in determining its suitability for irrigation are: (1) Total concentration of soluble salts, expressed in terms of specific conductance, (2) the relative proportion of sodium to the other principal cations (magnesium, calcium, and potassium), expressed as percent sodium or sodium-adsorption ratio (SAR), (3) residual sodium carbonate (equivalents per million of carbonate in excess of calcium and magnesium), and (4) concentrations of boron or other elements that may be toxic. The report also includes a method for classifying irrigation waters.

## Treatment

Many waters of substandard quality can be made usable by various treatment methods. These include dilution (blending of poor and good quality waters to achieve an acceptable quality), softening, aeration, filtering, cooling, and the addition of various chemical additives. The limiting factor in water treatment is one of economy. Treatment processes for ground water need not be designed to handle a large variation in quality.

# OCCURRENCE AND AVAILABILITY OF GROUND WATER

The aquifers of the Trinity River Basin are discussed on a regional basis, starting with Region I. The primary aquifers of each region are discussed first, the secondary aquifers next, and other aquifers of limited significance are noted briefly at the end of the discussion for each region.

## Region I

The primary aquifer in Region I of the Trinity River Basin is the Trinity Group. The secondary aquifer in this region is the Woodbine Group. The areal extent of fresh water in the primary and secondary aquifers is shown on Figure 7. Other aquifers that presently supply small amounts of water for municipal, industrial, irrigation, and domestic and livestock use have a limited potential for further development. These other aquifers are rocks of Pennsylvanian age (undifferentiated), Nacatoch Formation, and alluvium.

### Primary Aquifers

#### Trinity Group Aquifer

The Trinity Group has been divided into the Trinity Group, undifferentiated, and the Travis Peak, Glen Rose, and Paluxy Formations for the purpose of ground-water discussion. However, the availability of water for development is estimated for the Trinity Group as a single combined aquifer because of the geologic and hydraulic interrelationships of the units comprising the aquifer.

The Trinity Group crops out at the surface in the northwestern part of Region I, as shown on Plate 6. In the southern two-thirds of Region I, the sands of the Trinity Group are separated by the Glen Rose limestone into two hydrologic units. This separation is illustrated by the geologic sections B-B' and C-C' (Figures 5 and 6).

In this report, the sands of the Trinity Group north of the northern limit of the Glen Rose limestone are termed Trinity sands and constitute the Trinity Group, undifferentiated. The part of the Trinity Group below the Glen Rose constitutes the Travis Peak Formation, and the part above the Glen Rose constitutes the Paluxy Formation.

The northern limit of the Glen Rose is difficult to define because it is a transitional zone. Consequently, this limit is arbitrary and no two persons would likely agree on its placement. (See Hendricks, 1957, for a discussion of the Glen Rose transition.) The basis for its delineation in this report is primarily the thickness of the limestone. When the Glen Rose is sufficiently thick and continuous to permit its being picked on electric logs as a unit rather than as limestone lentils, the hydraulic continuity of water in the Trinity Group is probably restricted, and separate hydrologic units exist. However, these separate units display a hydraulic relationship, especially near the updip edge of the Glen Rose. The effects of the Glen Rose on ground-water movement and quality and on the hydraulic characteristics of the aquifer have not been fully evaluated.

Trinity Group, Undifferentiated

<u>Geologic Characteristics</u>.--The Trinity Group, undifferentiated, consists chiefly of fine-grained quartz sand occurring in lenses or layers which are as much as 50 feet thick. Minor amounts of coarse sand and gravel occur in the Trinity, especially near the base. Clay and shale lenses interfinger with the sand lenses, and gradations from sand to clay occur laterally and vertically.

The location and extent of the Trinity Group, undifferentiated, the entire Trinity Group aquifer updip from the northern limit of the Glen Rose, is shown on Plates 5 and 6. As shown by the contour lines drawn on the top of the Trinity Group, Plate 5, the Trinity Group, undifferentiated, dips in an east-southeast direction at rates ranging from less than 30 feet per mile near the outcrop to more than 70 feet per mile in Grayson County. The thickness of the unit ranges from zero at the updip edge of the Trinity Group outcrop to nearly 1,200 feet in the extreme northeastern part of Region I, as shown on Plate 6. Electric logs show that from 50 to 75 percent, or an average of about 60 percent, of the unit's total thickness is composed of water-bearing sands. The basal part of the Trinity contains the more massive and productive sands. Depths to the top of the Trinity Group, undifferentiated, range from zero at the edge of the outcrop to approximately 2,100 feet in southeastern Grayson and southwestern Fannin Counties, as shown generally on Plate 5.

Occurrence and Movement of Ground Water.--Ground water in the Trinity Group, undifferentiated, occurs under both water-table and artesian conditions. In the outcrop and for a short distance downdip, the Trinity is not completely saturated and water-table conditions exist.

Pumping levels in the vicinity of Gainesville, Cooke County, are below the top of the aquifer. However, the static water levels in wells in Gainesville are slightly above the top of the aquifer, and artesian conditions prevail. Northwest of the city, water levels are slightly below the top of the aquifer, and water-table conditions prevail.

In Denton, Denton County, the aquifer is at a greater depth and water in the Trinity Group, undifferentiated, being under artesian pressure, will rise about 260 feet above the top of the aquifer. Sufficient data are not available to determine with certainty where water-table conditions cease and artesian conditions begin. Apparently, artesian conditions prevail east and downdip from a general north-trending line parallel with the outcrop and passing through central Cooke and western Denton Counties.

Data concerning the movement of ground water are scarce. The water moves generally in an easterly direction approximately at right angles to the strike of the beds. Local variations in the direction of movement result from cones of depression that have been developed by pumping. The rate of ground-water movement is not known, but the hydraulic characteristics of the water-bearing materials indicate that the rate of ground-water movement outside the area of pumping is slow, probably on the order of a few feet to a few tens of feet per year. This rate of ground-water movement probably is applicable also to the Travis Peak and Paluxy Formations of the Trinity Group aquifer.

Recharge and Discharge.--Recharge to the Trinity Group, undifferentiated, occurs in the outcrop of Trinity Group in Region I, shown on Plate 5, and in the Trinity Group outcrop in adjoining basins. The outcrop is a region of sandy, rolling hills vegetated largely by post oak, and the soils are fairly permeable. Thus, precipitation falling on the outcrop and water from streams flowing over the outcrop readily enters the sands and recharges the Trinity Group, undifferentiated.

The sandy soils and vegetative cover in the recharge area are helpful in retaining rainfall and aiding infiltration. About 32 inches of precipitation falls in this locality annually and the amount of water received as recharge is more than adequate to supply present (1960) pumpage from the unit. The outcrop of the Trinity Group, undifferentiated, which is coterminous with the Trinity Group aquifer outcrop except in part of Parker and Tarrant Counties in Region I, also serves as a recharge area for the Travis Peak Formation and the Paluxy Formation of the aquifer.

Ground-water discharge occurs naturally by seepage springs in the outcrop and by upward leakage through confining beds downdip. Also, ground water contributes to the flow of Clear Creek, Denton Creek, Elm Fork of the Trinity River, and West Fork of the Trinity River in the outcrop at certain times of the year.

Pumping from wells constitutes the artificial discharge from the Trinity Group, undifferentiated. Many towns obtain their water supplies from this unit, although the only large concentrated withdrawal of water is at Gainesville in Cooke County.

Water Levels.--Depths to static water levels range from the surface in some parts of the outcrop to more than 320 feet below the surface at Gainesville. Fluctuations of water levels are due mainly to seasonal variations in pumpage and, to a lesser degree, to variations in rainfall and evapotranspiration.

Harden (1960, p. 7) shows that water-level declines of 55 to 80 feet occurred in various wells in the Gainesville area from 1942 to 1960. Depths to water measured in two wells in the outcrop area in southeastern and eastern Montague County indicate that there has been no significant change in water levels in this area. Measurements of water levels in the municipal wells at Denton show that an increase in artesian head has occurred since the city stopped using ground water as the sole source for its public supply. In general, available data indicate that water levels in the Trinity Group, undifferentiated, are stable or even rising except in the Gainesville area.

Water-Bearing Characteristics.--The Trinity Group, undifferentiated, is characterized by fine sand of fairly low permeability. Coefficients of transmissibility determined from pumping tests vary over the area. Some of the causes of variance are lensing and interbedding of sand and clay; variations in the amount and part of the formation screened by the wells; variations in sorting, deformation, and cementation of sand; and differences in methods and duration of pumping tests.

Results of pumping tests made by the Texas Water Commission and information reported by consultants and others show that coefficients of transmissibility in the Gainesville area of Cooke County range from 11,000 to 17,000 gpd/ft. (gallons per day per foot), and at Denton, Denton County, they range from 4,600 to 6,800 gpd/ft. The higher transmissibility figures obtained in the vicinity of Gainesville apparently result from screening sands in the basal part of the unit. In the wells tested at the City of Denton, basal sands are not screened.

In the vicinity of Sherman, which lies a few miles outside the Trinity River Basin in Grayson County, the coefficients of transmissibility from tests of four wells that screen large sections of the Trinity Group, undifferentiated, averaged 2,800 gpd/ft. (Baker, 1960, p. 48). In this area, a coefficient of transmissibility of 1,600 gpd/ft. was obtained from a test of one well, which screened 560 feet of the Trinity Group, undifferentiated, from near the top of the section to near the base. This indicates that a substantial reduction in transmissibility occurs to the northeast beyond the limits of the Trinity River Basin. No pumping-test data are available for the Trinity Group, undifferentiated, in Grayson County within the basin.

Coefficients of permeability range from about 5 gpd/ft.$^2$ in the vicinity of Sherman to more than 100 gpd/ft.$^2$ in the Gainesville area. Comparison of the tests at Denton and Gainesville indicates that the upper sands of the Trinity Group, undifferentiated, are not as permeable as the basal sands.

The coefficient of storage reported for a test made at the City of Denton was 0.000065. Baker (1960, p.48) shows coefficients of storage of 0.00008 and 0.00002 obtained from tests at Sherman in Grayson County. These coefficients are on the order of magnitude normally obtained from tests made of these sands where the water is under artesian pressure. Coefficients of storage for these sands under water-table conditions would be much larger.

The amount that water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time is shown by the distance-drawdown graph on Figure 9. The distances are measured along a line parallel with the outcrop area and passing through the pumped well. The coefficient of transmissibility of 10,000 gpd/ft. used in preparing the graph is believed to be generally applicable for the Trinity Group, undifferentiated, between Gainesville and Denton if the basal sands are screened in the wells. It may be applicable also in other parts of Region I. The pumping rate used for computing drawdowns was 350 gpm (gallons per minute) or approximately half a million gallons per day. Drawdowns for higher or lower pumping rates can be determined by applying the ratio of the pumping rates to the drawdown shown for 350 gpm. Thus, the drawdown at a given distance from a well pumping 700 gpm would be twice the amount shown by the graph of Figure 9.

Chemical Quality.--Water from the Trinity Group, undifferentiated, is a sodium bicarbonate type of good quality, which is fairly uniform in quality over the area. Dissolved solids generally range from 400 to 600 ppm (parts per million). Of 50 water samples collected from different wells and analyzed for dissolved solids, 21 contained less than 500 ppm dissolved solids, 28 contained from 500 to 1,000 ppm dissolved solids, and only 1 contained more than 1,000 ppm dissolved solids. The analyses show that the chloride and sulfate contents are low. Out of 50 samples, 1 contained more than 250 ppm of chloride and 1 contained more than 250 ppm of sulfate. Of the 25 samples analyzed for iron content, 8 showed more than the recommended limit of 0.3 ppm, and one of these was as high as 8.8 ppm. The few high iron contents reported may result in part from improper collection of water samples. However, iron may present a problem in some local areas in and near the outcrop. Excessive fluoride contents were not evident from the available analyses. Chemical analyses indicate that water in the outcrop is generally hard with the total hardness commonly being from 300 to 400 ppm. Downdip from the outcrop the water is soft and in most instances has a total hardness of less than 50 ppm. Chemical analyses of water from a few selected wells screening the Trinity Group, undifferentiated, are given in Table 2 to illustrate the general quality of water in various parts of the area.

Treatment, other than chlorination for public supply, does not seem necessary except possibly in areas of high iron concentration. The quality of water is generally acceptable for public supplies and industrial uses, particularly as it is quite soft.

Forseeable future quality of water problems probably would be related to improper disposal of wastes on the surface or in streams and through improperly constructed disposal wells. Interformational movement of poor quality water into the unit as a result of inadequate surface casing, poor cementing, or

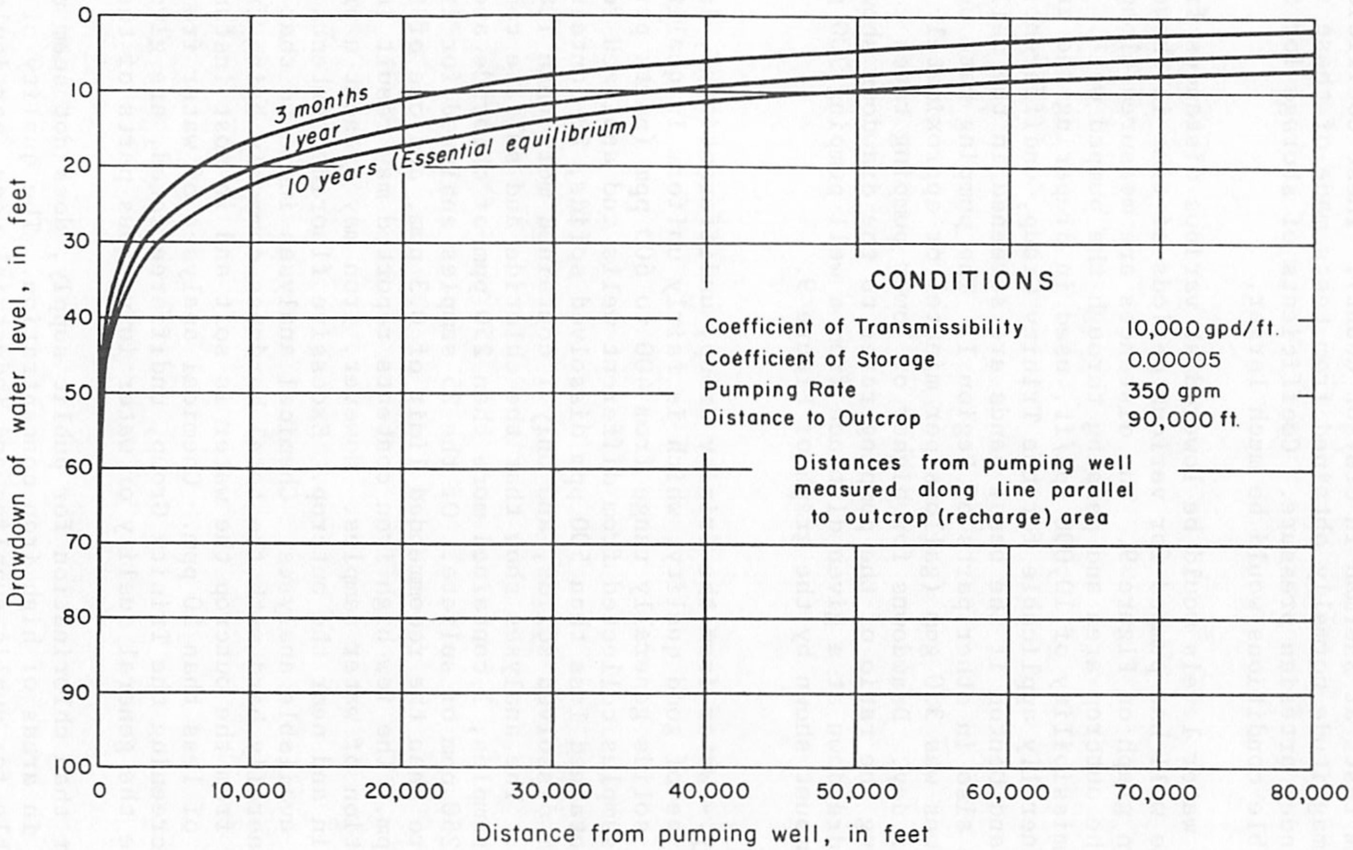


Figure 9

Distance - Drawdown Curves After Various Times of Pumping From the Trinity Group, Undifferentiated, Region I, Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

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Table 2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, Trinity River Basin

(Analyses by U. S. Geological Survey unless noted. Analyses expressed in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio.)

| Well | Owner | Depth of well (ft.) | Date of collection | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na + K) | Bicarbonate ($HCO_3$) 1/ | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Total hardness as $CaCO_3$ | Percent sodium | Sodium adsorption ratio (SAR) | Specific conductance (micromhos at 25°C.) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trinity Group Aquifer** | | | | | | | | | | | | | | | | | | | |
| Trinity Group undifferentiated | | | | | | | | | | | | | | | | | | | |
| 18-41-402 | City of Aubrey | 915 | 5-27-60 | 13 | 0.13 | 1.2 | 0.2 | 275 0.8 | 572 | 104 | 22 | 0.9 | 0.2 | 711 | 4 | 99 | 60 | 1,140 | 8.4 |
| 19-23-901 | City of Gainesville | 906 | 5-28-60 | 12 | .01 | 1.8 | .6 | 174 .8 | 429 | 28 | 3.2 | .2 | .0 | 438 | 7 | 98 | 29 | 716 | 8.4 |
| 19-28-801 | Forestburg School District | 180± | 5- 5-61 | 24 | 4.0 | 102 | 19 | 21 | 355 | 67 | 12 | .2 | .0 | 432 | 332 | 12 | .5 | 666 | 6.9 |
| 19-42-602 | City of Chico | 120 | 5-12-60 | 19 | .00 | 74 | 24 | 31 3.4 | 341 | 26 | 30 | .1 | 1.5 | 377 | 283 | 19 | .8 | 641 | 6.9 |
| 19-52-104 | City of Decatur | 534 | 5-12-60 | 16 | .03 | 25 | 9.6 | 88 2.4 | 291 | 26 | 22 | .2 | .0 | 335 | 102 | 65 | 3.8 | 555 | 7.4 |
| 19-55-601 | Whitson Food Prod. | 771 | 5-12-60 | 13 | -- | .8 | .4 | 222 | 496 | 55 | 14 | .4 | 2.0 | 552 | 4 | 99 | 48 | 900 | 8.6 |
| Travis Peak Formation | | | | | | | | | | | | | | | | | | | |
| 2/ 18-50-803 | City of Frisco | 2,660 | 4- -51 | 20 | .08 | 6 | 1 | 314 | -- | 98 | 188 | 0.2 | <0.4 | 832 | 19 | -- | -- | -- | 8.4 |
| 32-10-905 | Pythian Home | 460 | 6-14-61 | 15 | -- | 35 | 20 | 172 | 412 | 110 | 64 | .2 | .0 | 619 | 170 | 69 | 5.7 | 1,010 | 7.1 |
| 32-15-403 | City of Richland Hills | 1,277 | 6-14-61 | 13 | -- | 1.5 | .8 | 344 | 526 | 138 | 125 | 1.8 | .0 | 898 | 7 | 99 | 57 | 1,470 | 8.1 |
| 32-31-601 | City of Mansfield | 1,733 | 6-12-61 | 15 | -- | 1.8 | .5 | 275 | 500 | 94 | 66 | 1.5 | .0 | 710 | 6 | 99 | 49 | 1,150 | 8.1 |
| 33-18-201 | City of Dallas | 2,873 | 3-27-52 | 22 | .02 | 6.0 | 2.2 | 385 .8 | 542 | 259 | 95 | 1.8 | .5 | 1,040 | 24 | -- | -- | 1,650 | 8.2 |
| 2/ 33-20-401 | Dallas Co. WC&ID No. 7 | 4,121 | 11-30-59 | -- | .06 | 6 | 1 | 470 | 611 | 175 | 278 | 3 | < .4 | 1,410 | 20 | -- | -- | 2,350 | 8.1 |
| 33-34-702 | City of Waxahachie | 2,950 | 2-21-61 | 16 | -- | 6.8 | 2.8 | 461 | 500 | 165 | 315 | 1.7 | .0 | 1,210 | 28 | 97 | 38 | 2,100 | 7.9 |
| 39-10-201 | City of Hubbard | 3,441 | 4-21-61 | 31 | .09 | 5.0 | .8 | 452 4.8 | 656 | 267 | 134 | 3.4 | .0 | 1,220 | 16 | 98 | -- | 1,930 | 7.9 |
| Paluxy Formation | | | | | | | | | | | | | | | | | | | |
| 19-64-301 | Roy Harper | 870 | 5-31-60 | 14 | 0.01 | 1.0 | 0.0 | 240 0.07 | 504 | 83 | 15 | 0.6 | 0.8 | 605 | 2 | 99 | 74 | 984 | 8.5 |
| 32-15-404 | City of Richland Hills | 590 | 6-14-61 | 12 | -- | 1.0 | .3 | 250 | 500 | 102 | 19 | 1.0 | .0 | 631 | 4 | 99 | 54 | 1,010 | 8.5 |
| 32-19-603 | Mrs. A. C. Lasater | 119 | 6-14-61 | 13 | -- | 9.2 | 6.4 | 125 | 328 | 40 | 7.5 | .2 | .0 | 356 | 50 | 85 | 7.7 | 578 | 7.4 |
| 2/ 33-05-501 | City of Rockwall | 3,342 | 11-14-55 | 23 | .05 | 5 | 1 | 355 -- | 561 | 215 | 53 | 1.8 | < .4 | 956 | 17 | -- | -- | -- | 8.6 |
| 2/ 33-20-901 | City of Seagoville | 2,860 | 4- 1-54 | 43 | .2 | 10 | 5 | 857 -- | 561 | 1,201 | 142 | 3.6 | < .4 | 2,525 | 46 | -- | -- | -- | -- |

Table 2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, Trinity River Basin--Continued

| Well | Owner | Depth of well (ft.) | Date of collection | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na + K) | Bicarbonate ($HCO_3$) 1/ | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Total hardness as $CaCO_3$ | Percent sodium | Sodium adsorption ratio (SAR) | Specific conductance (micromhos at 25°C.) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Woodbine Aquifer | | | | | | | | | | | |
| 18-44-801 | City of Melissa | 1,366 | 9-11-56 | 14 | 0.14 | 0.8 | 0.0 | 238 1.1 | 432 | 100 | 37 | 2.8 | 3.0 | 610 | 2 | 99 | 73 | 987 | 8.5 |
| 32-16-701 | Chester Ditto | 150 | 8-21-53 | 11 | 13 | 43 | 16 | 79 | 240 | 91 | 37 | -- | 2.5 | 398 | 174 | 50 | -- | 667 | 7.3 |
| 32-31-602 | City of Mansfield | 200 | 6-12-61 | 12 | -- | 11 | 2.7 | 195 | 300 | 162 | 32 | .5 | 1.2 | 564 | 38 | 92 | 14 | 895 | 7.7 |
| 33-11-802 | Buckner Childrens Home | 1,330 | 5-10-61 | 15 | -- | 2.0 | .6 | 540 | 668 | 424 | 131 | 2.6 | .2 | 1,440 | 8 | 99 | 83 | 2,260 | 8.0 |
| 33-21-801 | City of Crandall | 2,340 | 7- 5-61 | 19 | .39 | 6.0 | 2.1 | 1,100 | 1,200 | 374 | 735 | 4.7 | 2.5 | 2,830 | 24 | 99 | 98 | 4,860 | 8.2 |
| 33-33-702 | Hi-View Hereford Ranch | 695 | 4-26-61 | 12 | -- | 3.5 | 1.0 | 537 | 560 | 572 | 82 | 2.3 | 4.2 | 1,490 | 12 | 99 | 67 | 2,240 | 7.9 |
| 33-44-402 | City of Ennis | 1,796 | 2-21-61 | 15 | -- | 3.2 | 1.6 | 792 | 1,010 | 488 | 275 | 4.8 | .5 | 2,080 | 14 | 99 | 92 | 3,280 | 7.8 |

1/ Includes equivalent of any carbonate ($CO_3$) present.
2/ Analysis by Texas State Department of Health.

improper plugging of oil and water test holes also could provide a means of contamination. Improper disposal or inadequate protective measures thus could result in contamination of fresh ground water, thereby rendering it unfit for beneficial use. These problems would be of a local nature initially and, if detected early enough, corrective measures could be taken to prevent their reaching major proportions.

Utilization and Development.--According to Hill (1901), considerable development of ground water already had taken place in north-central Texas by 1897. The use of water from the Trinity Group, undifferentiated, in Region I increased from the turn of the century to the middle 1950's, largely in relation to the growth of the two major cities, Denton and Gainesville. In 1955, total pumpage from the Trinity Group, undifferentiated, was 7,170 acre-feet, 6.4 mgd (million gallons per day). Municipal use accounted for 5,270 acre-feet (4.7 mgd) of this, and industrial use accounted for the remainder. About half the pumpage for the city of Gainesville is included in the amount pumped for municipal use in Region I because the other half is pumped from within the Red River Basin. Denton stopped using water from the Trinity Group, undifferentiated, as its sole source of supply in 1957, and as a result, the total municipal pumpage was reduced by 3,140 acre-feet (2.8 mgd). In 1960, the total pumpage from the Trinity Group, undifferentiated, of Region I was 3,600 acre-feet. Municipal pumpage accounted for 1,980 acre-feet, and industrial pumpage accounted for 1,620 acre-feet. Municipal and industrial pumpage from the Trinity Group, undifferentiated, by major drainage subdivisions of Region I, is given in Table 3. In addition there is an undetermined amount of water pumped from this unit for domestic and livestock use.

Pumping rates of wells constructed in the Trinity Group, undifferentiated, range from a few to as much as 700 gpm. The average pumping rate for the major wells is about 200 gpm. The larger municipal and industrial wells can be expected to have pumping rates that are above this average. Specific capacities of 5 wells in the northern part of the region ranged from 1 to 14 gpm per foot of drawdown. However, the specific capacities of most wells are generally 5 gpm per foot of drawdown or less.

The type of well construction ranges within wide limits and depends in a large part on the well's intended use. The casing of the major wells ranges from 10 to 18 inches at the surface. The casing is usually lapped or swedged to a liner, or screen section, ranging from 6 to 8 inches in diameter. The larger wells typically are underreamed and gravel packed, especially the ones constructed in recent years. All wells are cemented down to producing zones to shut off water from shallower formations. Total lengths of screens range from 40 to 250 feet, but most commonly range from 100 to 150 feet. Turbine pumps, either shaft type or submersible, driven by electric motors having as much as 150 horsepower, are used to bring the water to the surface.

Wells may pump considerable sand, even if gravel packed, because the sands of the Trinity Group, undifferentiated, are commonly very fine-grained. This condition is especially prevalent near the outcrop, but downdip the problem of wells sanding up is not as great. Corrosion is likely to be a problem in the outcrop where the water has a low pH. However, corrosion is not a likely problem downdip from the outcrop unless highly mineralized waters of other formations enter the well.

Table 3.--1960 Ground-water pumpage from aquifers in Region I, Trinity River Basin

(Pumpage expressed in acre-feet 1/ 2/ )

| Subdivision | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 17 | 20 | 21 | 22 | 23 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Trinity Group Aquifer** | | | | | | | | | | | | | | | | | | | | |
| Trinity Group, Undifferentiated | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | 401 | 63 | -- | -- | -- | 1,210 | 123 | 147 | 36 | -- | -- | -- | -- | -- | -- | -- | -- | 1,980 |
| Industrial | -- | -- | 171 | 162 | -- | -- | -- | 1,227 | -- | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,620 |
| Total | -- | -- | 572 | 225 | -- | -- | -- | 2,437 | 123 | 207 | 36 | -- | -- | -- | -- | -- | -- | -- | -- | 3,600 |
| Travis Peak Formation | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | 22 | 5,030 | 278 | -- | -- | 53 | 193 | -- | -- | 6,090 | -- | 49 | 196 | 129 | 105 | 12,145 |
| Industrial | -- | -- | -- | -- | -- | 2,630 | 215 | -- | -- | 1,697 | -- | -- | -- | 5,150 | -- | -- | -- | -- | -- | 9,692 |
| Total | -- | -- | -- | -- | 22 | 7,660 | 493 | -- | -- | 1,750 | 193 | -- | -- | 11,240 | -- | 49 | 196 | 129 | 105 | 21,837 |
| Paluxy Formation | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | -- | 4,880 | -- | -- | -- | 125 | 163 | -- | 157 | 1,835 | -- | -- | 182 | -- | -- | 7,342 |
| Industrial | -- | -- | -- | -- | 92 | 697 | -- | -- | -- | -- | -- | -- | -- | 654 | -- | -- | -- | -- | -- | 1,443 |
| Total | -- | -- | -- | -- | 92 | 5,577 | -- | -- | -- | 125 | 163 | -- | 157 | 2,489 | -- | -- | 182 | -- | -- | 8,785 |
| Summary of Pumpage from Trinity Group Aquifer | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | 401 | 63 | 22 | 9,910 | 278 | 1,210 | 123 | 325 | 392 | -- | 157 | 7,925 | -- | 49 | 378 | 129 | 105 | 21,467 |
| Industrial | -- | -- | 171 | 162 | 92 | 3,327 | 215 | 1,227 | -- | 1,757 | -- | -- | -- | 5,804 | -- | -- | -- | -- | -- | 12,755 |
| Total | -- | -- | 572 | 225 | 114 | 13,237 | 493 | 2,437 | 123 | 2,082 | 392 | -- | 157 | 13,729 | -- | 49 | 378 | 129 | 105 | 34,222 |
| **Woodbine Aquifer** | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | -- | -- | 125 | 46 | -- | 124 | -- | 392 | 50 | 2,341 | 92 | 42 | 68 | 1,057 | 56 | 4,393 |
| Industrial | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1,346 | -- | -- | -- | -- | -- | 1,346 |
| Total | -- | -- | -- | -- | -- | -- | 125 | 46 | -- | 124 | -- | 392 | 50 | 3,687 | 92 | 42 | 68 | 1,057 | 56 | 5,739 |
| **Other Aquifers 3/** | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | 32 | -- | -- | 1 | -- | 58 | -- | -- | -- | -- | -- | 22 | -- | -- | -- | -- | 24 | 137 |
| Industrial | 27 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 138 | -- | -- | -- | -- | -- | 165 |
| Irrigation | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 160 | -- | -- | -- | -- | -- | 160 |
| Total | 27 | -- | 32 | -- | -- | 1 | -- | 58 | -- | -- | -- | -- | -- | 320 | -- | -- | -- | -- | 24 | 462 |
| **Summary of Pumpage in Region I** | | | | | | | | | | | | | | | | | | | | |
| Municipal | -- | -- | 433 | 63 | 22 | 9,911 | 403 | 1,314 | 123 | 449 | 392 | 392 | 207 | 10,288 | 92 | 91 | 446 | 1,186 | 161 | 25,997 |
| Industrial | 27 | -- | 171 | 162 | 92 | 3,327 | 215 | 1,227 | -- | 1,757 | -- | -- | -- | 7,288 | -- | -- | -- | -- | -- | 14,266 |
| Irrigation | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 160 | -- | -- | -- | -- | -- | 160 |
| Total | 27 | -- | 604 | 225 | 114 | 13,238 | 618 | 2,541 | 123 | 2,206 | 392 | 392 | 207 | 17,736 | 92 | 91 | 446 | 1,186 | 161 | 40,423 |

1/ Municipal pumpage includes water supplied by privately owned systems.
2/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.
3/ Other aquifers include rocks of Pennsylvanian age, Nacatoch Formation, and Alluvium.

Lowering of water levels commonly is a matter of concern in areas of ground-water development. However, if development is to take place, the decline of water levels is necessary to create water-level gradients required to move the water to the wells. If well fields become concentrated in small areas severe overdrafts may occur. The overdrafts generally result from the low transmissibility of the sands, requiring steep hydraulic gradients to transmit the required water. Lowering of water levels can become so serious as to cause abandonment of wells because of high pumping costs. In some instances the depths of the water-bearing sands screened in wells, or the types of well construction, limit the amount that water levels can be lowered by pumping. This in turn limits the hydraulic gradient that can be established and consequently the amount of water that can be induced to move to the area of pumping. Thus far, overdevelopment has not occurred in the areas where water is being produced from the Trinity Group, undifferentiated. If well fields are not confined to small areas, and wells within the well fields are properly spaced, severe drawdowns of water levels due to interference can be avoided. However, this may result in increased costs for water transportation (pipeline costs) if many wells or well fields are required to supply the needed water.

## Travis Peak Formation

Geologic Characteristics.--The Travis Peak Formation is composed of fine-grained quartz sand interlensed with shale, clay, and some thin limestone lentils. Some coarse sand and fine gravel occurs near the base. The sand lenses grade vertically and laterally into clay.

The lower part of the formation is predominately sand, whereas the upper part is mainly clay and shale with some sand stringers and lenses. Consequently, the term "basal Trinity sands" commonly used by engineers and well drillers often excludes the upper part of the Travis Peak Formation. In this report, the Travis Peak interval is synonymous with that defined by Leggat (1957, p. 15-20) and includes the upper sands and shales. The Travis Peak Formation includes the rocks in the interval between the basal anhydrite or lowest limestone of the Glen Rose and the top of the underlying Paleozoic rocks.

Thickness of the Travis Peak ranges from 200 feet in central Parker County to more than 900 feet downdip in the eastern part of Region I. This is illustrated by the isopachous map shown on Plate 6 and by the geologic sections shown on Figures 5 and 6. Sand constitutes from 45 to 75 percent of the total thickness of the Travis Peak and averages about 60 percent of the total thickness. The areal extent of fresh water in the Travis Peak Formation is shown on Plate 7.

The Travis Peak Formation has a homoclinal east-southeasterly dip, which increases progressively in an easterly direction. Dips range from about 30 feet per mile in the western part of Region I to more than 110 feet per mile in the eastern part of the region, as shown by the contour lines on Plate 7.

The depth to the top of the Travis Peak ranges from 200 feet below the land surface in the western part of Region I near Weatherford in Parker County to more than 4,000 feet in the eastern part of the region, as shown generally on Plate 7.

Occurrence and Movement of Ground Water.--Water in the Travis Peak Formation occurs under artesian head throughout most of the Trinity River Basin. In a small area in west-central Tarrant County, static water levels have been lowered to below the top of the formation as a result of pumping, and water-table conditions prevail. The general position of the water level in this area is illustrated on the geologic section of Figure 6. Water-table conditions also may prevail in some areas of Parker County.

Near the outcrop of the Trinity Group aquifer in Parker County, the water in the Travis Peak Formation moves approximately at right angles to the strike of the beds. Downdip, a major and large-scale cone of depression has formed as a result of the large amount of pumping that is concentrated in Tarrant and Dallas Counties. The cone is elongate with its longer axis trending in a southeasterly direction and passing through the northern part of Fort Worth in Tarrant County and the southern part of Dallas in Dallas County. The deepest part of the composite cone is at Fort Worth, and smaller cones have been developed near Arlington and between Grand Prairie and Dallas. Water is moving into this area of lowered hydrostatic pressure, as represented by the cone of depression, from all directions.

Recharge and Discharge.--Part of the recharge to the Travis Peak Formation in Region I is derived from precipitation and leakage from streams in its outcrop area in the Brazos River Basin. The remainder of the recharge to the Travis Peak is derived from water moving through the Trinity Group, undifferentiated. Thus, water received in the outcrop of the Trinity Group, undifferentiated, also serves to recharge the Travis Peak Formation. Annual precipitation of about 32 inches falls on the outcrop areas of both the Trinity Group, undifferentiated, and the Travis Peak Formation. The sandy soils on the rolling hills support post oaks and, in general, provide favorable conditions for recharge. The amount of recharge to the Travis Peak has not been determined, but conditions are such that recharge probably is more than adequate to support the quantity of water that is pumped from the formation.

In the Trinity River Basin, natural discharge from the Travis Peak is limited to upward leakage through confining beds. Some water is probably discharged to streams or to the atmosphere in its outcrop outside the basin. Heavy municipal and industrial pumpage, especially in Dallas and Tarrant Counties, constitutes the artificial discharge. The Travis Peak is by far the most heavily developed water-bearing formation in Region I and is the source of supply for many towns and industries of the region.

Water Levels.--The depth to water in wells tapping the Travis Peak Formation ranges from relatively near the surface in areas of Parker County and in the far eastern part of the region to more than 700 feet below the surface in west-central Tarrant County, an area of heavy pumping. A hydrograph of a well in the refinery district of northeast Fort Worth, shown on Figure 10, illustrates the large seasonal water-level fluctuations in the Travis Peak that occur in this area. In this well a seasonal fluctuation on the order of 40 to 50 feet occurs primarily as a result of seasonal changes in the rate of pumping. Greater changes in water levels may occur in other areas as a result of changes in pumping. Other factors, such as changes in the amount of recharge in the outcrop area, have a relatively small overall effect on water levels in the Travis Peak Formation.

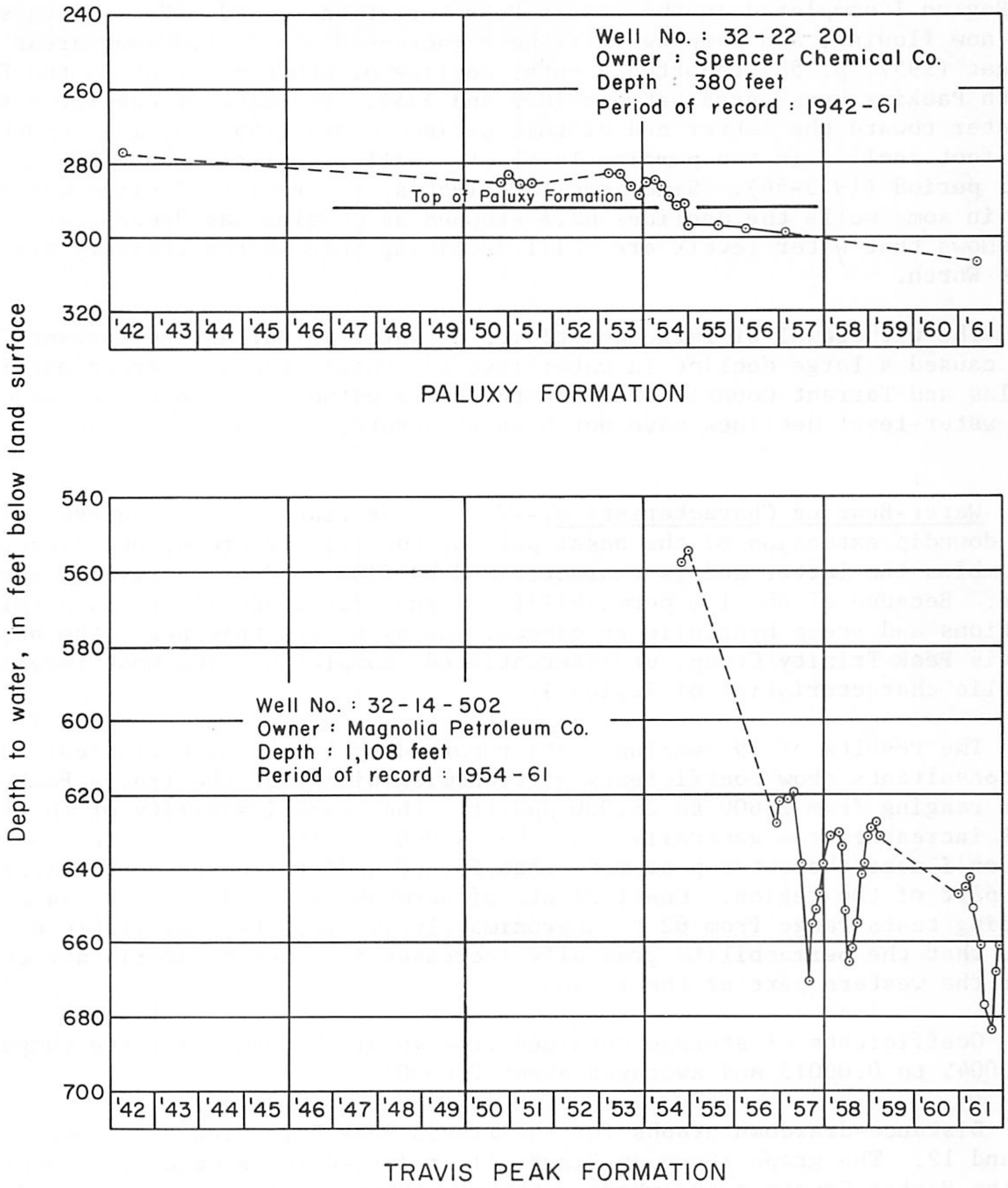


Figure 10

Hydrographs of Wells Screened in the Travis Peak Formation and in the Paluxy Formation of the Trinity Group Aquifer, Region I, Trinity River Basin

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Water-level declines have been serious in most of Tarrant County and in parts of Dallas County. During the first 20 years of this century many wells in Region I completed in the Travis Peak Formation flowed. None of these wells are now flowing, and pumping lifts have increased greatly in some areas. Leggat (1957, p. 58) reported a total decline of about 770 feet in the Fort Worth Packing House area between 1892 and 1954. The rate of decline was much greater toward the latter end of this period. Gard (1957, p. 11) reported a 300-foot decline in the pumping level of a well in Dallas County during a 3-1/2 year period (1953-56). Since the late 1950's, the rate of decline has slowed and in some wells the declines have stopped as pumping has decreased. Figure 10 shows that water levels are still declining some in the refinery area of Fort Worth.

The withdrawal of large quantities of water in Dallas and Tarrant Counties has caused a large decline in water levels. Water levels in areas outside Dallas and Tarrant Counties reflect the heavy withdrawals in these two counties, but water-level declines have not been as severe.

Water-Bearing Characteristics.--The Travis Peak unit, being essentially the downdip extension of the basal part of the Trinity Group, undifferentiated, resembles the latter and is characterized by fine sand of fairly low permeability. Because of the low permeability, large yields usually require thick sand sections and steep hydraulic gradients. Owing to its thickness, the basal Travis Peak-Trinity Group, undifferentiated, complex has the most favorable hydraulic characteristics of Region I.

The results of 19 pumping tests reported by the U. S. Geological Survey and by consultants show coefficients of transmissibility of the Travis Peak Formation ranging from 2,600 to 28,000 gpd/ft. The transmissibility of the Travis Peak increases from generally less than 4,000 gpd/ft. in the western part of Region I near the outcrop to more than 25,000 gpd/ft. in the northeastern, downdip part of the region. Coefficients of permeability indicated by 14 of the pumping tests range from 62 to approximately 115 gpd/ft$^2$. Available data indicate that the permeability gradually increases in a northeasterly direction from the western part of the region.

Coefficients of storage obtained from 10 of the pumping tests ranged from 0.000045 to 0.00013 and averaged about 0.00008.

Distance-drawdown graphs for the Travis Peak Formation are shown on Figures 11 and 12. The graph shown on Figure 11, referred to as Case I, is applicable to the Parker County area, whereas the one shown on Figure 12, referred to as Case II, is applicable to the areas of higher transmissibility, such as that in the vicinity of northern Dallas County.

Chemical Quality.--Water from the Travis Peak Formation is characteristically soft, of the sodium bicarbonate type, and somewhat high in dissolved solids. Chemical analyses of 62 samples show that 6 had less than 500 ppm dissolved solids; 30 had from 500 to 1,000 ppm; 24 had from 1,000 to 1,500 ppm; and 2 had more than 1,500 ppm. The water generally becomes more mineralized downdip, and the Glen Rose limestone wedge has some effect upon quality.

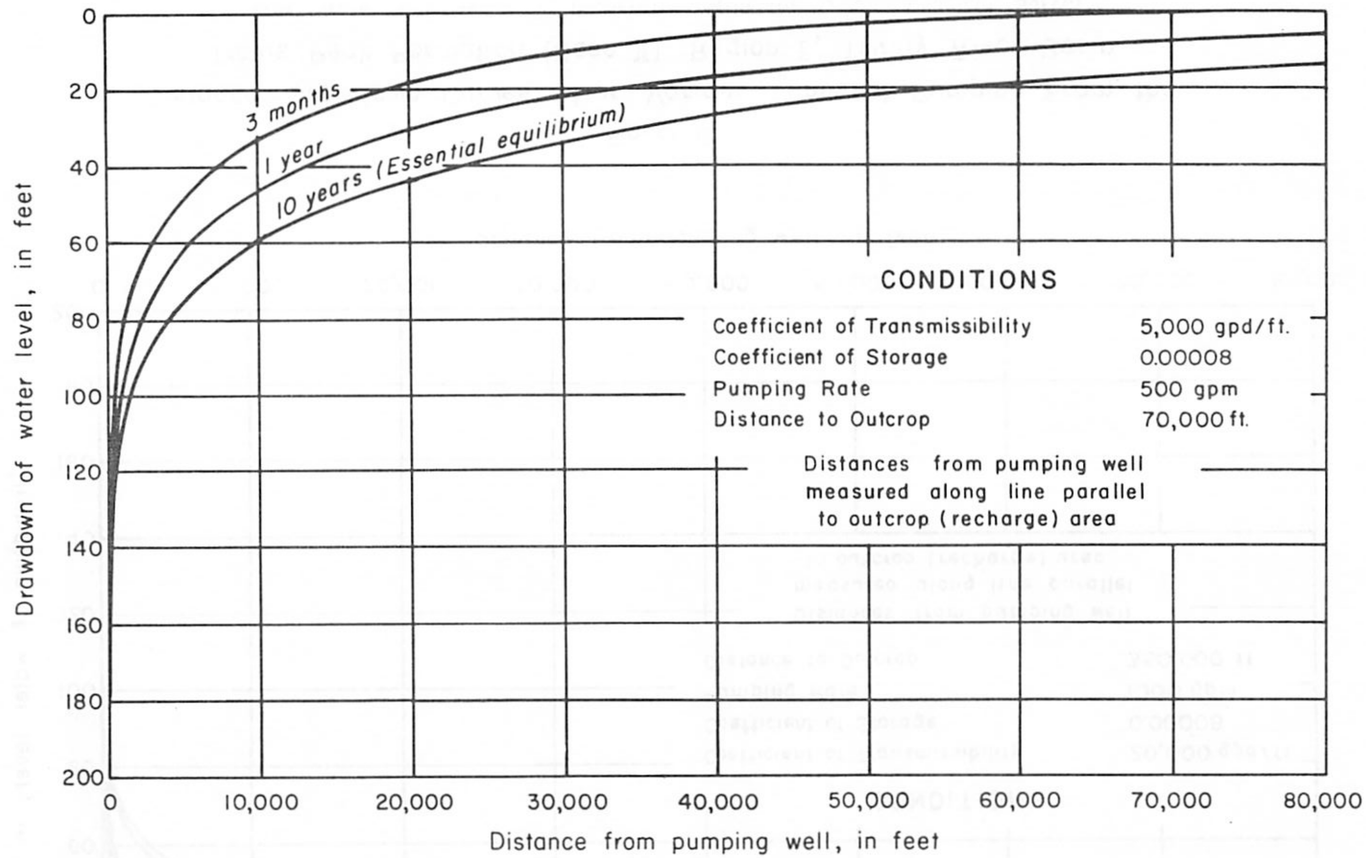


Figure 11

Distance - Drawdown Curves After Various Times of Pumping From the Travis Peak Formation (Case I), Region I, Trinity River Basin

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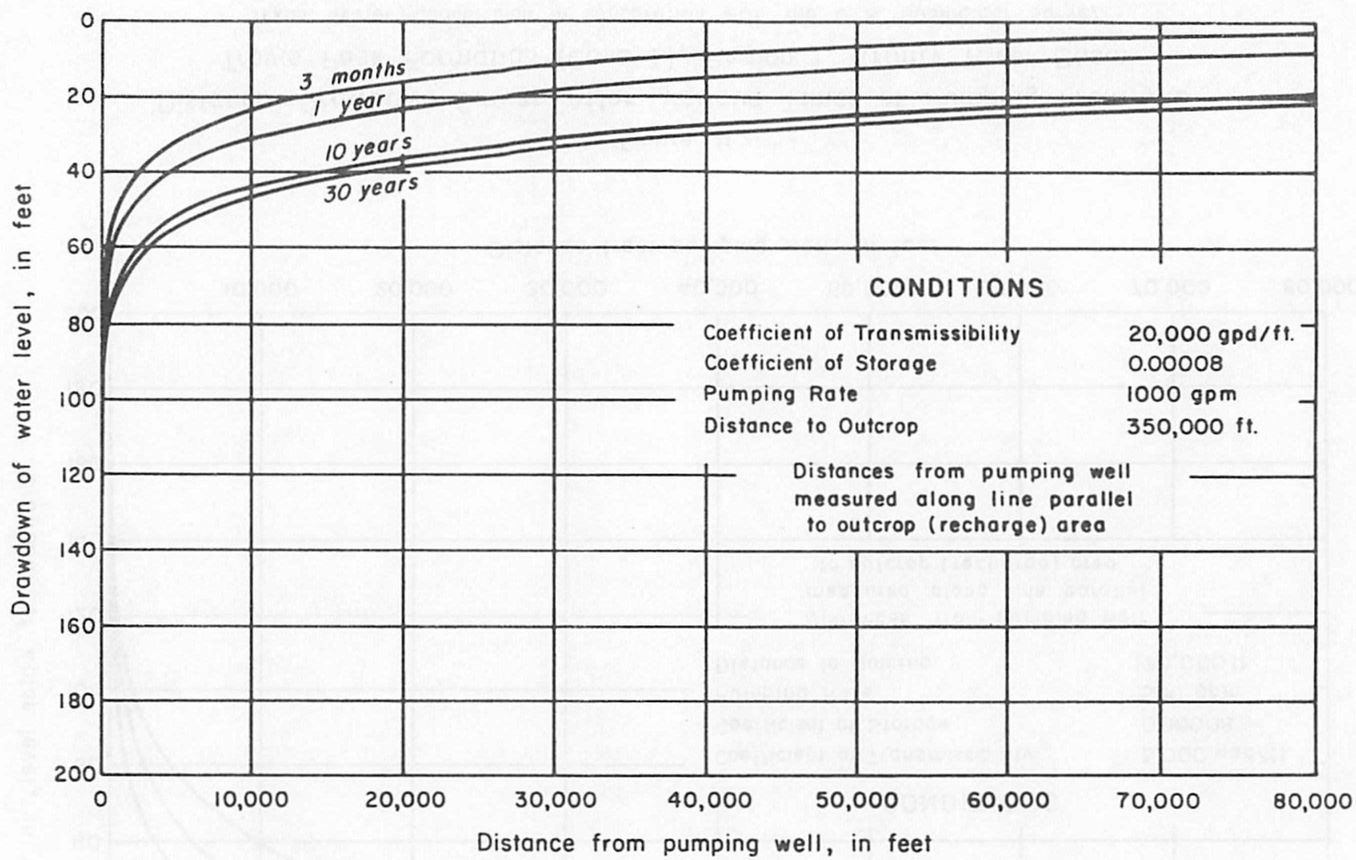


Figure 12

Distance - Drawdown Curves After Various Times of Pumping From the Travis Peak Formation (Case II), Region I, Trinity River Basin

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The chloride and sulfate content of the water is not above the recommended limits set by the U. S. Public Health Service except where the sands are at considerable depth. The chloride content of 6 of 62 samples was more than 250 ppm, and the sulfate content of 10 of the 62 samples was more than 250 ppm. A high iron content is not commonly associated with water from the Travis Peak Formation. Water from only 7 of 48 wells sampled exceeded 0.3 ppm iron. The higher iron content may result from poor sampling techniques because water from nearby wells producing from the same sand interval usually contained considerably less than 0.3 ppm iron. Of 43 samples analyzed for fluoride, 35 had concentrations of more than 1.5 ppm. The softness of the water is illustrated by the fact that 58 out of 64 samples had less than 60 ppm hardness, expressed as calcium carbonate. Those samples with a hardness greater than 121 ppm were from wells in Parker County near the outcrop. Chemical analyses of water from selected wells are presented in Table 2 to illustrate the quality of water from the Travis Peak Formation in various parts of Region I.

The temperature of water in the Travis Peak Formation, as well as that in other water-bearing units in Region I, increases with the depth. It is most noticeable in the Travis Peak because the deepest water wells of Region I are completed in this formation. Water having the highest temperature, 136° F, was from a well completed at a depth of 4,040 feet in eastern Dallas County. Because of the high water temperatures encountered in some places, the water may require cooling before it can be used for some purposes.

The quality of the water from the Travis Peak should not change appreciably in the future. Water is moving into the Tarrant and Dallas County area from all directions; thus, a slight deterioration in quality may occur as more mineralized water from areas downdip moves toward the areas of pumping and mixes with the better quality water. Downward leakage of water of poor quality from the overlying Glen Rose limestone perhaps occurs, or will occur if the hydrostatic pressure in the cone of depression is reduced sufficiently. The quality of the water produced from individual wells may become very poor and possibly be unfit for beneficial use if the highly mineralized water from the Glen Rose is allowed to enter the wells as a result of casing corrosion or improper well construction.

<u>Utilization and Development</u>.--The Travis Peak Formation is the most heavily pumped aquifer in Region I of the Trinity River Basin. The water is used for municipal, industrial and domestic supplies. Most of the major pumpage is concentrated in the Dallas-Tarrant County area.

Before the turn of the century, water from wells completed in the Travis Peak Formation in Tarrant County flowed at the surface. It was somewhat later before flowing wells were developed in Dallas County. Many of the wells were abandoned in the Fort Worth area when they ceased flowing, and withdrawal of water from the Travis Peak in Tarrant County probably declined for a time. However, withdrawals began to increase about 1920 and they continued to increase until about 1956. Since 1956, withdrawals of ground water from the Travis Peak in Tarrant County have gradually declined. Available data indicate that the rates of pumpage in Dallas County have followed a pattern similar to that for Tarrant County. Development of water from the Travis Peak in Dallas County began after that of Tarrant County primarily because of the greater depth to the water-bearing sands. However, withdrawals of water from this formation in Dallas County soon became larger than those for Tarrant County and have remained so to the present. Comparative figures of estimated municipal and industrial pumpage from the Travis Peak Formation during selected years are given for Dallas and Tarrant Counties in the following table.

| Year | Tarrant County | | Dallas County | | Total | |
|---|---|---|---|---|---|---|
| | Acre-ft. | Mgd | Acre-ft. | Mgd | Acre-ft. | Mgd |
| 1900 | 2,200 | 2 | 0 | 0 | 2,200 | 2 |
| 1942 | 5,600 | 5 | 7,300 | 6.5 | 13,000 | 11.5 |
| 1956 | 13,000 | 12 | 21,000 | 19 | 34,000 | 31 |
| 1960 | 7,800 | 7 | 11,000 | 10 | 19,000 | 17 |

Pumpage in Dallas and Tarrant Counties constitutes most of the pumpage from the Travis Peak Formation in Region I. In 1960, 19,000 acre-feet of the 21,837 acre-feet of water pumped from the Travis Peak Formation in Region I was withdrawn in this area. Municipal and industrial pumpage from this formation in Region I during 1960 is presented by major drainage subdivisions in Table 3. Of the 21,837 acre-feet pumped in 1960, 12,145 acre-feet was pumped for municipal use, and 9,692 acre-feet was pumped for industrial use.

Total pumpage from all aquifers in Region I has declined since the middle 1950's, due principally to a reduction in pumpage from the Travis Peak Formation. Indications are that future pumpage from the Travis Peak in Region I of the Trinity River Basin probably will decrease further.

Industries and municipalities requiring large quantities of ground water usually drill wells to the Travis Peak. Pumping rates from individual wells range from 50 to 2,200 gpm and average about 550 gpm.

Specific capacities indicate that large pumping rates require relatively large drawdowns. The range in specific capacity of wells completed in the Travis Peak Formation in Region I is from 1.0 to 10.4 gpm per foot of drawdown. In Tarrant County, tests made of 27 wells show that the specific capacity ranged from 1.1 to 5.8 gpm per foot of drawdown and averaged 3.4 gpm per foot of drawdown (Leggat, 1957, p. 65). The specific capacity of 9 wells in Dallas County ranged from 4.1 to 10.4 gpm per foot of drawdown and averaged 7.0 gpm per foot of drawdown. Consultant reports indicate that the specific capacity from tests of 25 wells, also in Dallas County, averaged 5.0 gpm per foot of drawdown. In Ellis, Johnson, and Hill Counties, specific capacities probably are less. Two tests in that area show specific capacities of 1.0 and 2.6 gpm per foot of drawdown. In general, specific capacity increases from west to east, and is proportional to the coefficient of transmissibility, which also increases in this direction.

Wells completed in the Travis Peak near the outcrop may pump considerable sand, although the problem is generally not great. Corrosion usually does not occur unless highly mineralized water from the Glen Rose limestone enters the well.

Wells completed in the Travis Peak Formation are usually large with the casing at the surface ranging from 10 to 20 inches in diameter. The casing commonly is lapped or swedged to smaller casing, generally 8 to 14 inches in diameter. The diameter of screens and liners generally ranges from about 6 to 10 inches. Wells are underreamed, gravel packed, and cemented from the surface to near the top of the producing zones.

Total lengths of screens range from about 50 feet near the outcrop to about 250 feet in the extreme northeastern part of Region I and averaged about 160 feet for the entire region. Shaft-driven and submersible turbine pumps are used to lift the water to the surface. Pump settings range from 200 to 1,020 feet and average 680 feet. Electric motors as large as 600 horsepower drive the pumps. The average horsepower of motors of 89 major wells surveyed was 140.

The Travis Peak Formation in Dallas and Tarrant Counties is an example of local overdevelopment in a water-bearing unit that has a limited capacity for transmitting water from areas of recharge to areas of discharge. As development occurred, the artesian head was lowered and a large cone of depression developed. Individual industries and municipalities in this metropolitan area drilled wells on the limited property accessible to them. As it was not practical to provide for adequate well spacing or well-field spacing because of property limitations and distribution problems, the withdrawals were concentrated in a relatively small space, and the competition for water resulted in lower and lower pumping levels. The end results of this competition for water were increased pumping lifts and costs, decreased yields, and even the abandonment of some wells. In several instances wells were abandoned when reductions in casing diameter prevented further lowering of pumps as the water levels declined. The problem of declining water levels became especially acute during the drouth of the 1950's when the demand for water was at an all-time high and more and larger wells were drilled to meet the demand. This situation merely increased the rate of decline of the artesian head and led to greater pumping costs.

Although the lowering of water levels in the Dallas-Tarrant County area caused serious problems, the effects of this local overdevelopment were not excessive outside the 2-county area. Construction of well fields north and south of these two counties would have permitted development of greater quantities of water from the Travis Peak without the excessive lowering of water levels in the Dallas-Tarrant County area. A potential for developing additional ground water from the Travis Peak still exists in the areas removed from the Dallas-Tarrant County area.

### Paluxy Formation

Geologic Characteristics.--Fine-grained, massive to crossbedded lenticular sand interbedded with clay, sandy clay, and some lignite constitute the lithology of the Paluxy Formation. The sand grades both laterally and vertically into finer sediments.

The areal extent of fresh water in the Paluxy Formation is shown on Plate 5; it includes the area between the approximate northern limit of the Glen Rose Formation, the approximate southernmost extent of the Paluxy where it pinches out in Hill and Navarro Counties, and the approximate downdip extent of water containing less than 3,000 ppm dissolved solids in Kaufman and Navarro Counties. The Paluxy dips uniformly east-southeastward, as shown by the structural contours on Plate 5. The dip of the beds becomes progressively steeper in the downdip direction, ranging from less than 30 feet per mile west of Fort Worth to more than 100 feet per mile in the eastern part of Region I. A series of small normal faults, downthrown on the northwest side, is present in southern Hill County. The faults in this area are shown by the geologic section B-B' on Figure 5 and the geologic map on Plate 1.

The Paluxy Formation thins southward from about 450 feet in north-central Collin County to a complete pinch out in southern Hill County and west-central Navarro County. Thinning of the Paluxy in a southward direction is illustrated by the geologic section B-B' shown on Figure 5. The approximate area of pinch out in the southern part of Region I is shown on Plate 5. With the exception of some localized thickening and thinning, the thickness of the Paluxy in a downdip direction is relatively constant.

The Paluxy Formation consists of 45 to 100 percent sand and averages about 65 percent. As the Paluxy thins southward, the percentage of sand increases until in places in southern Hill County it is composed entirely of sand.

The Paluxy Formation contains fresh water, with less than 3,000 ppm dissolved solids, from its outcrop in Parker County eastward to northwestern Kaufman, western Rockwall, and southeastern Collin Counties where the top of the Paluxy is more than 3,000 feet below land surface. Plate 5 shows generalized depths to the top of the Paluxy where it contains fresh water.

Occurrence and Movement of Ground Water.--Artesian conditions prevail in the Paluxy Formation throughout most of Region I. Water-table conditions generally exist in the Paluxy outcrop in Parker County although some flowing wells in the outcrop indicate that locally ground water is under artesian pressure. Downdip from the outcrop, the water levels in the Paluxy are below the top of the formation as far east as a general line passing through the southwest corner of Tarrant County to about the center of Tarrant County and then northward into Denton County. The sands between this general line and the outcrop have been partially dewatered as a result of pumping large quantities of water from the Paluxy in the Dallas-Fort Worth area, principally for municipal use. This is illustrated by the generalized piezometric surface in the Paluxy in the geologic section C-C' on Figure 6.

A large cone of depression in the Paluxy, similar in shape and position to the one in the Travis Peak Formation, has developed in the Tarrant County and central Dallas County area as a result of heavy pumpage. Although the depth and extent of the cone is not as great as the cone developed in the Travis Peak, scattered water-level data indicate that water is moving toward the area of pumping from all directions. Near the outcrop, the water moves generally downdip and at right angles to the strike of the beds. In Ellis and eastern Johnson Counties, south of Dallas and Tarrant Counties, the water moves generally in an east-northeasterly direction.

Recharge and Discharge.--Conditions of recharge for the Paluxy Formation are identical to those of the Trinity Group, undifferentiated, and Travis Peak Formation. Recharge occurs in the outcrop of the Trinity Group in the Trinity River Basin, shown on Plate 5, and in the Brazos River Basin. Rainfall and soil conditions appear favorable for recharge in quantities that will be more than adequate to supply all the water the Paluxy can transmit under conditions of forseeable development.

Natural discharge of water from the Paluxy occurs in the form of springs and seeps in the outcrop, which contribute to the streamflow of the Clear Fork and West Fork of the Trinity River during parts of the year, and upward leakage through confining beds where water in the formation is under artesian head. Artificial discharge is confined largely to Dallas and Tarrant Counties, where large quantities of water are pumped for public supply, industrial, domestic, and livestock uses.

Water Levels.--The depth to water ranges from near the surface in the outcrop in Parker County to approximately 600 feet below the surface in western Dallas County. Water levels fluctuate largely in response to seasonal pumping. Climatic conditions affecting recharge and evapotranspiration cause fluctuations near the outcrop in eastern Parker and western Tarrant Counties, but these fluctuations are relatively small.

The decline of water levels in Dallas and Tarrant Counties has been large. A net decline of 300 feet was observed in the central Fort Worth area between 1890 and 1961, and the upper part of the sands have been dewatered. The hydrograph of well 32-22-201 at the Spencer Chemical Company, given on Figure 10, shows the decline of water levels in the Paluxy Formation in Fort Worth from 1942 to 1961. It also shows that dewatering of the upper part of the Paluxy at this well began in 1954.

The rate of decline in water levels in eastern Tarrant and western Dallas Counties accelerated during the drouth of the 1950's, when pumpage was greatest. The water levels in 3 wells in this area declined an average of 10 feet per year during the period 1953 to 1961. One of these wells located in eastern Tarrant County had an average decline of about 25 feet per year during this period.

Water-Bearing Characteristics.--Nearly all of the data relating to water-bearing characteristics of the Paluxy Formation pertain to Dallas and Tarrant Counties, where the formation is relatively uniform in thickness, transmissibility, and lithologic character. The Paluxy Formation becomes thicker in the transitional zone with the Trinity Group, undifferentiated, at the edge of the Glen Rose limestone to the north, and it thins to extinction southward. Therefore, before the coefficients of transmissibility can be used outside of this 2-county area, they must be properly considered and adjusted to fit local conditions. Coefficients of permeability probably are relatively uniform for the Paluxy Formation, and consequently the coefficients of transmissibility can be expected to increase northward from the Dallas-Tarrant County area and decrease southward from this area.

Coefficients of transmissibility determined from pumping tests of 11 wells in Dallas and Tarrant Counties ranged from 3,000 to 5,700 gpd/ft. and averaged 4,400 gpd/ft. Coefficients of permeability determined from 6 of these tests ranged from 36 to 47 gpd/ft$^2$. The coefficients of storage determined from 5 of these tests ranged from 0.000087 to 0.000034.

Figure 13 presents a distance-drawdown graph prepared by using a coefficient of transmissibility of 4,000 gpd/ft., a coefficient of storage of 0.0001, a pumping rate of 200 gpm, and a distance to the recharge area of approximately

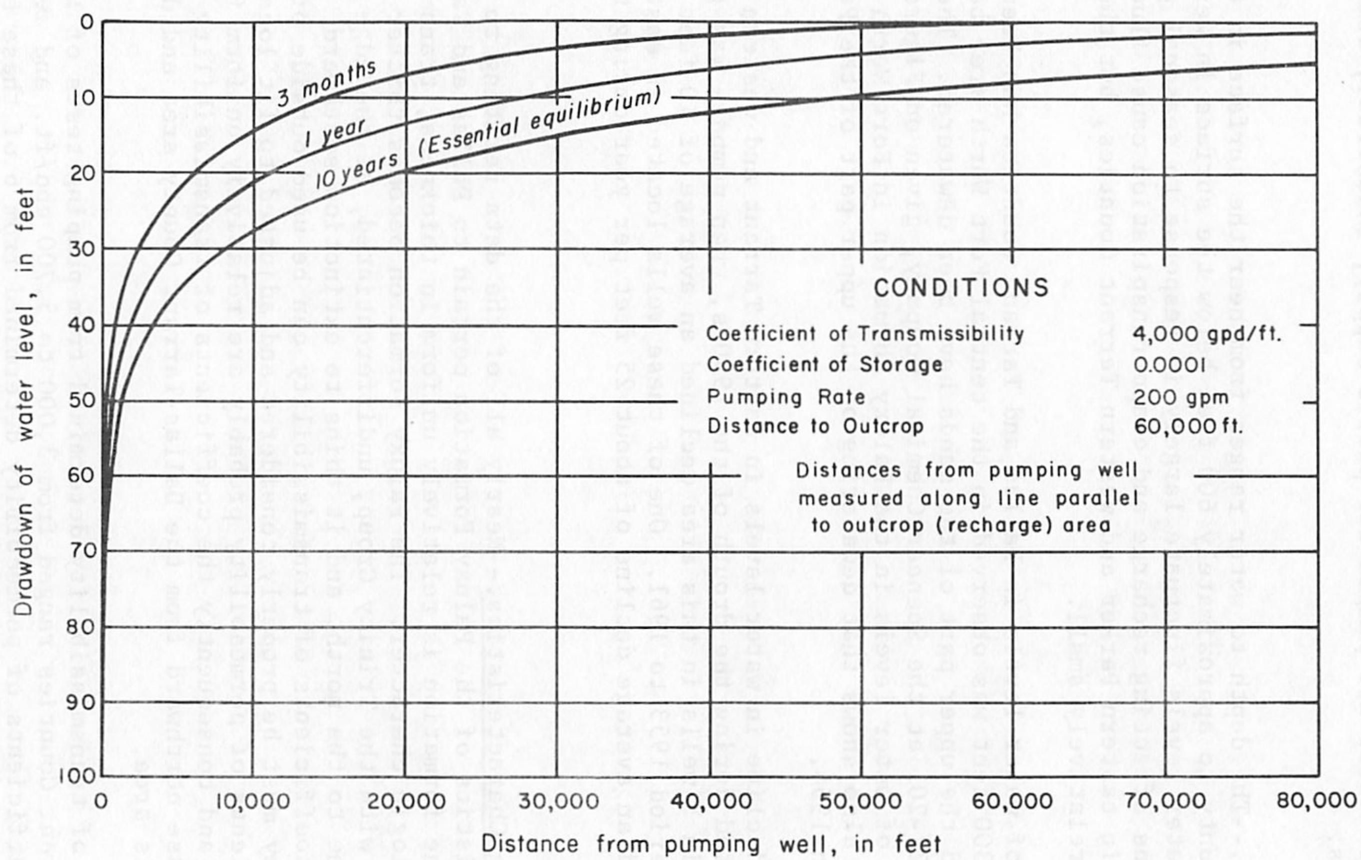


Figure 13

Distance-Drawdown Curves After Various Times of Pumping From the Paluxy Formation, Region I, Trinity River Basin

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12 miles. This graph is considered generally applicable only to central Tarrant County. Smaller drawdowns should be expected north of this area and greater drawdowns should be expected to the south.

Chemical Quality.--Water from the Paluxy Formation is soft, of the sodium bicarbonate type, and of good quality over large areas. Water from two deep wells in southeastern Dallas County were the only samples analyzed that significantly exceeded recommended limits for dissolved solids and sulfate content. One water sample, collected from a 2,780-foot well, contained 1,676 ppm dissolved solids and 442 ppm sulfate. The other water sample, collected from a 2,860-foot well, contained 2,525 ppm dissolved solids and 1,201 ppm sulfate. Of 38 samples collected from wells completed in the Paluxy Formation in the rest of Region I, the chemical analyses show 8 with less than 500 ppm dissolved solids, 29 with 500 to 1,000 ppm, and 1 with 1,000 to 1,500 ppm. Five of 38 samples contained more than 1.5 ppm fluoride. Only 2 of 24 water samples contained more than 0.3 ppm iron. None of the 38 samples contained magnesium, chloride, or sulfate in excess of the maximum recommended by the U. S. Public Health Service. The chemical analyses show that water from the Paluxy Formation in and near the outcrop area in Parker County generally is harder than it is downdip and is reported to contain some iron.

Table 2 presents chemical analyses of water samples from selected wells that illustrate the general quality of the water from the Paluxy Formation in Region I north of Johnson and Ellis Counties. Chemical analyses are not available for water from the Paluxy in the southern part of Region I. The chemical quality of water from the Paluxy is good, and little if any treatment is required for most uses. Water quality is not expected to change in areas of development and should remain essentially the same under present conditions of pumping. However, chemical analyses show that poorer quality water exists in the deeper part of the formation in Dallas County. Calculations of water quality based on the spontaneous-potential curve of electric logs also show that water of relatively poor quality occurs in Ellis County. Therefore, a large additional reduction in artesian head in the present cone of depression could lead to migration of the poorer quality water updip and into the area of pumping. Individual wells drilled through the Paluxy Formation and into the Glen Rose Formation may yield water of poor quality if they are ineffectively plugged to seal off the more highly mineralized water in the Glen Rose. Improper cementing of casing also may allow water of poor quality from shallower formations to leak into the wells.

Utilization and Development.--The Paluxy Formation, yields the second largest quantity of ground water in Region I. Approximately 90 percent of the pumpage from the Paluxy is in Dallas and Tarrant Counties. Parker, Johnson, Denton, and Collin Counties have a few major wells that obtain water from the Paluxy. The water is used primarily for municipal purposes, although many industries also depend upon the Paluxy for their supplies.

The Paluxy Formation was one of the first water-bearing formations to be developed in Region I because it is encountered at a shallower depth than the Travis Peak Formation. Before 1900, when water demands were small, the Paluxy could supply most needs adequately. The deeper Travis Peak sands were developed later, as water demands increased.

Pumpage from the Paluxy Formation increased during and after World War II and probably reached a peak in 1955 or 1956. Withdrawals from this unit have not varied as much as that from other units of the Trinity Group aquifer or from other aquifers in the region. From 1955 to 1960, the total annual municipal and industrial pumpage from the Paluxy decreased by about 400 acre-feet while industrial pumpage increased about 100 acre-feet. Municipal pumpage from the Paluxy Formation in 1960 was 7,342 acre-feet, and industrial pumpage was 1,443 acre-feet. Municipal and industrial pumpage by major drainage subdivisions in 1960 are given in Table 3.

Pumping rates of wells completed in the Paluxy are as much as 400 gpm, or possibly more. The more common pumping rates of the major wells are on the order of 150 to 200 gpm. Specific capacities are low. Tests made of 21 wells in Tarrant County (Leggat, 1957, p. 72) show specific capacities ranging from 0.5 to 4.0 gpm per foot of drawdown. Two wells in Dallas County had specific capacities of 2.1 and 2.6 gpm per foot of drawdown respectively. Specific capacities are generally less than 2.0 gpm per foot of drawdown. This indicates that large drawdowns are necessary for large yields, and as the Paluxy Formation is thin, a substantial artesian head (available drawdown) is required for large yields. As an example, if a well with a specific capacity of 2.0 gpm per foot of drawdown is to be pumped at 400 gpm, more than 200 feet of available drawdown will be required to prevent dewatering the producing sands.

Small wells have been constructed to draw water from the Paluxy Formation in Tarrant County for supplying the small water systems because the water-bearing sands are relatively shallow and will produce adequate quantities of water. Large wells are constructed in the Paluxy downdip where it occurs at greater depth. Surface casing ranges from 6 to 18 inches in diameter and laps to casing of smaller diameter. Screens and liners range from 4 to 9 inches in diameter. A typical well has 12-inch surface casing and 5- or 6-inch screen and liner. Wells are underreamed or straight wall with gravel envelopes around the screen. Surface casing usually is cemented from the top of the producing zone to the land surface.

Total lengths of screen range from about 25 to 155 feet. The average screen length is about 85 feet. Most wells are equipped with shaft-driven or submersible turbine pumps, but a few large cylinder pumps are used. Pump settings range from about 240 feet to 800 feet or more and average slightly less than 500 feet. Motors as large as 100 horsepower drive the pumps installed in major wells, the average motor having about 40 horsepower.

Shallow Paluxy wells may pump large quantities of sand. Corrosion of discharge pipe, pump column, and pump is unlikely unless casing leaks permit highly mineralized water to enter the well.

Lower pumping levels, increased costs, and lower yields result as development of the aquifer increases. These usually can be controlled if development is not confined to a small area and if the wells and well fields are properly spaced. The water levels in Dallas and Tarrant Counties exhibit the effects of production confined to a relatively small area, and water-level declines with their associated problems have been serious in parts of these counties. Outside the areas of heavy pumping, water-level declines have not been serious and additional development probably can take place.

Ground Water Available for Development

Availability of ground water for future development has been determined for the Trinity Group aquifer rather than for each of its three units because of the hydraulic and geologic interrelationship of the units. The Travis Peak Formation is geologically and hydraulically continuous with the basal sands of the Trinity Group, undifferentiated, updip from the Glen Rose limestone, and the Paluxy Formation is geologically and hydraulically continuous with upper sands of the Trinity Group, undifferentiated, in the same area. Thus, north of the Glen Rose limestone wedge the two formations are combined to form the Trinity Group, undifferentiated, and because there is a vertical hydraulic connection between the two formations, they have a common piezometric surface and the same quality of water. Downdip, however, two separate hydrologic units exist, with different piezometric surfaces, different quality of water, and different hydrologic characteristics, even though the quantity of water that can be developed from them on a sustained basis is in part dependent on conditions in the Trinity Group, undifferentiated.

The amount of water available for development from the Trinity Group aquifer determined during this study is based on pumpage under assumed conditions and is related primarily to the ability of the aquifer to transmit water to the areas of pumping. It is assumed that the effect of pumping is such that the static water level is drawn down to the top of the aquifer where this depth is 400 feet below land surface. The line along which the top of the aquifer is 400 feet below the surface is roughly parallel with the outcrop. Thus, the hydraulic gradient causing water to move through the aquifer under assumed future conditions of pumping is the difference in the altitude of the water level in the outcrop and the altitude of the top of the aquifer immediately downdip where it is 400 feet below the land surface, divided by the distance between these points of altitude. The product of the average coefficient of transmissibility of the aquifer, the hydraulic gradient, and the effective length of the line along which the top of the aquifer is 400 feet below the land surface is the quantity of water the aquifer will transmit to supply withdrawals under these conditions. If the recharge to the aquifer is sufficient to supply the quantity of water moving downgradient through the aquifer, pumping under these conditions can be maintained indefinitely.

Problems encountered in applying this method of determining water availability for the Trinity Group aquifer were: the subsurface appearance of the Glen Rose Formation downdip from the outcrop area to form separate water-bearing units; variations in the coefficients of transmissibility of the water-bearing units in the region; variations in hydraulic gradients created by assumed conditions of pumping; and insufficient historical water-level and pumpage data for adequately evaluating the results of computations. The assumptions and generalizations made in an effort to circumvent these problems necessarily limit the accuracy of the results.

Insufficient water-level data are available to determine accurately the quantity of water moving through the aquifer prior to development. However, the hydraulic gradients undoubtedly were low, and probably on the order of 5,000 acre-feet of water annually was being discharged from the aquifer by means of vertical movement through overlying confining beds. In 1960, on the order of 35,000 to 40,000 acre-feet of water was discharged from the aquifer, based on hydraulic gradients existing at that time. Under the future hydraulic gradient that would be established under conditions of assumed development, on the order of 50,000 to 55,000 acre-feet of water would be transmitted each year from the outcrop to areas of pumpage.

With development taking place in accordance with the assumptions used for computations, it should be possible to obtain from 50,000 to 55,000 acre-feet of ground water from the aquifer each year. Thus, the quantity of additional water available from the aquifer on a sustained basis under the assumed conditions of development is on the order of 15,000 to 20,000 acre-feet per year over and above the estimated 34,000 acre-feet pumped in 1960.

Recharge to the Trinity Group appears to be more than adequate to supply the water needed to support pumpage under the assumed conditions of future development. The outcrop of the Trinity Group within the Trinity River Basin is approximately 768,000 acres. Therefore, less than 1 inch of the annual precipitation of 32 inches, or less than 3 percent of the annual precipitation, is needed as recharge to supply 55,000 acre-feet per year of withdrawals on a sustained basis. It seems that even under conditions of maximum development, water received by the Trinity Group aquifer as recharge will be greater than the amount that can be transmitted to supply withdrawals, and the excess will be discharged in the outcrop by natural means.

On the order of 15,000 to 20,000 acre-feet of water is available from storage in the aquifer during the course of establishing the assumed conditions of development. While this source of water is available for supporting short-term pumpage in excess of the sustained yield of the aquifer, it cannot be considered available on a sustained basis. Therefore, it should not be considered in planning as additional water that can be withdrawn on a continuous basis under assumed conditions.

Computation of available water was made by segments of the aquifer because of the problems noted. The computations indicate that roughly 75 percent of the additional water available for development occurs north of Dallas and Tarrant Counties, and pumpage data show that about 75 percent of the 1960 withdrawals from the Trinity Group aquifer occurred in Dallas and Tarrant Counties.

In 1956, about 50,000 acre-feet was pumped from the aquifer in Region I. This was approximately the total amount calculated to be available from the Trinity Group aquifer on a sustained basis under the assumed conditions. However, distribution of pumpage was such that the assumed conditions did not develop; parts of the aquifer were locally overdeveloped, and serious problems resulted. In effect, pumpage in the Dallas-Fort Worth area required steeper water-level gradients to move sufficient quantities of water to the area of withdrawal than were assumed for computations. In addition to water received from the outcrop, water also was obtained from artesian storage and from the surrounding areas.

In the Dallas-Fort Worth area, overproduction has created serious declines in water levels, and additional development there will only increase the related problems. Consequently, any additional development in this area will depend on economics rather than hydrology. Thick sections of fairly permeable sands in the area north of Dallas and Tarrant Counties contain water of good quality. These sands are considered capable of yielding significantly more water than they did in 1960. However, any large-scale development in this area will affect the future quantity of water available in Dallas and Tarrant Counties. The counties south of Dallas and Tarrant Counties probably are capable of more water production. The amount of development to the south, however, depends on withdrawals from the Paluxy and Travis Peak Formations in the Brazos River Basin on the west. Water is moving into this area from the outcrop in the Brazos River Basin. If the Trinity Group aquifer is not developed to its maximum capacity in the Brazos River Basin, then additional water will be available in the southern part of Region I (Johnson, Hill, Ellis, and western Navarro Counties).

The principal limitation to further development of the Trinity Group aquifer in Region I of the Trinity River Basin is the aquifer's relatively low coefficients of transmissibility, which require the spacing of wells or well fields throughout the region to obtain maximum development. However, this may not be practical from an economic viewpoint. The Trinity Group aquifer north of Dallas and Tarrant Counties is capable of more extensive production in Denton, Collin, southern Cooke, and southern Grayson Counties. The quality of water from the Trinity Group aquifer is acceptable for most uses.

A review of the conditions in Dallas and Tarrant Counties shows that this area is turning more and more to other sources of supply because of the difficulties experienced in overproduction. However, wells in the Dallas-Tarrant County area are sensibly being held in standby reserve for civil defense and emergency supplies.

Development of the Trinity Group aquifer in the area north of Dallas and Tarrant Counties has declined, possibly because of fears of duplicating problems experienced in the Dallas-Tarrant County area This would not necessarily be the case. Ground water in an amount that is several times the present pumpage is available in the area north of Dallas and Tarrant Counties, but its development will require wise planning to obtain full utilization. Of course, many factors other than those related to hydrology need to be considered and will have a direct bearing on the economics of developing the aquifer's full potential.

## Secondary Aquifers

### Woodbine Aquifer

#### Geologic Characteristics

The Woodbine aquifer is composed of lenticular, crossbedded, loose to slightly consolidated, fine-grained, ferruginous sand and sandstone interbedded with laminated clay. The sandbeds are more massive in the lower part of the formation and are replaced vertically by a higher percentage of laminated clay, gypsiferous clay, sandy clay, and lignite. The sands comprise approximately 50 percent of the Woodbine's total thickness.

The areal extent of the Woodbine aquifer in Region I is illustrated on Plates 8 and 9, which show the approximate altitude of the top of the aquifer and the thickness of the aquifer. The areal extent of fresh water is also shown on Figure 7. As shown by the contours on Plate 8, the Woodbine formation has a homoclinal east-southeast dip except in the extreme northeastern part of the region, where the dip is to the south. The rate of dip ranges from less than 35 feet per mile near the outcrop to nearly 100 feet per mile in the eastern part of Region I. The formation is cut by a series of northeast-trending normal faults, downthrown to the northwest, in southeastern Hill County. This is illustrated by the geologic section B-B' on Figure 5.

The horizon mapped as the top of the Woodbine aquifer and shown by the contours of Plate 8 is the top of the first massive sand below typical Eagle Ford shale. The type electric log used for determining the position of this horizon is from a test hole located in Dallas County. The horizon selected as the top of the Woodbine Group for use in this report is approximately 100 feet below the horizon mapped by Bergquist (1949) as the top of the Woodbine in the Red River area.

The top of the Woodbine, as defined by Bergquist, is a series of thin sand stringers that can be readily picked on logs in northeast Denton, northern Collin, and southern Grayson Counties. However, south of this area, the thin sand marking the top of this 100-foot interval becomes increasingly indistinct on electric logs, and the interval resembles the shales of the Eagle Ford Group in appearance on the electric logs. Consequently, the first massive or prominent sand below the shale zone becomes more acceptable as a pick for the top of the Woodbine in the Trinity River Basin. This pick is carried throughout Denton, Collin, and southern Grayson Counties for the sake of uniformity.

The Woodbine Group thickens downdip and to the north. Thickness in the direction of dip increases from 0 at the edge of the outcrop to more than 500 feet in eastern Collin County. The Woodbine thins southward along the strike from southern Grayson County, where its thickness is 400 to 450 feet, to southern Hill County, where its thickness is about 200 feet.

The depth to the top of the Woodbine, where it contains fresh water, ranges from the surface in its outcrop to more than 2,000 feet below the surface in western Kaufman County. At greater depths downdip, the water probably is too mineralized for most uses. Plate 8 shows generalized depths to the top of the aquifer.

Occurrence and Movement of Ground Water

Water occurs in the Woodbine aquifer under both water-table and artesian conditions. Water-table conditions exist west of a line roughly coincident with the +400-foot contour line in southern Denton County and in western Dallas and Ellis Counties shown on Plate 8. This area includes the outcrop of the Woodbine Group and areas immediately downdip. East of this line, static water levels generally are above the top of the aquifer and artesian conditions prevail. However, pumping levels of wells just east of where water-table conditions exist, are below the top of the aquifer.

In most of Region I, water in the Woodbine aquifer generally moves downdip at approximately right angels to the strike of the beds. In Dallas County, where there is a large amount of pumpage, a cone of depression has developed. Water-level observations in scattered wells indicate water moves into this area of development from the north, west, and south. Information is too limited to ascertain whether water is moving updip from the east and entering this area of pumpage.

## Recharge and Discharge

Recharge to the Woodbine aquifer occurs in its outcrop, which is shown on Plate 8. The outcrop forms a south-trending band, averaging about 10 miles in width and extending from the northern boundary of Region I at the Cooke-Grayson County line to the southern boundary of Region I in Johnson County. The outcrop is an area of gentle rolling hills and knobs, sandy soils, and post oaks. The sandy soils of the outcrop are fairly permeable and relatively conducive to the intake of water that falls as precipitation or seeps from streams flowing over the outcrop.

Ground water is discharged naturally from the Woodbine at springs and seeps and by evapotranspiration in the outcrop. Rejected recharge during certain seasons of the year furnishes water to such streams as the Trinity River, Denton Creek, and the Elm Fork of the Trinity River. Downdip, where the formation is under artesian head, natural discharge occurs by means of upward leakage through confining beds.

Pumping from wells constitutes the artificial discharge from the Woodbine aquifer with the heaviest concentration of pumpage occurring in Dallas County for municipal and industrial use.

## Water Levels

Depths to water range from the surface in the outcrop to more than 440 feet below the land surface in the areas of high surface elevation in Dallas and Ellis Counties. Fluctuations of water levels in the Woodbine aquifer are caused principally by changes in the rate of pumping. Leggat (1957, p. 53) has shown that evapotranspiration is a cause of water-level changes in the Woodbine outcrop. These changes are similar to those that occur in the outcrop area of the Trinity Group aquifer. Variations in the amount of recharge also will cause fluctuations which are more easily observed in and near the outcrop. Fluctuations caused by factors other than pumping generally are minor.

Information is too sparse to make anything but general statements about water-level declines. In the Sherman area of Grayson County in the Red River Basin, water levels in the Woodbine declined 240 feet from 1909 to 1958, with 65 percent of the decline occurring from 1945 to 1958 (Baker, 1960, p. 45). The situation in the Dallas area is probably analogous except that the decline probably has been at a slower rate.

Over the extent of the aquifer, water levels have lowered as pumping increased, but the magnitude of this decline has not been determined for lack of sufficient data. The few records available from Dallas and Ellis Counties indicate an average water-level decline in this area of approximately 8 feet per year for the last 20 years. These figures are largely reported and may be subject to question.

Water-Bearing Characteristics

Sediments of the Woodbine Group were deposited near the shore of an ancient sea under nonmarine, littoral, and marine environments. The sediments make up a heterogenous collection of fine-grained sand, clay, gypsiferous clay, lignite, and silt that are anything but uniform. Thus, the modes of deposition profoundly affect the hydraulic characteristics of the aquifer and the quality of the water it contains. The fine sand, pronounced lenticularity of the beds, and intricate interfingering of clay and sand are factors contributing to the low transmissibilities of the aquifer.

Data available from pumping tests made on wells completed in the Woodbine aquifer illustrate the aquifer's low transmissibility. A coefficient of transmissibility of about 300 gpd/ft. is indicated for western Kaufman County, and one of about 1,000 gpd/ft. was obtained from a pumping test made in Ellis County. Coefficients of transmissibility of 1,900 and 3,200 gpd/ft. were obtained from 2 tests made in Dallas County. The coefficient of permeability indicated for western Kaufman County is approximately 1 gpd/ft$^2$. Coefficients of permeability determined from the tests in Ellis and Dallas Counties noted above were 13, 12, and 29 gpd/ft.$^2$, respectively. Baker (1960, p. 54) reported that a coefficient of transmissibility of 12,500 gpd/ft. and a coefficient of permeability of 110 gpd/ft.$^2$ were determined from a pumping test made in southern Grayson County. In the Red River Basin part of Grayson County, Baker (1960, p. 54) reported coefficients of transmissibility ranging from 2,100 to 6,000 gpd/ft. with the average for tests of 8 wells being 2,570 gpd/ft. Coefficients of permeability for the same 8 wells ranged from 14 to 48 gpd/ft.$^2$ and averaged 32 gpd/ft$^2$.

The coefficients of transmissibility and permeability obtained from the test in southern Grayson County within the Trinity River Basin are probably higher because of thick sand lenses in the Woodbine Group in this area. The lithology and coefficients of transmissibility of the Woodbine aquifer vary considerably. In general, coefficients of transmissibility on the order of 2,500 to 3,000 gpd/ft. or more may be anticipated in the area north of Dallas County. South of Dallas County, the aquifer is thinner; hence, coefficients of transmissibility on the order of 1,000 gpd/ft. might be expected.

Coefficients of storage determined from 5 wells in Grayson County (Baker, 1960, p. 54) ranged from 0.0002 to 0.00002 and averaged 0.00012. This general range of coefficients probably is applicable for the aquifer in areas to the south.

Two distance-drawdown graphs have been prepared based on coefficients believed to be generally applicable in one case to the northern part of the region and in the other case to the southern part of the region. Figure 14, the graph for the northern area (Case I) was prepared by using a coefficient of transmissibility of 3,000 gpd/ft., a coefficient of storage of 0.0001, a pumping rate of 500 gpm, and a distance to the outcrop of about 8 miles. The graph for the southern area (Case II), shown on Figure 15, was based on a coefficient of transmissibility of 1,000 gpd/ft., a coefficient of storage of 0.0001, a pumping rate of 100 gpm, and a distance to the outcrop of about 13 miles. Drawdowns in both graphs were computed along a line parallel with the outcrop and passing through the pumped well.

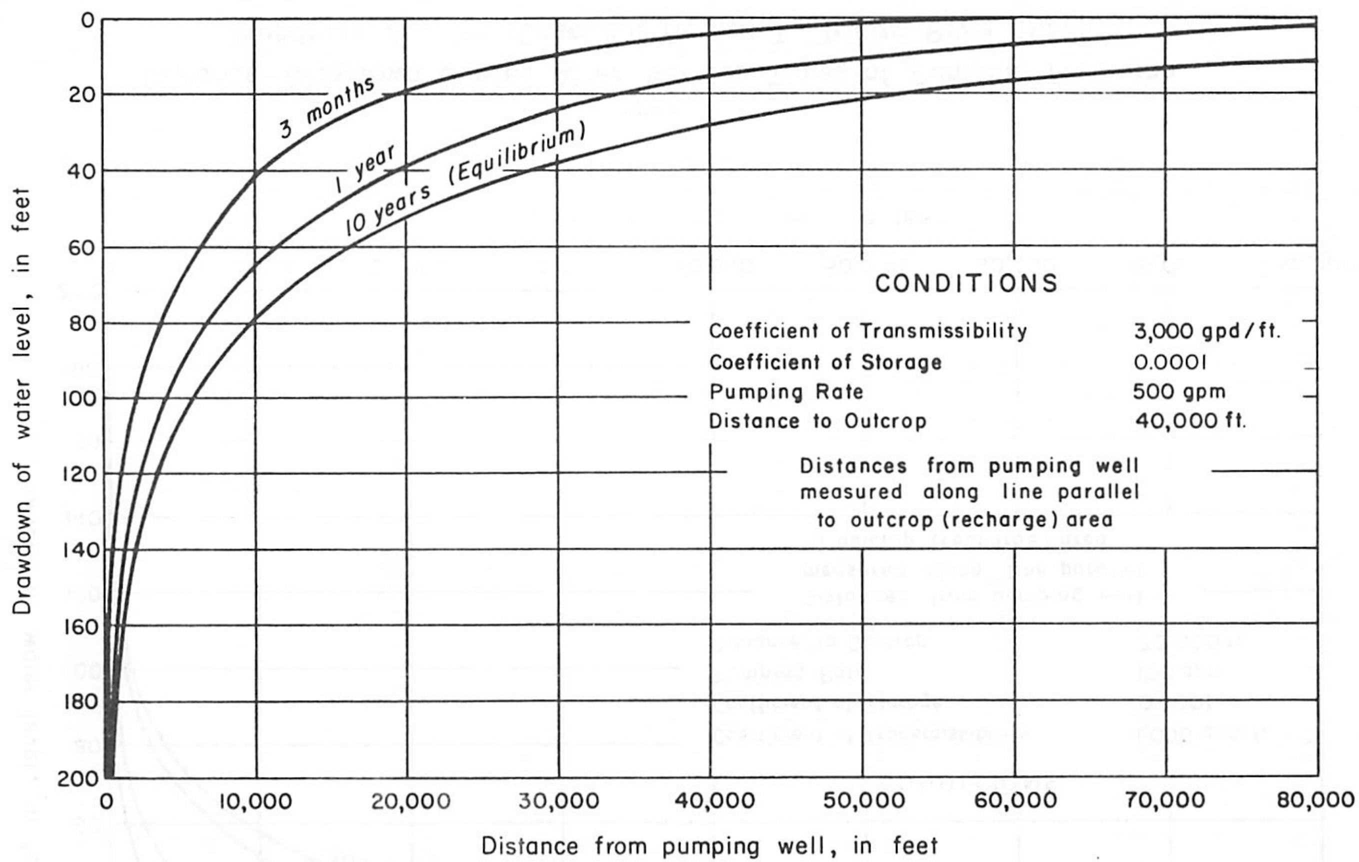


Figure 14

**Distance-Drawdown Curves After Various Times of Pumping From the Woodbine Aquifer (Case I), Region I, Trinity River Basin**

Texas Water Commission in cooperation with the U. S. Geological Survey

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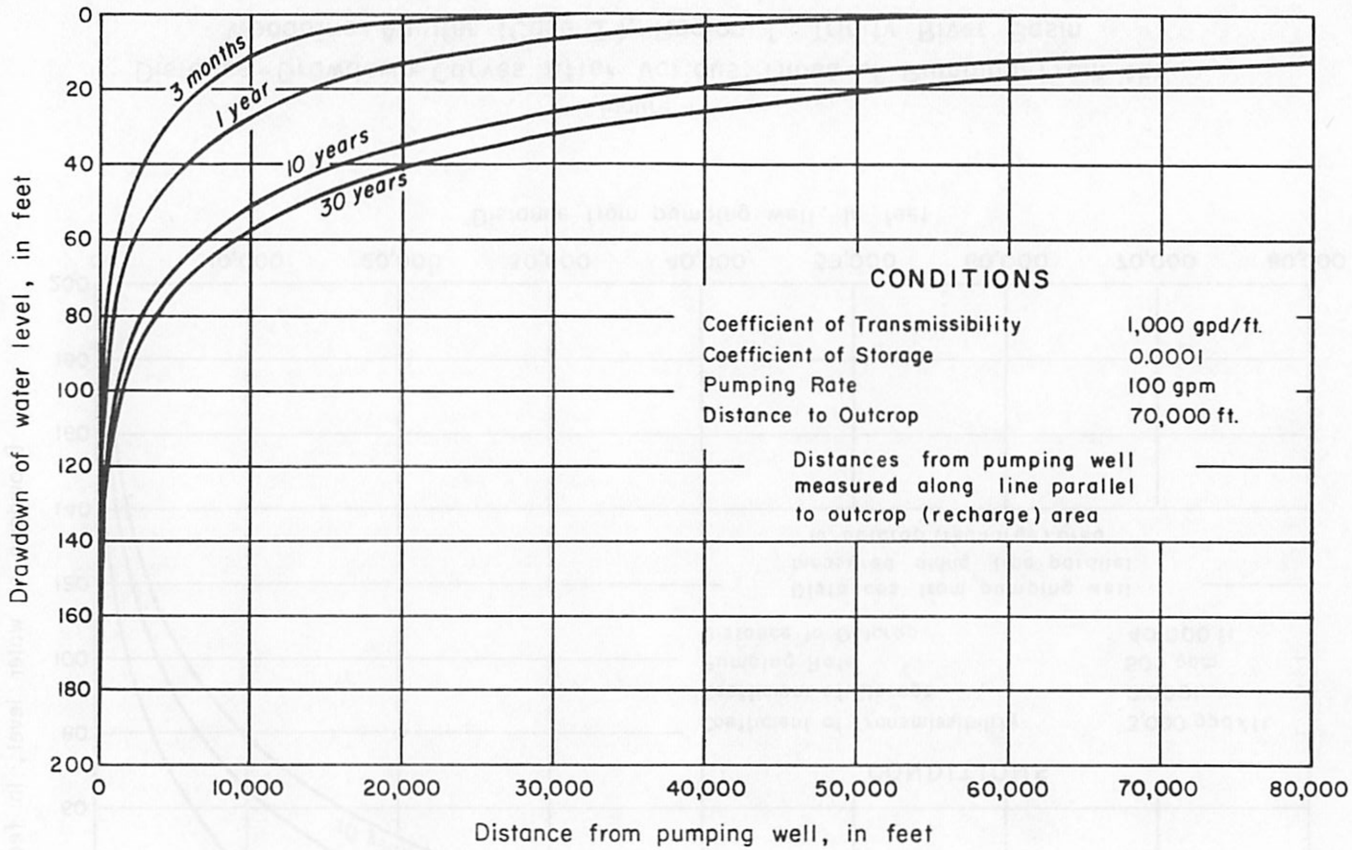


Figure 15

Distance-Drawdown Curves After Various Times of Pumping From the Woodbine Aquifer (Case II), Region I, Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

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## Chemical Quality

The chemical quality of the water from the Woodbine aquifer is the poorest of the primary and secondary aquifers in Region I. It is principally a sodium bicarbonate type water that is generally high in dissolved solids, sulfate, fluoride, and in places chloride. Excess iron concentrations occur in several localities, especially near the outcrop. Chemical analyses show that water from 25 of the 51 wells sampled contained in excess of 1,500 ppm dissolved solids. Electric logs indicate that generally poorer quality water is encountered in the upper sandbeds of the aquifer, and in most cases only the lower part of the aquifer is developed to supply major wells.

The water is soft except in small localized areas in the outcrop. In general, the quality of water in the Woodbine aquifer becomes progressively poorer in the downdip direction, and in many parts of the region various mineral constituents greatly exceed the maximum limits recommended by the U. S. Public Health Service. Chemical analyses of water from selected wells are given in Table 2 to illustrate the general quality of water encountered in the Woodbine aquifer in various parts of Region I.

Generally, dilution with water of better quality is the most feasible means for improving the water quality. Aeration and filtration may be used satisfactorily to treat for excess iron concentration where it occurs.

Future quality of water problems are largely limited to more mineralized water entering individual wells through surface-casing leaks. Encroachment of poorer quality water from downdip areas of the aquifer is not a forseeable problem. However, much of the water in the aquifer is presently of relatively poor quality, and those areas that have good quality Woodbine water may experience an increase in mineralization of the water if pumpage increases considerably.

## Utilization and Development

The Woodbine aquifer is a popular source of water for small housing developments, water companies, small towns, and industries not requiring large quantities of water. Development of the Woodbine aquifer in Dallas County has been similar to development of the Paluxy Formation of the Trinity Group aquifer in Tarrant County.

Construction of wells to draw water from the Woodbine aquifer took place before the turn of the century, and for many years this aquifer was the main source of water in the eastern part of Region I. Development progressed steadily until World War II, when a noticeable increase in production occurred. Many water systems designed for small industries and housing developments were expanded to keep pace with the rapid urbanization. Pumpage from the Woodbine aquifer probably reached its peak in 1955 or 1956, when the water needs of an expanding population were augmented by severe drought conditions. Since the drought, pumpage has declined slightly. Total pumpage from the Woodbine aquifer in 1955 was about 6,000 acre-feet (5.4 mgd), as compared to about 5,700 acre-feet (5.1 mgd) in 1960. During this period annual municipal pumpage increased by by about 200 acre-feet, while industrial pumpage decreased. About 60 percent of the total 1960 pumpage occurred in the Dallas County area. Pumpage from the Woodbine aquifer for 1960 is presented by major drainage subdivisions in Table 3.

Woodbine wells produce from fine-grained sands of low permeability, which limits their yield. Reported pumping rates of the wells inventoried ranged from very small to about 600 gpm. The average pumping rate was about 130 gpm.

Specific capacities of 6 wells reported or computed from drillers' test data ranged from 0.84 to 5.7 gpm per foot of drawdown. Leggat (1957, p. 75) reported that specific capacities of 7 wells in Tarrant County ranged from 0.3 to 3.9 gpm per foot of drawdown. In the Red River Basin part of Grayson County, specific capacities of 12 wells ranged from 0.36 to 6.0 gpm per foot of drawdown (Baker, 1960, p. 53). Most specific capacities are less than 3.0 gpm per foot of drawdown.

Major wells have casing ranging from 4 to 20 inches in diameter at the surface and lapped or swedged to liners and screens ranging from 3 to 10 inches in diameter. The overlying formations are cemented off, and the more recent wells are generally underreamed and gravel packed.

Public-supply and industrial wells have screen lengths ranging from 20 to 150 feet and averaging about 85 feet. Shaft-driven turbine pumps are installed in most of the wells, although some submersible turbine and cylinder pumps are used. Pumps such as the Peerless Hi-lift are popular in small wells requiring yields of 10 to 40 gpm. Depths of pump settings in the major wells range from less than 200 feet to 700 feet and average 440 feet. Motors up to 110 horsepower drive the pumps. The average horsepower for the major wells inventoried was 85.

Woodbine wells pump some sand, especially the ones near the outcrop. Some corrosion and encrustation of well screens occurs in Woodbine wells.

Because the Woodbine aquifer has extremely low coefficients of transmissibility, very large drawdowns are required to obtain large amounts of water. This is illustrated by the distance-drawdown curves of Figures 14 and 15. Increases in pumpage withdraw the water faster than the initial gradient will allow it to move in from the areas of recharge. As a result, water is removed from artesian storage to make up the difference, and water levels are lowered until a new equilibrium gradient is established.

The problem of declining water levels is increased where wells are closely spaced. The drawdowns caused by well interference are greater, and severe water-level declines result. This condition has developed in Dallas County, although it is not overly severe. Consequently, pumping levels have lowered, pumping costs have increased, and pumping rates have decreased and will continue to do so if pumpage is increased in areas of concentrated withdrawal. Because well fields in small areas are not always practical, the cost of pipelines and other facilities for transporting water must be considered in determining the cost of a water system where several wells in the Woodbine aquifer are required to supply the needs.

## Ground Water Available for Development

Approximately 5,700 acre-feet (5.1 mgd) of water was pumped from the Woodbine aquifer in 1960 in the Trinity River Basin. If assumed conditions of pumpage occur so as to draw the water levels down to the top of the aquifer where it is 400 feet below land surface, approximately 12,000 acre-feet per year (10 mgd), or double the 1960 pumpage, could be developed from the Woodbine aquifer in Region I.

In the Trinity River Basin, the Woodbine crops out in an area of about 900 square miles, on which an average of 34 inches of precipitation falls annually. To supply the 12,000 acre-feet of potential withdrawals, less than one-fourth of an inch of recharge per year is needed. An inch of precipitation reaching the aquifer's water table in the outcrop represents 48,000 acre-feet of recharge. It appears that more than this amount can reach the water table each year. Thus, if the aquifer can transmit only 12,000 acre-feet of this water to areas of development every year under the assumed conditions of withdrawal, the remainder of the recharge must be rejected by the aquifer to points of natural discharge in the outcrop. Some of this rejected recharge might be salvaged by development of additional water supplies in the outcrop area.

It is estimated that on the order of 15,000 to 20,000 acre-feet of ground water can be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed. Although this is a sizeable quantity of water in relation to present pumpage, it will have been withdrawn by the time assumed conditions of pumpage are established and thus should not be considered as water available for development on a sustained basis.

The most favorable area for further Woodbine development is in southern Grayson County and the northern half of Collin County. Here the sand beds are thicker, the transmissibility is higher, the water quality is fair, and the depth to the aquifer is not excessive. The Woodbine aquifer also could be developed more extensively in Ellis and Hill Counties, but conditions are not as favorable as they are in the northern part of Region I. The aquifer probably has been developed to near its perennial yield capacity in Dallas County.

The principal problem of developing water from the Woodbine is a "pipeline" problem; that is, the aquifer has low coefficients of transmissibility that limit the quantity of water that can move through it from the area of recharge to the points of discharge under hydraulic gradients that are within the economic limits of development. Thus, one of the main points to be considered in developing water supplies in the Woodbine aquifer is an orderly and systematic spacing of well fields. However, this may not always be economically feasible or practical.

Another limiting factor in the development of water from the Woodbine aquifer is the chemical quality of its water. Water with an excess of dissolved solids, sulfate, chloride, fluoride, and iron is presently being used satisfactorily for many purposes. If certain industrial or public health standards must be strictly followed for a water system, the quality of the water that can be obtained from the aquifer should be inspected before development. The problem of encroachment of more mineralized water from downdip areas does not seem probable in the near future.

Water levels will continue to decline as pumpage increases, for this is essential for development. However, with proper well spacing, declines should not be severe. It is only in areas of concentrated pumpage that severe water-level declines are experienced.

Individual wells should be properly constructed with surface casing cemented through the overlying formations to prevent highly mineralized waters from entering the wells.

## Other Aquifers

### Rocks of Pennsylvanian Age

The rocks of Pennsylvanian age that crop out in the northwestern part of Region I, shown on Plate 1, are a source of water for small public supplies, small industries, and for livestock and domestic wells. The structure of the rocks, as shown by the geologic section on Plate 4, and their lithologic characteristics are generally unfavorable for obtaining large quantities of water of good quality.

Pumping rates range from a few to as much as 60 gpm. Major pumpage from these rocks was estimated to be 300 acre-feet in 1955 and 117 acre-feet in 1960.

The chemical quality of the water varies from good to brines. Production from these rocks is very spotty and localized. Thus, additional future development is extremely limited.

### Nacatoch Formation

The Nacatoch Formation of the Navarro Group crops out in central Navarro County in the extreme southeastern part of Region I. It occurs in a narrow southwestward-trending belt about 2 miles wide, extending generally from near the Trinity River at the western part of Henderson County to near the Navarro-Limestone County line. It is very limited as an aquifer because of a rapid change in water quality downdip and because of its poor transmission characteristics. Although pumping rates of wells are less than 10 gpm, about 24 acre-feet of water was pumped from the aquifer in 1960 for municipal use. Domestic and livestock supplies also are obtained from the sands of the Nacatoch Formation.

### Alluvium

Alluvial deposits of sand, silt, clay, and gravel along the Trinity River and its main tributaries furnish water for some small industries, small public supplies, irrigation, and for livestock and domestic purposes. Pumpage for industrial and public supplies was about 190 acre-feet in 1955 and about 160 acre-feet in 1960. The quantity of water pumped for irrigation is not known but may be on the same order as that for industrial and public supplies.

Pumping rates of large-diameter wells may be as high as 200 gpm. The water quality varies from place to place, but generally is only fair. However, this source of supply can be easily contaminated by improper disposal of municipal or industrial wastes on the land surface or into streams crossing the alluvium.

The level of water in the alluvium is delicately balanced between local recharge and discharge because of the small amount of saturated section. Excessive disturbance of this balance by increasing withdrawals can cause the failure of wells. Generally, the aquifer has a limited potential for development in Region I.

## Region II

Primary aquifers in Region II of the Trinity River Basin consist of the Carrizo Formation and Wilcox Group, and the Sparta Formation. The only secondary aquifer in this region is the Queen City Formation. The areal extent of the primary and secondary aquifers of the Trinity River Basin is shown on Figure 7. The Trinity Group aquifer and the Woodbine aquifer, which occur in Region I, extend into the northern part of Region II in Rockwall and northern Kaufman Counties. Their extent in Region II is small, and the quality of the water is marginal. Therefore, those parts of the Trinity Group and Woodbine aquifers that occur in Region II have been treated in the discussion on Region I and will not be discussed further in this section. Other aquifers that presently supply small amounts of water for municipal, industrial, irrigation, domestic and livestock use have a limited potential for further development. These aquifers are the Nacatoch Formation of the Navarro Group, Cook Mountain Formation, Yegua Formation, Jackson Group, and alluvium.

### Primary Aquifers

#### Carrizo-Wilcox Aquifer

The Carrizo Formation and Wilcox Group are two separate geologic units, having their own distinct geologic and hydrologic characteristics. The sand of the Carrizo Formation overlies the sands and shales of the Wilcox Group. In places, shale separates the sand beds of the two geologic units, and in other places the shale is missing and the sand of the Carrizo is in direct contact with upper sandbeds of the Wilcox. Because the shale is absent in many places, the two units are hydraulically connected and therefore are considered in this report as one aquifer.

##### Geologic Characteristics

The Carrizo Formation is a white to gray, well-sorted, quartz sand or poorly cemented sandstone which contains only a few very thin beds of shale. In general, the sand is medium grained near the base, grading upward into a fine-grained sand. Sand makes up 90 to 100 percent of the formation's total thickness, which is generally between 100 and 200 feet. The composition of the Wilcox Group ranges from lignite and shale to a loose quartz sand. It is made up of alternating beds of sand, sandy shale, and shale whose thicknesses and stratigraphic position in the formation vary widely from well to well. The thicknesses of the individual sand layers range from a few to 200 feet. The sands are gray to brown and highly lenticular and make up approximately 40 to 50 percent of the Wilcox's total thickness. Sands of the two units make up approximately 50 percent of the aquifer's total thickness.

The areal extent of the Carrizo-Wilcox aquifer, where it contains water of less than 3,000 ppm dissolved solids, is illustrated on Plates 10 and 11, which show the thickness and approximate altitude of the top of the aquifer. The areal extent of the aquifer also is shown on Figure 7.

As shown by the contours on Plate 10, the Carrizo-Wilcox aquifer in the area generally north of U. S. Highway 84 between Palestine and Fairfield dips approximately 20 to 25 feet per mile to the southeast into the East Texas embayment, the axis of which lies east of the Trinity River Basin. South of this area, in Leon and southern Anderson Counties, structural highs and faults disrupt the general regional dip. South of these structural features, the beds dip south-southeast toward the Gulf of Mexico at a rate of 50 to 60 feet per mile in Houston and southern Leon Counties, increasing to more than 100 feet per mile in the extreme southern part of Region II.

In addition to the above-mentioned structural features, numerous salt domes in Anderson, Freestone, Leon, and Houston Counties, affect both the attitude of the beds and the thickness of the aquifer (Plates 10 and 11).

The Carrizo-Wilcox aquifer thickens downdip from its outcrop area. Thickness of the aquifer ranges from zero at the northwest extent of the outcrop to more than 2,600 feet in southern Leon County. The Carrizo Formation and Wilcox Group continue to thicken south of this area, but the water in the lower part of the Wilcox Group contains more than 3,000 ppm dissolved solids. The fresh water-salt water interface is best illustrated on Plate 4. The aquifer is thinner over the salt domes; in some places it has been completely removed and older rocks are exposed at the surface.

The depth to the top of the aquifer ranges from zero in the outcrop area to more than 2,000 feet in the southern part of Region II. Plate 10 shows generalized depths to the top of the aquifer. The Carrizo Formation and Wilcox Group downdip at greater depths probably contain water too mineralized for most uses.

### Occurrence and Movement of Ground Water

Water in the outcrop of the Carrizo-Wilcox aquifer occurs under water-table conditions, whereas immediately downdip water occurs under artesian conditions. The outcrop area of the Carrizo-Wilcox aquifer is shown on Plates 10 and 11. Locally, impermeable layers of shale create both perched water zones and localized artesian conditions in the outcrop area.

In and north of Leon and Anderson Counties, water in the Carrizo-Wilcox aquifer tends to move toward the Trinity River. South of these counties the water-level gradient, although somewhat flattened, indicates that water is moving toward the south-southeast. The present water-level gradient, as determined from water-level measurements in scattered wells, is between 5 and 10 feet per mile. The distribution of wells available for water-level measurements are such that only generalized gradients can be determined. In the immediate vicinity of Palestine, a small cone of depression has developed because of pumping in the area, causing water to move into the area from all directions.

### Recharge and Discharge

Recharge to the Carrizo-Wilcox aquifer occurs in its outcrop area which forms a southward-trending band from the eastern boundary of the basin in Van Zandt and Henderson Counties to the western boundary of the basin in Freestone County. The outcrop ranges in width from 12 miles in Henderson County to approximately 22 miles in Freestone County and includes more than 1,100 square miles. The outcrop area is characterized by gently rolling to hilly topography and is covered by loose sandy soils which are timbered with oak trees. The sandy soils are permeable and allow much of the rainfall to be absorbed.

Ground water is discharged naturally from the Carrizo-Wilcox aquifer by springs and seeps and by evapotranspiration in the outcrop area. Both ground-water discharge and rejected recharge furnish water to the Trinity River and its tributaries. Downdip, where the aquifer is under artesian conditions, natural discharge occurs by means of upward leakage through the confining beds.

Flowing and pumping wells constitute the artificial discharge from the Carrizo-Wilcox aquifer. The pumping wells are scattered throughout the area, whereas most of the flowing wells occur along the Trinity River or some of its major tributaries where the elevation is lower than the hydrostatic head of the aquifer. The water from flowing wells normally drains into nearby streams and eventually into the Trinity River.

### Water Levels

Depths to water in the Carrizo-Wilcox aquifer range from zero in the outcrop area to 430 feet in the vicinity of Palestine. Part of this depth in the vicinity of Palestine can be attributed to the altitude of the land surface and part to pumping in the area. Generally, the depths to water along the basin boundaries are between 200 and 300 feet, owing to the high altitude of the land surface. The water levels throughout most of the rest of the region are less than 100 feet below the land surface. In areas of concentrated pumping, water levels fluctuate in response to changes in the rate of pumping. In the outcrop area, evapotranspiration as well as variations in the amount of rainfall cause changes in the water level.

There is little historic data on water levels in the Carrizo-Wilcox aquifer from which to determine water-level declines. In the vicinity of Palestine, according to reported water-level measurements, the water levels have declined 60 to 90 feet between 1940, which was prior to the development of the city wells, and 1960. These declines are not excessive, and are necessary to produce gradients sufficient to transmit the amount of water being pumped from the aquifer in this area. Over the remainder of the aquifer there appears to have been no lowering of water levels although minor seasonal fluctuations occur.

Water-Bearing Characteristics

The Carrizo Formation is a massive, well-sorted, homogeneous sand that is poorly cemented and contains only minor amounts of shale. The Carrizo Formation has relatively high coefficients of permeability and transmissibility, whereas the Wilcox Group consists of lenticular beds of sand, clay, and lignite and has lower and varying coefficients of permeability. However, owing to its thickness, the Wilcox generally has a relatively high coefficient of transmissibility.

The coefficients of transmissibility from 3 pumping tests made on wells completed in the Carrizo Formation in Anderson and Leon Counties ranged from 21,000 to 31,000 gpd/ft. and averaged 27,500 gpd/ft. The coefficients of permeability determined from the 3 tests ranged from 248 to 480 gpd/ft.$^2$ and averaged 355 gpd/ft$^2$. The coefficients of permeability determined from a number of tests made in the Neches River Basin averaged 220 gpd/ft.$^2$, indicating that the permeabilities obtained on the 3 tests mentioned above may be slightly higher than would generally be expected throughout the Trinity River Basin. The coefficients of transmissibility obtained from the tests made in the Neches River Basin were similar to those obtained in the Trinity River Basin.

The coefficients of transmissibility in the Wilcox Group differ greatly from well to well. The coefficients of transmissibility from tests conducted in the Trinity River Basin at the cities of Elkhart, Fairfield, and Palestine ranged from 5,000 gpd/ft. at Fairfield to 19,000 gpd/ft. at Palestine. The wide range in transmissibility was caused by different amounts of sand being screened and by changes in permeability which ranged from 40 gpd/ft.$^2$ at Fairfield to 145 gpd/ft.$^2$ at Elkhart. At the city of Fairfield, several sand beds near the middle of the Wilcox Group were screened, totaling 133 feet. In the city of Elkhart well, approximately 105 feet of massive sand was screened, between the depths of 905 and 1,010 feet, in the upper section of the Wilcox. The coefficient of transmissibility of 19,000 gpd/ft. at the city of Palestine was an average of tests conducted on 4 wells in which the coefficients of transmissibility ranged from 14,000 to 24,000 gpd/ft. These wells screened large sections of the sands in the middle and lower part of the Wilcox. Pumping tests conducted on wells in the Neches River Basin indicate the same wide variation in transmissibilities as those found in the Trinity River Basin tests. Here also, the variations are due to changes in permeability and to different amounts of sand being screened.

In general, coefficients of transmissibility on the order of 25,000 to 30,000 gpd/ft. can be expected from the Carrizo Formation in the areas downdip from the outcrop, except in the immediate vicinity of salt domes. Similar coefficients of transmissibility can be obtained from the Wilcox Group if all of the sand beds are screened. This is not always practical, and in many places the lower part of the Wilcox contains water of poorer quality than the remainder of the aquifer.

Coefficients of storage obtained from tests of wells completed in the Carrizo-Wilcox aquifer in the Neches River Basin ranged from 0.0001 to 0.0004 and averaged about 0.0002. This general range of coefficients probably is applicable for the aquifer in the Trinity River Basin.

A distance-drawdown graph has been prepared based on coefficients believed to be the most applicable to the aquifer. Figure 16 shows the amount that water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances are measured along a line parallel with the outcrop and passing through the pumped well. The pumped well is located 15 miles from the outcrop area and pumps at a rate of 700 gpm. A coefficient of transmissibility of 25,000 gpd/ft. was used to prepare this graph, in as much as most wells completed in the area will either screen the Carrizo sand or the Wilcox sands separately. The coefficient of storage used was 0.0002.

## Chemical Quality

Water from the Carrizo-Wilcox aquifer is of good and relatively uniform quality in the region. Chemical analyses of water samples collected from 48 wells showed 35 contained less than 500 ppm dissolved solids; 10 contained between 500 and 1,000 ppm; 2 contained between 1,000 and 1,500 ppm; and only 1 contained between 1,500 and 2,000 ppm. Of the 3 samples containing more than 1,000 ppm dissolved solids, 1 was from a well located in the vicinity of a salt dome, 1 was from a well located at the southern end of the region, and the other was from a well located in the center of the region but producing from the lower part of the aquifer. Sulfate content ranged from 0 to 213 ppm, and all but 3 samples had less than 100 ppm. Chloride ranged from 3 to 264 ppm, with only 1 analysis exceeding the recommended limits of 250 ppm, and only 6 exceeding 100 ppm. The bicarbonate in the analyzed samples ranged from 4 to 888 ppm, with most analyses exceeding 100 ppm, and many had as much as 500 ppm bicarbonate. Of the 34 samples analyzed for iron content, 18 were above the recommended limits of 0.3 ppm. The range of iron was from 0.02 to 10 ppm. High iron contents are quite common in the outcrop and for a short distance downdip. Hydrogen sulfide gas is also encountered in some localized areas throughout the region. The water in the Carrizo-Wilcox is relatively soft except in localized areas of the outcrop, where the water in places contains as much as 300 ppm total hardness. Chemical analyses of water from a few selected wells screening the Carrizo-Wilcox aquifer are given in Table 4 to illustrate the general quality of water in various parts of the region.

The amount of dissolved solids in the water increases with depth, toward the base of the Wilcox. The base of the Wilcox in much of Region II contains dissolved solids near 3,000 ppm and in the southern part of the region contains more than 3,000 ppm. Few samples are available from the lower part of the aquifer or from the southern part of the region where the aquifer is quite deep. Electric logs, however, indicate water of poor quality in the lower part of the Wilcox in the southern half of the region.

Water from the Carrizo-Wilcox aquifer is suitable for most uses where it occurs in Region II and no treatment appears to be necessary except where high iron or hydrogen sulfide concentrations are encountered. Iron and hydrogen sulfide can be removed by rather simple treatment methods.

Future quality of water problems in the Carrizo-Wilcox aquifer can be caused by improper casing of wells and casing leaks, which will allow water of poorer quality, usually water from overlying formations containing iron, to enter the individual wells. A few wells in the region contain chloride concentrations higher than is normally expected for the Carrizo-Wilcox aquifer, which

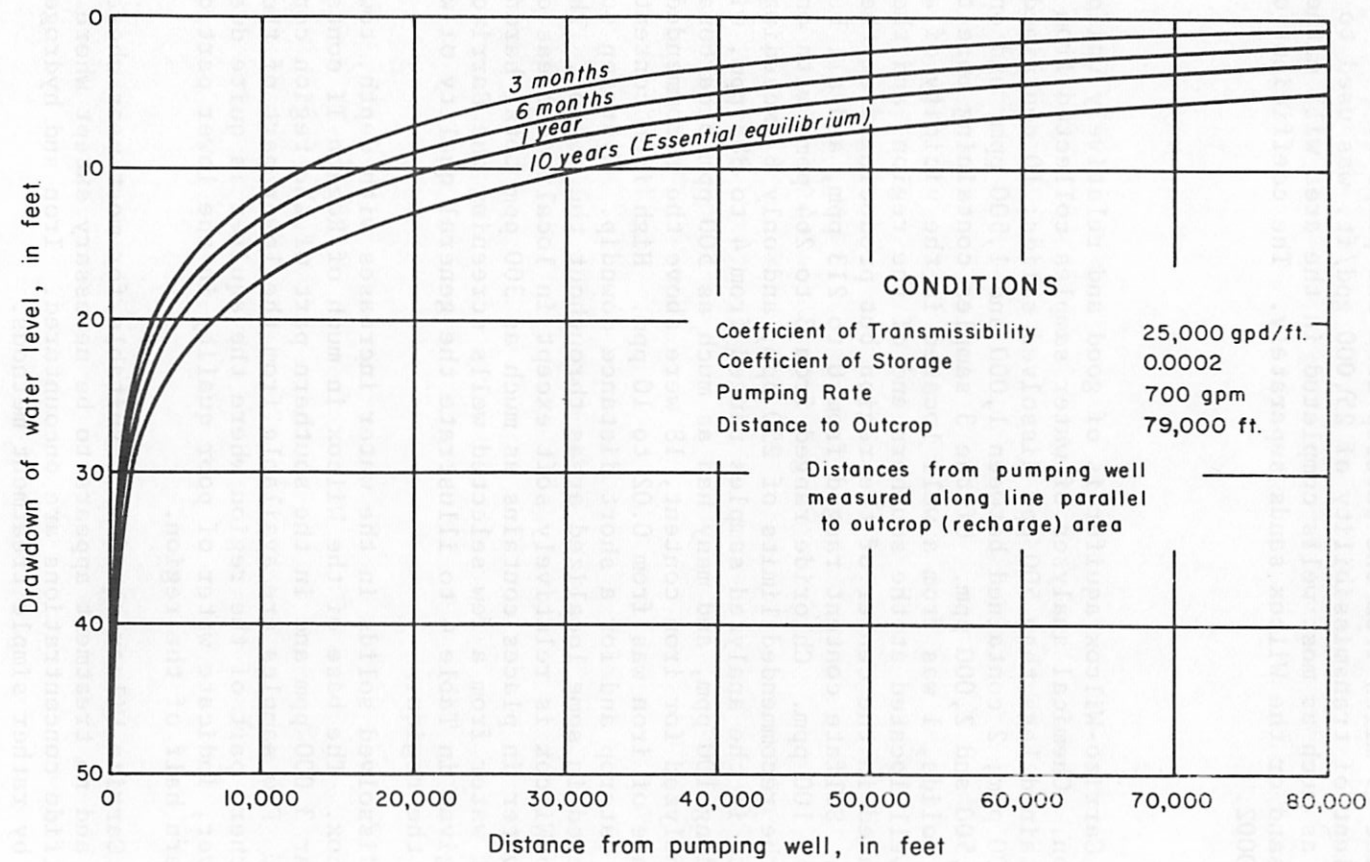


Figure 16

**Distance-Drawdown Curves After Various Times of Pumping From the Carrizo-Wilcox Aquifer, Region II, Trinity River Basin**

Texas Water Commission in cooperation with the U. S. Geological Survey

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Table 4.--Representative chemical analyses of water from primary and secondary aquifers, Region II, Trinity River Basin

(Analyses by U. S. Geological Survey unless noted. Analyses expressed in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio.)

| Well | Owner | Depth of well (ft.) | Date of collection | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na + K) | Bicarbonate ($HCO_3$) [1] | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Total hardness as $CaCO_3$ | Percent sodium | Sodium adsorption ratio (SAR) | Specific conductance (micromhos at 25°C.) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Carrizo-Wilcox Aquifer** | | | | | | | | | | | | | | | | | | | |
| 33-48-604 | R. D. Frazier | 242 | 5- 3-61 | 14 | 0.20 | 6.0 | 1.9 | 126 | 234 | 31 | 51 | 0.2 | 0.0 | 350 | 23 | 92 | 11 | 574 | 7.9 |
| [2] 34-50-104 | City of Athens #6 | 859 | 6- 2-54 | 16 | .1 | 9 | 2 | 103 | 183 | 3 | 58 | -- | -- | 410 | -- | -- | -- | -- | 8.4 |
| [3] 38-01-902 | Engeling Wildlife Refuge | 280 | 7-26-54 | 31 | 2.1 | 22 | 8 | 15 -- | 85 | 16 | 25 | .1 | .4 | 175 | 88 | -- | -- | -- | 6.4 |
| [3] 38-11-902 | City of Palestine #4 | 2,227 | -59 | 19 | .02 | 8 | 1.0 | 215 -- | 387 | 4 | 132 | .1 | .4 | 609 | 23 | -- | -- | 1,015 | 8.0 |
| 38-26-202 | R. H. Bell #2 | 450 | 9- 9-58 | 11 | .04 | 10 | 3.0 | 60 3.9 | 164 | 21 | 11 | -- | .2 | 216 | 37 | 76 | 4.3 | 333 | 7.6 |
| 38-28-903 | Geier & Jackson Co. | 890 | 8- 1-49 | 14 | .14 | .1 | .3 | 147 2.0 | 337 | 23 | 15 | .4 | 1.0 | 379 | 1 | -- | -- | 612 | 8.4 |
| 38-43-102 | Rex Cauble #1 | 681 | 9-10-58 | 15 | -- | 2.1 | .9 | 97 | 221 | 27 | 7.0 | -- | 1.5 | 260 | 9 | 96 | 14 | 418 | 7.7 |
| 38-59-202 | Seven "J" Stock Farm | 1,500± | 7-25-61 | 15 | .14 | .2 | .2 | 195 | 430 | 33 | 26 | .4 | .0 | 481 | 2 | 100 | 60 | 773 | 8.1 |
| 39-16-202 | Roger Young | 150 | 1-20-61 | 26 | 2.4 | 88 | 25 | 82 | 191 | 147 | 135 | .1 | .0 | 618 | 322 | 36 | 2.0 | 997 | 6.7 |
| 39-22-502 | John H. Horton | 671 | 1-17-61 | 50 | 7.0 | 25 | 11 | 44 | 94 | 12 | 80 | .3 | .0 | 274 | 108 | 47 | 1.8 | 441 | 5.9 |
| 39-40-202 | City of Buffalo | 681 | 9- 3-58 | 22 | -- | 13 | 2.6 | 49 | 150 | 14 | 9.0 | .1 | .2 | 185 | 43 | 71 | 3.3 | 293 | 7.7 |
| 39-64-701 | City of Normangee | 1,209 | 9- 4-58 | 14 | -- | .6 | .0 | 96 | 219 | 12 | 12 | .4 | 1.0 | 251 | 2 | 99 | 34 | 396 | 8.1 |
| [2] 59-16-303 | J. M. West Estate | 1,825 | 5- 5-56 | 17 | -- | 2 | .5 | 343 -- | 756 | 1.6 | 72 | -- | -- | 1,249 | 7 | -- | -- | -- | 8.4 |
| **Sparta Aquifer** | | | | | | | | | | | | | | | | | | | |
| 38-44-701 | Porter Springs School | 375 | 7-24-61 | 11 | 1.1 | 12 | 4.3 | 233 | 326 | 184 | 63 | 0.8 | 5.9 | 674 | 48 | 91 | 15 | 1,080 | 7.6 |
| 38-46-501 | Dr. H. E. Prince | 696 | 7-19-61 | 18 | 1.5 | 1.0 | 1.2 | 131 | 256 | 45 | 24 | .1 | .0 | 352 | 8 | 97 | 20 | 563 | 7.5 |
| 38-50-402 | Ben Coleman | 234 | 11-18-59 | 19 | .76 | 14 | 4.3 | 75 | 131 | 51 | 39 | .1 | .0 | 266 | 53 | 76 | 4.5 | 435 | 7.1 |
| 38-59-102 | Seven "J" Stock Farm | 742 | 7-25-61 | 13 | .15 | .2 | .5 | 70 | 162 | 3.0 | 12 | .5 | .0 | 179 | 3 | 98 | 1.8 | 292 | 8.6 |
| [3] 60-01-602 | City of Madisonville #2 | 1,316 | 7- -56 | -- | .10 | 1 | 2 | 63 -- | -- | 11 | 25 | -- | -- | 264 | 11 | -- | -- | -- | 7.4 |
| [3] 60-03-201 | Ferguson Prison Farm #2 | 1,622 | 11-19-59 | 1 | .2 | -- | 1 | 76 | 160 | 10 | 17 | .2 | -- | 186 | 3 | -- | -- | 310 | 8.9 |
| **Queen City Aquifer** | | | | | | | | | | | | | | | | | | | |
| 38-10-301 | Montalba Providence School | 30 | 7-12-61 | 30 | 0.45 | 9.5 | 5.0 | 8.3 | 21 | 0.0 | 24 | 0.0 | 14 | 101 | 44 | 29 | 0.5 | 145 | 6.1 |
| 38-27-304 | Emmett Coleman | 380 | 7-13-61 | 37 | 8.5 | 35 | 12 | 17 | 100 | 59 | 21 | .1 | .0 | 245 | 137 | 21 | .6 | 350 | 5.9 |
| 38-34-703 | J. E. Boykin | 40 | 11-18-59 | 17 | .14 | 20 | 1.4 | 3.3 5.6 | 58 | 4.0 | 5.5 | .1 | 15 | 101 | 56 | 10 | .2 | 147 | 6.5 |
| [2] 38-41-702 | City of Centerville #2 | 365 | 3-19-51 | 10 | .1 | 40 | 13 | 82.9 | 185 | 117 | 32 | -- | -- | 512 | 151 | -- | -- | -- | 8.1 |
| 38-45-104 | G. E. Brubaker | 570 | 7-18-61 | 12 | .31 | .5 | .5 | 182 | 404 | 41 | 15 | .7 | 2.0 | 468 | 3 | 99 | 46 | 731 | 7.9 |
| 38-59-203 | Seven "J" Stock Farm | 1,058 | 7-25-61 | 12 | .10 | .5 | .5 | 270 | 640 | 6.6 | 39 | 1.1 | .0 | 651 | 3 | 99 | 68 | 1,050 | 8.1 |

[1] Includes equivalent of any carbonate ($CO_3$) present.
[2] Analysis by Curtis Laboratories, Houston.
[3] Analysis by Texas State Department of Health.

may result from downward seepage of oil-field brines from surface disposal pits, or brines leaking into the aquifer from improperly cased oil and gas test holes. Improper disposal of wastes and inadequate protective measures can result in the contamination of the fresh ground water supply, rendering it unfit for beneficial use.

### Utilization and Development

The Carrizo-Wilcox aquifer is a source of water for towns, communities, industries, irrigation, and camps, as well as for domestic and livestock wells. The development of this aquifer is small and scattered throughout most of the region, with most of the production occurring in the northern two-thirds of the region.

Facts on the history of ground-water development are not available; however, it is believed that pumpage from the Carrizo-Wilcox aquifer, which is very small in comparison with that from the aquifers of Region I, probably has increased gradually over the past 20 years to its present rate, and that at no time has there been any large increases or decreases in pumpage. The total pumpage from the Carrizo-Wilcox aquifer in 1960 was 4,506 acre-feet (4.0 mgd). Of this total, 3,447 acre-feet was pumped for municipal use, 220 acre-feet for industrial use, and 839 acre-feet for irrigation purposes. The estimate for 1960 irrigation pumpage is based on 1958 pumpage reported by the Texas Board of Water Engineers (1960, p. 11-18). Irrigation pumpage is confined mainly to the Trinity River bottom, and the wells are used only to supplement rainfall during rain-deficient years. Therefore, irrigation pumpage will vary greatly from year to year. Pumpage from the Carrizo-Wilcox aquifer for 1960 is presented by major drainage subdivisions in Table 5.

The yields of wells producing from the Carrizo-Wilcox aquifer vary greatly from well to well, depending on the needs of the well owner. In other words, wells are constructed in such a manner as to supply only the amount of water needed. The yields of the major wells inventoried ranged from 65 to 1,050 gpm, with an average yield of about 420 gpm.

Specific capacities of 13 wells reported or computed from drillers' test data ranged from 1.5 to 27.5 gpm per foot of drawdown and averaged 9.0 gpm per foot of drawdown. The specific capacities are dependent upon the well construction as well as the transmissibility of the aquifer.

Major wells in the region have casing ranging from 4 to 24 inches in diameter at the surface, and many are lapped or swedged to liners and screens ranging from 4 to 10 inches in diameter. Some of the wells are cemented from the land surface to the top of the aquifer, and some of the larger producing wells are underreamed and gravel packed.

Most public supply and industrial wells have commercial screens, whereas most irrigation wells have slotted pipe opposite the production zone. The lengths of the screened sections ranged from 20 to 325 feet and averaged about 100 feet per well. A number of the wells screen multiple zones. Shaft-driven turbine pumps are the most common type used in the region, although there are some submersible turbine and cylinder pumps. The source of power for most of the public-supply and industrial wells is electricity, whereas irrigation wells

Table 5.--1960 Ground-water pumpage from aquifers in Region II, Trinity River Basin

(Pumpage expressed in acre-feet [1] [2])

| Subdivision | 18 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Carrizo-Wilcox Aquifer** | | | | | | | | | | |
| Municipal | 891 | -- | 177 | 1,313 | 302 | 685 | 37 | 42 | -- | 3,447 |
| Industrial | 82 | -- | 48 | 90 | -- | -- | -- | -- | -- | 220 |
| Irrigation | 30 | -- | 31 | 24 | 178 | 400 | 42 | 134 | -- | 839 |
| Total | 1,003 | -- | 256 | 1,427 | 480 | 1,085 | 79 | 176 | -- | 4,506 |
| **Sparta Aquifer** | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | -- | 721 | -- | 274 | -- | 995 |
| Irrigation | -- | -- | -- | -- | -- | 42 | -- | 176 | 42 | 260 |
| Total | -- | -- | -- | -- | -- | 763 | -- | 450 | 42 | 1,255 |
| **Queen City Aquifer** | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | -- | -- | 107 | -- | -- | 107 |
| Total | -- | -- | -- | -- | -- | -- | 107 | -- | -- | 107 |
| **Other Aquifers [3]** | | | | | | | | | | |
| Municipal | -- | -- | 7 | -- | -- | -- | -- | 75 | 29 | 111 |
| Industrial | -- | -- | 13 | -- | -- | -- | -- | -- | -- | 13 |
| Irrigation | -- | -- | -- | -- | -- | -- | -- | 41 | -- | 41 |
| Total | -- | -- | 20 | -- | -- | -- | -- | 116 | 29 | 165 |
| **Summary of Pumpage in Region II** | | | | | | | | | | |
| Municipal | 891 | -- | 184 | 1,313 | 302 | 1,406 | 144 | 391 | 29 | 4,660 |
| Industrial | 82 | -- | 61 | 90 | -- | -- | -- | -- | -- | 233 |
| Irrigation | 30 | -- | 31 | 24 | 178 | 442 | 42 | 351 | 42 | 1,140 |
| Total | 1,003 | -- | 276 | 1,427 | 480 | 1,848 | 186 | 742 | 71 | 6,033 |

1/ Municipal pumpage includes water supplied by privately owned systems.
2/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.
3/ Other aquifers include Nacatoch Formation, Yegua Formation, and alluvium.

are powered by butane or gas. The pumps are powered by motors of 1 to 300 horsepower, with the average horsepower for the major wells inventoried being 55.

Some corrosion and encrustation of well screens may occur where the iron content of the water is high. Pumping of sand is common, especially near the outcrop where the sand is loose.

Large amounts of water can be withdrawn from the Carrizo-Wilcox aquifer with relatively small drawdowns. When large quantities of water are to be withdrawn, care should be taken in planning the design of well fields so as to minimize interference between wells.

Concentrated withdrawal in a small area has not occurred under the present development of the Carrizo-Wilcox aquifer. There has been some decline in water levels in the vicinity of Palestine in response to pumping. No serious water-level declines have occurred in the Carrizo-Wilcox aquifer in Region II, and the results of this investigation indicate that large quantities of additional water are available for development throughout most of the region.

Most of the aquifer's development is from the Carrizo Formation, where it meets the water-quality requirements. This is for two reasons. It occurs at a shallower depth than the Wilcox Group, and the Carrizo Formation can yield approximately the same quantity of water from its 100- to 200-foot section as can be obtained from screening most of the sands in the Wilcox. Thus, the total amount of screen necessary and the total depth of the well are much less for a Carrizo well than for a Wilcox well. Therefore, it is most probable that future development will take place first in the Carrizo, with later development in the Wilcox part of the aquifer. It also may be desirable to complete wells in both units of the aquifer in areas where both are present and large quantities of water are desired.

## Ground Water Available for Development

The amount of water available for development from the Carrizo-Wilcox aquifer determined during this study is based on pumpage under assumed conditions and is related primarily to the ability of the aquifer to transmit water to the areas of pumping. It is assumed that the effect of pumping is such that the static water level is drawn down to the top of the aquifer where this depth is 400 feet below land surface. The line along which the top of the aquifer is 400 feet below the surface is roughly parallel with the outcrop. Thus, the hydraulic gradient causing water to move through the aquifer under the assumed conditions of pumping is the difference in the altitude of the water level in the outcrop area and the altitude of the top of the aquifer immediately downdip where it is 400 feet below the land surface, divided by the distance between these points. The product of the coefficient of transmissibility of the aquifer between the outcrop and the 400-foot line, the hydraulic gradient, and the effective length of the line along which the top of the aquifer is 400 feet below the land surface is the quantity of water the aquifer will transmit to supply withdrawals under these conditions. If the recharge to the aquifer is sufficient to supply the quantity of water moving downgradient through the aquifer, pumping under these assumed conditions can be maintained indefinitely.

At the present water-level gradients, approximately 15,000 to 20,000 acre-feet of water is being discharged from the Carrizo-Wilcox aquifer annually. Of this amount, approximately 4,500 acre-feet is being pumped annually for municipal, industrial, and irrigation use. In addition, large amounts of water are being discharged in the region through domestic, livestock, and flowing wells. There are numerous flowing wells in the region whose combined yields are estimated to be equal to that being produced for municipal, industrial, and irrigation purposes. The remainder is being discharged naturally from the aquifer by means of vertical movement through the overlying confining beds. Under the hydraulic gradient that would be established under assumed conditions of development, on the order of 70,000 to 80,000 acre-feet of water would be transmitted annually from the outcrop area to the areas of pumping. Thus, the quantity of additional water available from the aquifer on a sustained basis under the assumed conditions of development is on the order of 65,000 to 75,000 acre-feet per year more than was pumped in 1960.

Recharge to the Carrizo-Wilcox aquifer appears to be more than adequate to supply the quantity of water that would be moving through the aquifer under the assumed conditions of development. The outcrop area of the Carrizo-Wilcox aquifer from which the recharge is supplied for pumpage in the Trinity River Basin is approximately 660,000 acres. Therefore, less than 1.5 inches of the 40 inches of annual precipitation would be required to supply the 70,000 to 80,000 acre-feet of water that can be transmitted by the aquifer. This amounts to a little less than 4 percent of the annual rainfall. It appears that even under conditions of maximum development, water received by the Carrizo-Wilcox aquifer as recharge will be greater than the amount needed to supply withdrawal. Some of this rejected recharge might be salvaged by development of additional water supplies in the outcrop area.

It is estimated that on the order of 30,000 to 35,000 acre-feet of ground water can be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed. Although this source of water is available to support short-term pumpage in excess of the sustained yield of the aquifer, it will have been withdrawn by the time the assumed conditions of pumpage are established and thus should not be considered as water available for development on a sustained basis.

Conditions are favorable for further development of the Carrizo-Wilcox aquifer throughout the region from the edge of the outcrop, where it dips under younger beds, to Madison and southern Houston Counties. It also would be possible to develop supplies in Madison and southern Houston Counties, but the depth to the aquifer and the chemical quality of the water would make this area less favorable than that to the north.

Both quantitative and quality problems may occur in developing water from the Carrizo-Wilcox aquifer in the immediate vicinity of salt domes or faults. Before any large-scale development is undertaken, a detailed evaluation of the immediate area should be made to determine the feasibility of the site. Production outside the basin also should be considered in future large-scale developments, as it can influence the total quantity of water which can be obtained on a sustained basis from the aquifer.

Individual wells should be properly constructed with surface casing cemented through the overlying formations to prevent more highly mineralized water or poorer quality water from entering the well. Many Carrizo-Wilcox wells have been contaminated by iron-bearing water from overlying formations owing to improper casing or leaking casing.

## Sparta Aquifer

### Geologic Characteristics

The Sparta Formation consists chiefly of fine to medium-grained, round to subangular quartz sand, gray to buff in color. The lower part of the aquifer is a massive unconsolidated sand with minor amounts of shale. The massive sand grades upward to shaley sand and clay interfingered with sand lenses, with gradations from sand to clay occurring both laterally and vertically. The Sparta Formation locally contains minor amounts of glauconite and lignite. Sand makes up 60 to 70 percent of the Sparta's total thickness.

The areal extent of the Sparta aquifer is shown on Plates 12 and 13, which show the approximate altitude of the top and the thickness of the Sparta aquifer. The areal extent of the Sparta aquifer and its relationship to the other aquifers of Region II also is shown on Figure 7.

The Sparta crops out across the Trinity River Basin in southern Leon and northern Houston Counties with a small extension of the outcrop in southern Anderson County. The formation dips toward the southeast at a rate of approximately 50 feet per mile immediately downdip from the outcrop; the dip steepens in the southern part of Region II to as much as 150 feet per mile. There is little variation in the structure of the Sparta Formation. The one exception occurs on the Houston-Walker County line south of Region II, where the regional dip of the Sparta has been affected by a salt dome, which caused a structural high and a thinning of the aquifer. The structural features of the Sparta Formation are best illustrated on Plate 12.

The thickness of the Sparta aquifer ranges from zero at the northwest extent of the outcrop to as much as 380 feet in Grimes and Walker Counties. The Sparta is more than 300 feet thick, as shown on Plate 13, in most of the region downdip from the outcrop and updip from the line marking the approximate extent of water containing less than 3,000 ppm dissolved solids. The thickest part of the aquifer occurs in the western part of the region with a slight thinning to the east.

The depth to the top of the Sparta aquifer ranges from zero in the outcrop area to more than 2,000 feet in the southern part of Region II in Grimes and Walker Counties. The aquifer extends into a small part of Region III. Plate 12 shows the generalized depths to the top of the aquifer in the Trinity River Basin.

### Occurrence and Movement of Ground Water

Water in the outcrop of the Sparta aquifer occurs under water-table conditions; immediately downdip from the outcrop water occurs under artesian conditions. The outcrop area of the Sparta aquifer is shown on Plates 12 and 13.

In Leon and northern Madison Counties, water in the Sparta aquifer moves from the basin boundary to the southeast, toward the Trinity River. In northern Houston County, the water movement is to the southwest. In the center of the basin, the water-level gradients flatten and water moves to the southeast, the same direction as the dip of the beds. Present water-level gradients, indicated by available water-level measurements, average about 5 feet to the mile. The water-level gradients in and near the outcrop area are somewhat steeper because of the differences in elevation of the land surface along the Trinity River and basin boundaries.

### Recharge and Discharge

Recharge to the Sparta aquifer occurs in its outcrop, which includes an area of approximately 250 square miles in the Trinity River Basin. Recharge to the Sparta aquifer is derived from rainfall which averages approximately 44 inches per year in the outcrop area. The sand of the Sparta Formation weathers to a loose sandy soil, supporting only small amounts of vegetation. The topography is gently rolling to hilly. The sandy soils of the outcrop are very permeable, allowing much of the rainfall to be absorbed.

Ground water is discharged naturally from the Sparta by springs and seeps and by evapotranspiration in the outcrop. Ground-water discharge in the outcrop furnishes water to the Trinity River and its tributaries. Downdip, from the outcrop where the aquifer is under artesian head, natural discharge from the aquifer occurs by means of upward leakage through the confining beds.

Artificial discharge from the Sparta aquifer is through flowing and pumping wells. The pumping wells are scattered throughout the area, and most of the flowing wells occur along the Trinity River and some of its major tributaries at points where the land surface elevation at the wells is lower than the artesian head of the aquifer.

### Water Levels

Depths to water range from zero in the outcrop to as much as 160 feet in the vicinity of Crockett. Differences in depths to water below the land surface result, for the most part, from variations in land-surface elevations. The depths to water throughout most of Region II are less than 100 feet. Water levels in the Sparta aquifer fluctuate in areas of pumping in response to seasonal changes in pumpage. In and immediately downdip from the outcrop area, changes in transmpiration as well as variations in the amount of rainfall cause changes in the water levels. It is believed that these fluctuations are sometimes quite large.

There appears to have been little or no progressive lowering of water levels throughout most of the region. According to reported water-level measurements in wells at the city of Crockett, the water-level declines have not been excessive. One well showed only a 7-foot decline since 1934, while another showed approximately 25 feet since 1930. Flowing wells drilled in Madisonville in the early 1950's still flow, although probably at a reduced rate. Based on data available, pumpage appears to have had very little overall effect on the water levels in the Sparta aquifer.

### Water-Bearing Characteristics

The lower part of the Sparta Formation consists of massive, unconsolidated sand with minor amounts of shale, whereas the upper part of the aquifer consists of interbedded sand and clay. The lower sand beds are "clean" and relatively well sorted and have high permeabilities. The Sparta aquifer also has relatively high transmissibilities.

Pumping tests were run on 2 wells completed in the Sparta aquifer. A coefficient of transmissibility of about 16,500 gpd/ft. was obtained from a pumping test of well 38-46-501 in Houston County, which had approximately 30 feet of slotted pipe set in 150 feet of sand. The average coefficient of permeability was approximately 110 gpd/ft$^2$. A coefficient of transmissibility of about 21,000 gpd/ft. was obtained from a test of well 60-01-201 in Madison County. The screen in this well is set in a 50-foot sand in the lower part of the aquifer. The coefficient of permeability for this test was 450 gpd/ft$^2$. The average coefficient of permeability of the Sparta aquifer in the Trinity River Basin probably is between 100 and 200 gpd/ft$^2$. The pumping tests were made in wells which have not screened the entire aquifer thickness; that is, only some of the available sand beds are open to the wells. Coefficients of transmissibility between 20,000 and 40,000 gpd/ft. could be expected throughout most of the region if the entire sand thickness were screened.

Coefficients of storage obtained from tests of the Sparta aquifer in the Neches River Basin indicate a range in artesian coefficients of storage from 0.00026 to 0.00052. The use of 0.0002 as the coefficient of storage in the Trinity River Basin appears to be reasonably applicable.

A distance-drawdown graph has been prepared based on coefficients believed to be the most applicable to the aquifer, if the entire aquifer were screened. Figure 17 shows the amount that the water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances on the graph are measured along a line parallel with the outcrop area and passing through the pumped well, which is located 8 miles from the outcrop and pumping at a rate of 700 gpm. The coefficient of transmissibility of 20,000 gpd/ft. was used to prepare this graph and the storage coefficient used was 0.0002. It should be stated again that in order to obtain transmissibilities of this magnitude, it would be necessary to screen most or all of the sands of the Sparta aquifer.

### Chemical Quality

The Sparta aquifer contains water of good quality that extends downdip for a considerable distance and remains fairly uniform in quality over the entire region. Of the 15 samples analyzed from wells obtaining water from the Sparta aquifer, only 1 contained more than 500 ppm dissolved solids. The range of dissolved solids was 176 to 674 ppm. Three wells in the southern part of Region II, completed to depths of 1,600 feet or more, contained water with 320 ppm or less dissolved solids. In 14 samples analyzed for iron, the iron content ranged from 0.05 to 2.05. Half of these samples contained iron in excess of the recommended limit of 0.3 ppm. A number of the wells were reported to be producing water containing hydrogen sulfide gas, which occurs locally in various areas and the occurrence of which cannot be predicted. All other constituents analyzed in

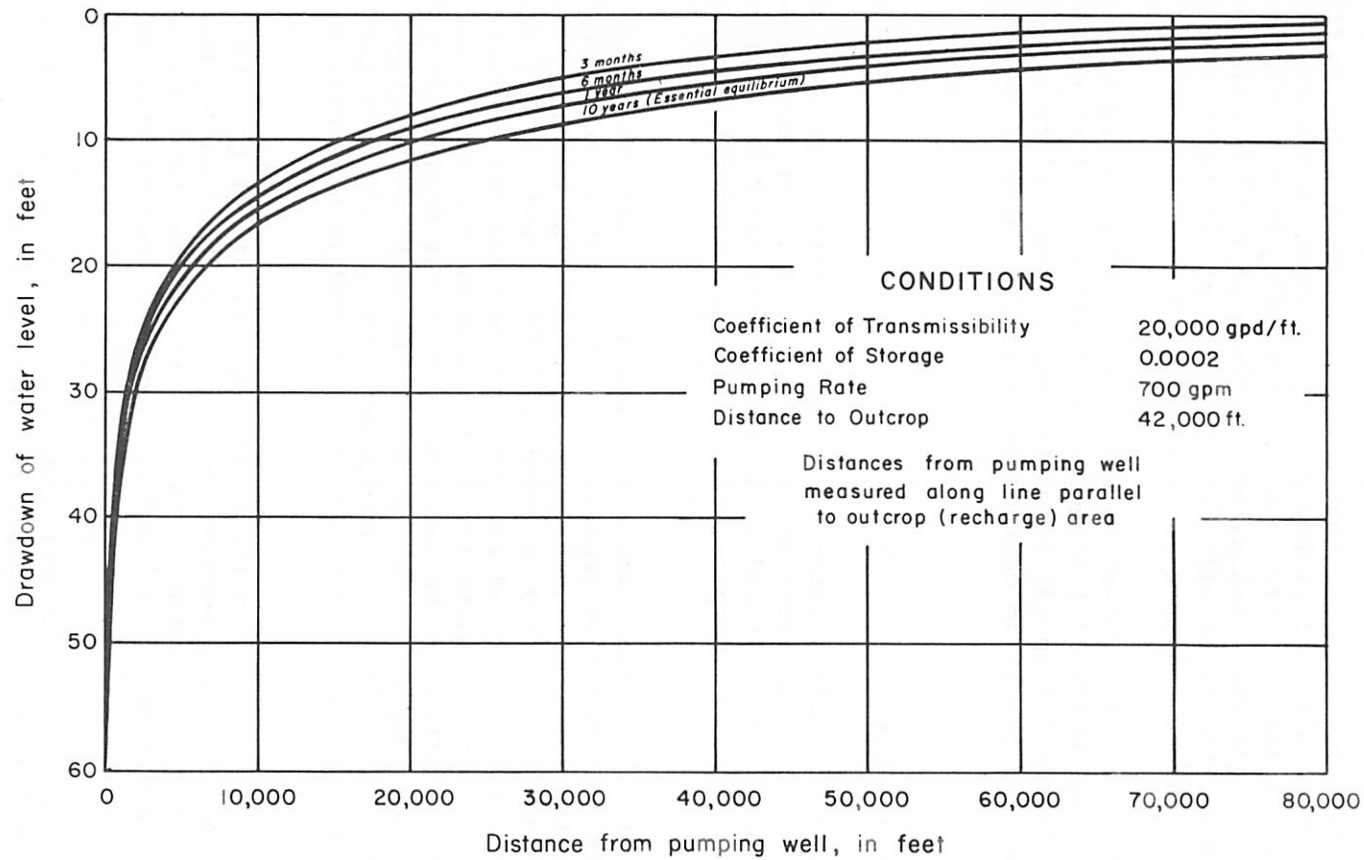


Figure 17

Distance-Drawdown Curves After Various Times of Pumping From the Sparta Aquifer, Region II, Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

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the 15 samples were well within the limits set forth by the U. S. Public Health Service. Available analyses of water in the Sparta aquifer show the water to be very soft. Chemical analyses of water from a few selected wells screening the Sparta aquifer are given in Table 4 to illustrate the general quality of water for various parts of the region.

Electric logs of wells indicate that water of usable quality in the Sparta aquifer extends into a small part of Region III, as shown on Plates 12 and 13. The Sparta water is suitable in this area for most uses, with little or no treatment necessary except where undesirable amounts of iron or hydrogen sulfide are encountered. Here, treatment will provide water of generally acceptable quality for public supplies and most industries.

Future quality of water problems in the Sparta can be caused by improper casing and casing leaks, which will allow water of poorer quality to enter the individual wells. Improper disposal of wastes and inadequate protective measures for the aquifer can result in contamination of the water, rendering it unfit for beneficial use.

Utilization and Development

The Sparta aquifer supplies water to towns, communities, prison farms, and irrigation wells as well as domestic and livestock wells. The development of the Sparta aquifer has been small and is scattered throughout Madison and Houston Counties, with most of the pumpage occurring in the vicinity of Crockett and Madisonville.

Data on the history of ground-water development are not available. However, the pumpage probably has increased gradually over the past 20 or 30 years with few fluctuations in the rates of annual pumpage. Municipal and irrigation pumpage from the Sparta aquifer in 1960 amounted to 1,255 acre-feet (1.1 mgd). Of this total, 995 acre-feet was pumped for municipal use and 260 acre-feet was pumped for irrigation. The estimate for 1960 irrigation pumpage is based on 1958 pumpage figures reported by the Texas Board of Water Engineers (1958, p. 11-18). The irrigation pumpage is used primarily to supplement rainfall during rain-deficient years. Therefore, the irrigation pumpage will vary greater from year to year. Pumpage from the Sparta aquifer for 1960 is presented by major drainage subdivisions in Table 5.

Yields of wells producing from the Sparta aquifer differ greatly from well to well and are dependent on the need of the user. In other words, the wells are constructed to supply the amount of water needed. The yields of the major wells inventoried ranged from 70 to 1,200 gpm, with an average yield of approximately 560 gpm.

The specific capacities of 12 wells reported or computed from drillers' test data ranged from 2.3 to 17.7 gpm per foot of drawdown and averaged 10.5 gpm per foot of drawdown. The specific capacities obtained on wells are dependent upon well construction as well as the transmissibility of the aquifer.

Major wells in the region have casing ranging from 4 to 16 inches in diameter at the surface, reduced in size by overlapping or swedging to liners and screens that range from 2-1/2 to 9 inches in diameter. A few wells are of one size without overlap and some of the wells are cemented from the surface to the top of the aquifer. Several of the large producing wells are underreamed and gravel packed.

Most of the major wells are completed with screens, although several of the irrigation wells have slotted pipe. The length of the screen or slotted pipe sections range from 30 to 124 feet and average about 65 feet per well. The majority of the wells are equipped with shaft-driven turbine pumps, with a few submersible and jet pumps being used. The main source of power for the public-supply and irrigation wells is electricity although a few use butane or gasoline. The pumps on the major wells inventoried are powered by motors ranging from 1-1/2 to 150 horsepower with an average of about 47 horsepower.

Some corrosion and encrustation of well screens may occur where the iron content of the water is high. Wells using slotted pipe or screens with improperly sized openings are likely to pump sand owing to the unconsolidated nature of the sand in the Sparta aquifer.

If wells completed in the Sparta aquifer are properly constructed and maintained, large amounts of water can be withdrawn with relatively small drawdown because of the relative high transmissibility of the aquifer. The drawdowns that can be expected at various distances from a well pumping at a rate of 700 gpm are illustrated by the distance-drawdown curves on Figure 17. Under present development there has been no noticeable declines due to pumpage. The Sparta aquifer is capable of supporting additional pumpage throughout the aquifer.

## Ground Water Available for Development

The amount of water available for development from the Sparta aquifer determined during this study is based on pumpage under assumed conditions and is related primarily to the ability of the aquifer to transmit water and on the amount of recharge available in the outcrop area.

Under the present water-level gradient, based on the available water-level measurements in the region, there is estimated to be approximately 6,000 acre-feet of water discharged from the aquifer annually. Of this amount, about 1,300 acre-feet is being pumped annually for municipal and irrigation use. In addition, some of this water is being discharged through domestic, livestock, and flowing wells in the region. The remainder of the water is being discharged naturally from the aquifer by means of vertical leakage through the overlying confining beds. If assumed conditions of pumpage occur to draw water levels down to the top of the aquifer where it is 400 feet below the land surface, on the order of 50,000 to 60,000 acre-feet of water would be transmitted annually from the outcrop to the areas of pumping. The top of the Sparta aquifer where it is 400 feet below the land surface is approximately 8 miles from its outcrop, whereas the similar 400-foot line in the Carrizo-Wilcox aquifer occurs at an average of about 15 miles from its outcrop. Thus, the Sparta aquifer, under the assumed conditions on which the availability calculations were made, would have a steeper hydraulic gradient than the Carrizo-Wilcox aquifer. The steeper gradient would allow the Sparta aquifer to transmit almost as much water as the Carrizo-Wilcox aquifer under the assumed conditions, even though the transmissibility of the Sparta aquifer is smaller.

In the Trinity River Basin, the outcrop of the Sparta includes approximately 160,000 acres, on which an average of 44 inches of precipitation falls annually. In order to supply the quantity of water that the aquifer is capable of transmitting under the assumed conditions, between 4 and 5 inches, or approximately 10 percent, of the annual precipitation would be required as recharge to the aquifer. The amount of recharge received by the aquifer is not known, but the conditions of the Sparta outcrop are such that it does not appear unreasonable to assume that sufficient recharge would be available to supply the 50,000 to 60,000 acre-feet transmitted by the aquifer under the assumed conditions of pumpage.

It is estimated that on the order of 20,000 to 25,000 acre-feet of ground water could be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which the availability was computed. Although this source of water is available to support short-term pumpage in excess of the sustained yield of the aquifer, it will have been withdrawn by the time assumed conditions of pumpage are established, and thus should not be considered as water available for development on a sustained basis.

Further development of the Sparta aquifer is favorable throughout the region from the Sparta outcrop in Leon and Houston Counties to the downdip extent of the fresh water. The most favorable area for development is along a line passing through Madisonville and Crockett, where the aquifer is thickest and the depths are not too great. Production probably will not develop along the lines considered for estimating the availability, and it is probable that some areas will become overdeveloped. Care should be taken in planning future well fields to see that wells are properly spaced so as not to cause serious local declines and to insure maximum utilization of the water available.

Quality of water does not seem to be a problem in the development of water supplies from the Sparta aquifer. In some areas undesirable amounts of iron and hydrogen sulfide will be encountered. However, this can be removed by simple means of treatment. The problem of encroachment of more mineralized water from downdip as development takes place does not seem probable in the near future. Individual wells should be properly protected with surface casing and cemented through the overlying beds to prevent more mineralized water from entering the wells from above.

## Secondary Aquifers

### Queen City Aquifer

#### Geologic Characteristics

The Queen City Formation consists chiefly of crossbedded, medium to very fine-grained gray micaceous quartz sands. The sand beds are massive to thin and interbedded with lenses of shale and sandy shale. The shale and sandy shale lenses interfinger with the sands, and gradations from sand to shale occur both laterally and vertically. The Queen City also contains minor amounts of lignite and several glauconitic sand layers. Sand makes up 60 to 70 percent of the Queen City's total thickness.

The areal extent of the Queen City aquifer in the Trinity River Basin is shown on Plates 14 and 15, which show the approximate altitude of the top of the aquifer and the thickness of the Queen City aquifer. The areal extent of the Queen City aquifer and its relation to the other aquifers of the basin are shown on Figure 7.

The Queen City outcrop extends from south of Athens in Henderson County along the eastern boundary of the basin through Anderson County, and then extends to the southwest across northern Leon County. The Queen City dips to the southeast at a rate of approximately 50 to 60 feet per mile immediately downdip from the outcrop throughout most of the area. North of Grapeland, in northern Houston County, the dip flattens and is disrupted by several faults in the vicinity of Elkhart in southern Anderson County. In the southern part of Region II, the rate of dip steepens to more than 100 feet per mile. The structural features of the Queen City Formation are best illustrated on Plate 14.

The thickness of the Queen City aquifer ranges from zero at the northwestern extent of the outcrop to as much as 460 feet in the vicinity of Palestine in Anderson County (Plate 15). Thicknesses in excess of 400 feet occur only in a small part of the region in Anderson and Houston Counties. This area is in the East Texas embayment. In the outcrop, thicknesses are influenced by the topography and structural highs of the older formations causing large variations in the thickness of the aquifer. West of the Trinity River and for some distance downdip, the aquifer is 300 feet or more in thickness. East of the Trinity River, the Queen City thins from more than 400 feet north of Grapeland to less than 100 feet southeast of Crockett. This thinning trend continues into the Neches River Basin until the sand of the Queen City is no longer distinguishable.

The depth to the top of the Queen City aquifer where it contains water of less than 3,000 ppm dissolved solids varies from zero in the outcrop area to more than 1,500 feet in Grimes and southern Madison County in the southwestern part of Region II. Plate 14 shows the generalized depths to the top of the aquifer where it contains fresh water. At greater depths downdip the water is probably too mineralized for most uses.

## Occurrence and Movement of Ground Water

Water in the outcrop of the Queen City aquifer occurs under water-table conditions. Immediately downdip from the outcrop, water occurs under aretesian conditions. The outcrop of the Queen City Formation is shown on Plates 14 and 15. Relatively impermeable shale layers in the outcrop create both perched water zones and localized artesian conditions.

Water in the Queen City aquifer moves from the basin boundaries toward the Trinity River. West of the river, water moves in a south-southeast direction and east of the river water moves in a south-southwest direction, with the average water-level gradient being approximately 5 feet per mile. The present water-level gradients were determined from available water-level measurements in wells scattered throughout the area. The distribution of wells available for water-level measurements are such that only generalized gradients could be determined.

## Recharge and Discharge

Recharge to the Queen City aquifer occurs in its outcrop which is shown on Plate 14. The area includes approximately 925 square miles. The Queen City Formation weathers to a loose sandy soil, and the topography is gently rolling to hilly with heavy vegetation consisting chiefly of oak and pine trees. The sandy soil of the outcrop is very permeable, allowing much of the rainfall to be absorbed by the aquifer.

Ground water from the Queen City aquifer is discharged naturally through numerous seeps and springs and by evapotranspiration in the outcrop area. Rejected recharge in the outcrop area furnishes water to the Trinity River and its tributaries. Downdip, where the aquifer is under artesian conditions, natural discharge from the aquifer occurs by means of upward leakage through the confining beds.

Artificial discharge from the Queen City aquifer is through flowing and pumping wells. Most of the wells are small domestic and livestock wells scattered throughout the outcrop area and for a short distance downdip. Most of the flowing wells occur along the Trinity River and some of its major tributaries, at points where the altitude of the land surface at the wells is lower than the artesian head of the aquifer.

## Water Levels

Depths to water range from zero in the outcrop to as much as 217 feet in a well in southwest Anderson County. Depths to water throughout most of the region are less than 100 feet except along the basin boundaries, where the surface elevation is much higher than the surrounding country. Variations in the amount of rainfall in the outcrop of the Queen City, as well as evapotranspiration, cause fluctuations in the water level. The only major pumpage from the Queen City aquifer occurs at the city of Centerville, where the water levels fluctuate in response to changes in the rate of pumping.

There is little past data on water levels in the Queen City aquifer. There are indications that a cone of depression has developed around the wells in the Centerville area. Based on the small amount of available data, it appears that water levels in the Queen City aquifer have changed very little over the years, except for minor natural fluctuations and the possible lowering of water levels in the vicinity of Centerville.

## Water-Bearing Characteristics

The heterogenous character of the sediments of the Queen City Formation and the lenticular nature of the beds are factors contributing to relatively low transmissibilities.

Data from 2 pumping tests made on wells completed in the Queen City aquifer had coefficients of transmissibility averaging approximately 2,500 gpd/ft. Both of these wells were at the city of Centerville and screened approximately 50 feet of sand near the bottom of the aquifer. Based on the sand thickness at the screened interval, the permeability for the 2 tests averaged 52 gpd/ft$^2$.

Coefficients of transmissibility reported from tests in the Neches and Sabine River Basins ranged from 3,000 to 12,700 gpd/ft., and the coefficients of permeability based on the sand thicknesses screened ranged from 10 to 165 gpd/ft$^2$. Therefore, it is believed that a coefficient of permeability, although it will vary from well to well and in different sands within the same well, of 50 gpd/ft.$^2$ is representative for the aquifer. Higher coefficients of transmissibility than were obtained on the pumping tests can be expected if all of the sand beds in the aquifer are screened. Coefficients of transmissibility up to 10,000 gpd/ft. can be expected in the western part of the basin and up to 8,000 gpd/ft. in the eastern part of the basin if the entire sand thickness is screened. The lower transmissibilities in the eastern part of the region are due to the thinning of the sands in that direction.

A distance-drawdown graph has been prepared assuming the entire aquifer is screened. Figure 18 shows the amount that the water levels would be lowered at various distances from a pumped well after the well has pumped for various periods of time. The distances on the graph were measured along a line parallel with the outcrop, and the line passes through the pumped well. The pumped well is located 8 miles from the outcrop area and pumps at a rate of 250 gpm. A coefficient of transmissibility of 8,000 gpd/ft. and coefficient of storage of 0.0002 were used in preparing the graph.

## Chemical Quality

Water from the Queen City aquifer in the Trinity River Basin is generally of good quality. Of the 10 wells from which water samples were obtained and analyzed, the dissolved solids ranged from 101 to 651 ppm, with only 3 of the analyses containing more than 500 ppm dissolved solids. The deepest well from which water was obtained and analyzed was 1,058 feet. This well is located in southwestern Houston County. Wells normally are not completed in the Queen City aquifer in Madison and southern Houston Counties, as water of good quality can be obtained from the Sparta aquifer at shallower depths.

The iron content in the 10 samples analyzed ranged from 0.05 to 8.5 ppm. Only 4 of the 10 analyses contain in excess of the 0.3 ppm limit recommended by the U. S. Public Health Service, and only 1 of these greatly exceeded the limit. The water containing 8.5 ppm iron is believed to be contaminated by casing leakage, and the well probably is obtaining some water from the overlying Weches Formation. Iron is considerably more of a problem than the analyses indicate. Normally in the outcrop near the Weches contact, large amounts of iron are encountered in the water. Hydrogen sulfide also is encountered in wells in some areas. Of the 10 water samples analyzed, half were acidic (pH less than 7), and the other half were basic (pH greater than 7). The waters with low pH generally were obtained from wells in the outcrop area of the Queen City, whereas the more basic water was obtained from wells downdip. Some of the shallow wells in the outcrop also contain nitrate slightly over the recommended limit. It is not uncommon to find shallow wells that have a high nitrate content, which indicates possible pollution from the surface. The other constituents analyzed in the 10 samples were well within the limits set forth by the U. S. Public Health Service.

The water in the Queen City aquifer was found to be generally soft with hard water found only occasionally in the outcrop area. Chemical analyses of

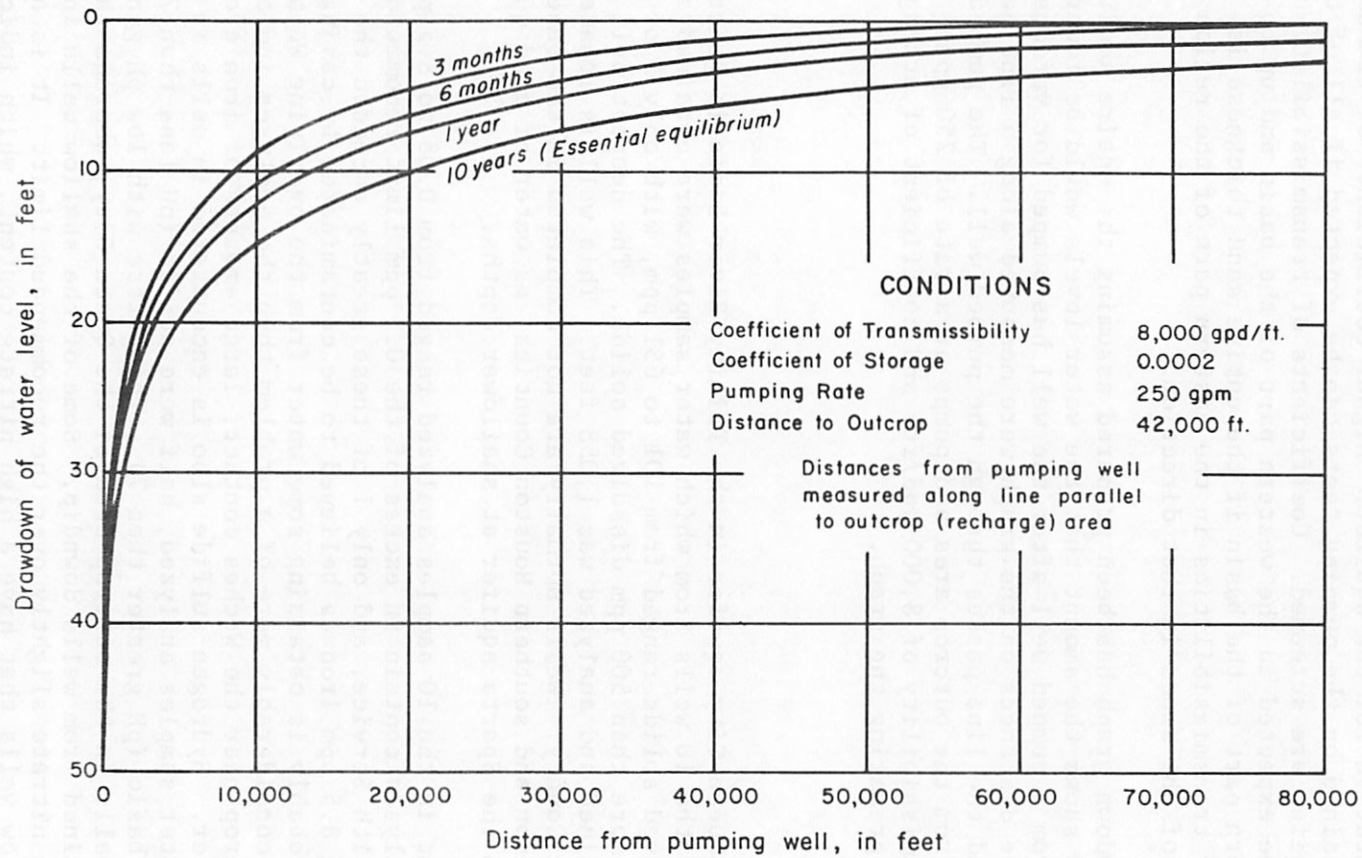


Figure 18

Distance-Drawdown Curves After Various Times of Pumping From the Queen City Aquifer, Region II, Trinity River Basin

Texas Water Commission in cooperation with the U. S. Geological Survey

water from a few selected wells in the Queen City aquifer are given in Table 4 to illustrate the general quality of the water for various parts of the area.

As stated before, wells in the southern part of Region II are not completed in the Queen City aquifer; however, electric logs indicate that water of usable quality occurs in the Queen City as far south as Grimes and southern Madison Counties.

The water from the Queen City aquifer where it occurs in the region is suitable for most uses, and no treatment appears to be necessary except where high iron concentrations and hydrogen sulfide are encountered. Simple treatment can remove the iron and hydrogen sulfide.

Future quality of water problems in the Queen City can be caused by improper casing and casing leaks which allow more mineralized water from the shallower beds to enter the individual wells. Improper disposal of wastes and inadequate protective measures can result in contamination of the water, rendering it unfit for beneficial use.

## Utilization and Development

Development from the Queen City aquifer has been extremely small with the only major pumpage from the aquifer occurring from 2 municipal wells at the city of Centerville. The total pumpage from these 2 wells in 1960 was 107 acre-feet. In addition to municipal pumpage, hundreds of domestic and livestock wells and some flowing wells discharge water from the aquifer. Pumpage from the Queen City aquifer in 1960 is presented by major drainage subdivisions in Table 5.

The 2 wells at Centerville are producing from the basal sand in the Queen City Formation. The wells are approximately 360 feet deep and the casing of both wells ranges from 8-5/8 to 4-1/2 inches in diameter. The yields from the 2 wells are 67 gpm and 130 gpm; a specific capacity of 2.0 gpm per foot of drawdown was reported for the well with the greater yield.

The wells are completed with 48 feet of 4-1/2 inch diameter screens which screen approximately 50 feet of sand in the lower part of the aquifer. The wells have shaft-driven turbine pumps powered by 10-horsepower electric motors.

The highly acidic water which occurs in some parts of the Queen City aquifer is very corrosive and in many cases will attack the metal of pipes and pressure tanks causing increased iron content in the produced water.

Because the Queen City aquifer has a low transmissibility, very large drawdowns are required to obtain large amounts of water. The drawdowns that can be expected at various distances from a well pumping at a rate of 250 gpm are illustrated by the distance-drawdown curves on Figure 18. Yields up to as much as 250 gpm can be anticipated from the Queen City aquifer if all of the available sand beds are screened. Care should be taken in the development of a water supply in the Queen City to insure proper spacing of the wells so that the cones of depression from the individual wells will not overlap excessively and cause severe water-level declines in the immediate area of pumping. The Queen City aquifer is capable of supplying water for small municipalities and industries, and additional pumpage can be obtained throughout the extent of the aquifer.

## Ground Water Available for Development

The amount of water available for development from the Queen City aquifer determined during this study is based on pumpage under assumed conditions and is related primarily to the ability of the aquifer to transmit water to the areas of pumpage and the available recharge. It is assumed that the effect of pumping is such that the static water level is drawn down to the top of the aquifer where its depth is 400 feet below the land surface. Under the present water-level gradients, based on the available water-level measurements in the region, there is estimated to be approximately 3,000 acre-feet of water presently being discharged from the aquifer annually. Of this amount, only 107 acre-feet is being pumped for municipal use by the city of Centerville. The remainder of the water is either being discharged through domestic, livestock, and flowing wells or is being discharged naturally from the aquifer by means of vertical movement through the overlying confining beds. Assuming that conditions of pumpage occur to draw water levels down to the top of the aquifer where it is 400 feet below the land surface, on the order of 20,000 to 30,000 acre-feet of water would be transmitted annually from the outcrop to the areas of pumpage. The top of the Queen City aquifer where it is 400 feet below the land surface is approximately 8 miles from its outcrop. The steep hydraulic gradient, which would be developed under the assumed conditions of pumpage, enables the Queen City to transmit substantial quantities of water, although it has relatively low transmissibilities.

In the Trinity River Basin the Queen City crops out in an area of approximately 590,000 acres, on which an average of 40 inches of precipitation falls annually. In order to supply the 20,000 to 30,000 acre-feet of water which the aquifer is capable of transmitting under the assumed conditions, less than 1 inch of the total rainfall would be required as recharge to the aquifer. This amounts to less than 2.4 percent of the annual rainfall. It appears that even under conditions of maximum development, water received as recharge by the Queen City aquifer will be greater than the amount needed to supply withdrawals. Some of this rejected recharge may be salvaged by the development of additional water supplies in the outcrop area.

It is estimated that on the order of 20,000 acre-feet of ground water will be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which the availability was computed. This source of water is available to support short-term pumpage in excess of the sustained yield of the aquifer; however, it will be withdrawn by the time assumed conditions of pumpage are established and thus should not be considered as water available for development on a sustained basis.

Further development of the Queen City aquifer is favorable throughout the region from the aquifer outcrop to its downdip extent of fresh water. The most favorable area for future development is west of the Trinity River in the northern part of Madison County, where the aquifer is thickest.

The principal problem of developing water from the Queen City aquifer is the low transmissibility, which limits the quantity of water that can move through the aquifer from the areas of recharge to points of discharge under hydraulic gradients that are within the economic limits of development. One of the main points to be considered in developing water supplies from the Queen City aquifer is the orderly and systematic spacing of wells. To get the ultimate amount of water available from the Queen City aquifer, it will be necessary to develop small well fields throughout the area of the aquifer. The aquifer is capable of supplying sufficient quantities of water for small industries and municipalities.

Water quality should not be a problem in the development of a water supply from the Queen City aquifer; however, some treatment will be required where large amounts of iron or hydrogen sulfide are encountered. The low pH or acidic water of the Queen City in the outcrop area can present problems through corrosion of the metal in the water systems and should be taken into account when planning a water supply. If and when the aquifer is developed to its maximum under assumed conditions, there may be some movement of the fresh water-salt water interface undip from its present location. It is unlikely, however, that this movement would extend far enough updip to reach the areas in which development will most likely take place; probably the highly mineralized water would still remain a considerable distance downdip from the areas of expected pumpage.

Even with the proper spacing and planning of well fields there will be declines in the water levels in the vicinity of pumped wells for this is essential in the development of ground water.

Individual wells should be properly protected with surface casing and cemented through the overlying beds to prevent highly mineralized water, such as that from the Weches Formation, from entering the wells.

## Other Aquifers

### Nacatoch Formation

The Nacatoch Formation of the Navarro Group crops out in a northeast-trending belt about 2 miles wide, extending from the Trinity River Basin boundary north of Terrell to near the Navarro-Limestone County line in Region I. Because of variations in its lithology along this line, the Nacatoch is not considered to be an aquifer throughout its extent in the basin. In Region II, the sand of the Nacatoch Formation is considered to be an aquifer in the north-central part of the region, northwest of Kerens. It is also an aquifer from the Trinity River Basin boundary north of Terrell to several miles south of Terrell. Its fresh water-bearing capabilities are very limited because of the rapid change in quality of water downdip and because of low transmissibilities.

About 7 acre-feet of water was pumped from the Nacatoch Formation in 1960 for municipal use. The city of Terrell, which is now using surface water, formerly obtained its municipal supply from the Nacatoch through small wells. Domestic and livestock supplies also are obtained from the Nacatoch Formation.

### Yegua Formation

The outcrop of the Yegua Formation ranges from about 10 to 20 miles in width across the southern end of Region II, as shown on Plate 2. The Yegua ranges in thickness from zero at the northern extent of its outcrop to as much as 1,500 feet in the downdip parts. The Yegua is composed of sand, sandy shale, shale, and a few beds of limestone and lignite. The sands of the Yegua supply water to several municipalities and communities in Madison, Houston, and Grimes Counties, as well as supplying numerous domestic and livestock wells.

The Yegua Formation contains water that has a wide range in quality, but generally the water contains less than 3,000 ppm dissolved solids in its outcrop and for a number of miles downdip into northern Trinity, Grimes, and Walker Counties in the southern part of Region II. From analyses of 11 water samples from the Yegua Formation, the dissolved solids ranged from 401 to 2,550 ppm, with only 2 of the 11 analyses exceeding 1,000 ppm. Chloride in two of the analyses exceeded the U. S. Public Health Service limits. All of the other constituents were within the limits except for iron, which ranged from 0.03 to 13 ppm. Generally speaking, the quality of water from the Yegua is not as good as that found in the primary and secondary aquifers and is much more unpredictable.

The municipal pumpage from the Yegua Formation was 104 acre-feet in 1960, and 41 acre-feet was used for irrigation purposes. The pumpage from the Yegua Formation accounts for all the pumpage shown for "other aquifers" in major drainage subdivisions 30 and 31 in Table 5.

The municipal and irrigation wells pumping from the Yegua Formation are located in the outcrop or slightly downdip from it. These wells range in depth from 157 to 590 feet and their reported yields range from 25 to 250 gpm.

The quantity and quality of water available from the Yegua Formation varies with the location owing to the lenticular nature of the sands. In the areas where adequate sand thickness is present and water quality is good, additional development can take place. The aquifer is capable of supplying water to small communities in many locations in Region II, as well as supplying many domestic and livestock wells. However, to obtain a dependable supply from the Yegua it would be desirable to drill test holes to determine the quantity and quality of water at any particular locality.

## Alluvium

Alluvial deposits of sand and gravel along the Trinity River and its main tributaries furnish water for small industries and domestic and livestock purposes. Approximately 13 acre-feet of water was pumped from the alluvium in Region II in 1960. This pumpage is shown in Table 5 and accounts for all of the industrial pumpage in the major drainage subdivision 25. Although alluvium occurs all along the Trinity River in Region II, the only major production is in subdivision 25. The quality of water in the alluvium varies from place to place, but is generally fair. This source of supply, however, can be easily contaminated by improper disposal of municipal and industrial wastes on the land surface or into the streams crossing the alluvium. Generally, the aquifer has limited potential for development in Region II and cannot be depended upon for large supplies of water.

### Cook Mountain Formation

The Cook Mountain Formation crops out across the southern part of the region through southern Leon and central Houston Counties, as shown on Plate 2. The Cook Mountain Formation ranges from 0 to 500 feet in thickness and is composed predominately of shale with only a minor amount of sand. This sand is locally known as the Spiller sand and usually is not more than 50 feet thick. The Spiller sand of the Cook Mountain Formation yields water to domestic and livestock wells in its outcrop area and for a considerable distance downdip. One well located south of Madisonville completed in this sand was drilled to a depth of 482 feet. Yields ranging up to 30 gpm have been reported from the sand.

The water quality is variable. Two chemical analyses from wells a short distance downdip from the outcrop show dissolved solids of 1,030 and 1,230 ppm. Although water of usable quality in the Spiller sand of the Cook Mountain Formation is present downdip for a considerable distance, the quality and quantity available from the underlying Sparta Formation is much better and is generally preferred to that of the Cook Mountain. The potential for development from the Cook Mountain Formation is small.

### Jackson Group

The Jackson Group crops out across the extreme southern end of Region II and yields water to domestic and livestock wells in northern Trinity, Walker, and Grimes Counties. The Jackson consists of sand, sandy shale, shale, and a few thin beds of limestone. Its thickness ranges from zero at the upper edge of the outcrop area to more than 1,200 feet in the downdip part in Region III. The Jackson yields small to moderate amounts of water in its outcrop in Region II. The sand beds are highly lenticular, and the quality of water differs from place to place. Analyses of 3 samples of water taken from the Jackson Group in Region II ranged from 455 to 1,700 ppm dissolved solids. There are no major wells in the region; however, in Region III some small municipalities and industries withdraw water from the Jackson. Owing to its lenticular nature, potential development from the Jackson Group is limited by its yield and quality of water. It should be possible to obtain water in some locations to supply small communities or small industries. The sands of the Jackson Group are important as a source of supply to small communities, as its outcrop is located in an area of the region in which no other ground water is available. To obtain a dependable supply from the Jackson it would be desirable to drill test holes to determine the quantity and quality of water at any particular locality. Over much of the outcrop area and a short distance downdip there should be numerous localities in which small supplies could be developed.

## Region III

The primary aquifer of Region III consists of the Miocene, Pliocene, and Pleistocene formations collectively referred to in this report as the Gulf Coast aquifer. The Gulf Coast aquifer is made up of seven geologic formations (Table 1), each defined on the basis of its physical characteristics. However, because of the difficulty in differentiating the formations in the subsurface, they are commonly grouped into three units for discussion purposes in ground-water reports. These three units are the Catahoula Sandstone, Oakville Sandstone, and Lagarto Clay; the Goliad Sand, Willis Sand, and Lissie Formation; and the Beaumont Clay. The areal extent of the Gulf Coast aquifer is shown on Figure 7. The Carrizo-Wilcox and Sparta aquifers, which crop out in Region II, contain water with less than 3,000 ppm dissolved solids in the extreme northern part of Region III (Figure 7). This source of water must be considered of limited potential in Region III because of the small areal extent of the aquifers and marginal quality of the water. Therefore, the Sparta and Carrizo-Wilcox aquifers which are discussed at length under the occurrence and availability of ground water in Region II will not be discussed further in this section. None of the aquifers in Region III are classified as secondary. Other aquifers that yield small quantities of water locally to municipalities and industries include the Jackson Group and Yegua Formation, which crops out in the northern part of the region (Plate 3).

The statements and data on the following pages are a general summary of conditions occurring in Region III. Most of the material on Region III presented in the following discussion was obtained from the report by Wood, Gabrysch, and Marvin (1963), prepared as a part of the statewide reconnaissance program. For a more detailed discussion of the Gulf Coast region, the reader is referred to that report.

## Primary Aquifers

### Gulf Coast Aquifer

#### Geologic Characteristics

The Catahoula Sandstone, Oakville Sandstone, and Lagarto Clay crop out in an extensive area in the northern part of Region III and dip toward the Gulf Coast at about 50 to 60 feet per mile. The Catahoula Sandstone, consisting of sand, clay, silt, tuff, volcanic ash, and in places fuller's earth, is the basal formation of this unit. Extensive cementing of the sand reduces the potential ground-water storage, movement, and production of the Catahoula. The Oakville Sandstone, which overlies the Catahoula, is a massive, light-colored sand or sandstone interbedded with gray or yellow clay and silt. The Lagarto Clay is predominantly a massive clay and sandy clay interbedded with sand and sandstone.

The Goliad Sand, Willis Sand, and Lissie Formation unit overlies the Catahoula, Oakville, and Lagarto and crops out across the central part of Region III. These formations dip toward the Gulf at a rate ranging from 10 to 45 feet per mile. The Goliad Sand, which is the basal formation of this unit, is overlapped by the younger formations; it is present in the subsurface of Region III as a bentonitic clay interbedded with reddish-colored sand and gravel cemented with lime. The Willis Sand is a fine to coarse, reddish sand interbedded or mixed with gravel, silt, and clay. The Lissie Formation is composed of massive beds and lenses of fine to coarse sand, which grade into and are interbedded with clay, sandy clay, and gravel.

The Beaumont Clay is principally a poorly bedded calcareous clay of various colors,,containing thin stringers and beds of silt and fine sand. The thicker sand lenses and beds are in the basal part of the formation.

The sand beds in the Gulf Coast aquifer that contain water with less than 3,000 ppm dissolved solids range in combined thickness from zero at the northern edge of the outcrop to more than 1,200 feet downdip, where they occur to a depth of more than 3,000 feet in southern Liberty County. Southward from southern Liberty County, the water in the deeper sand beds of the Gulf Coast aquifer becomes progressively more mineralized, resulting in a sharp decrease in the total thickness of the fresh-water sands. These features are best illustrated on Plates 4, 16, and 17. The contour lines shown on Plates 16 and 17 are after Wood, Gabrysch, and Marvin (1963). Plate 4 was prepared by the authors of this report and the position of the base of water containing less than 3,000 ppm dissolved solids was determined from a study of electric logs of oil tests in Region III.

The regional dip of the Gulf Coast aquifer as well as water quality may be abruptly changed in local areas due to the occurrence of salt domes. Several such domes exist in Region III of the Trinity River Basin.

### Occurrence and Movement of Ground Water

Both water-table and artesian conditions exist in the Gulf Coast aquifer. Water-table conditions generally exist in and near the outcrop area of the sand beds. Downdip, the water passes beneath confining layers and is under artesian pressure. Most of the water occurring in the Gulf Coast aquifer is under artesian pressure.

Where water-table conditions prevail in the Gulf Coast aquifer, ground water moves downdip and laterally from the recharge area to points of discharge at topographic lows, where water is discharged at seeps and springs. Where artesian conditions prevail, the movement of water is generally in the direction of the regional dip, in this case from the outcrop toward the Gulf Coast. Ground water occurring in the deeper and older formations of the Gulf Coast aquifer is under greater artesian head than that of the younger and shallower formations because of the higher altitude of their outcrops. The greater pressures in the deeper formations result in a vertical movement of water upward through confining beds toward points of less pressure. The rate of vertical movement depends on the vertical permeability, thickness of the confining layers, and the difference in artesian head.

### Recharge and Discharge

Conditions affecting recharge in the Trinity River Basin are generally favorable. It is likely that potential recharge is being rejected because of the large amount of rainfall and the relatively "full" condition of the aquifer in the outcrop.

Water is discharged by both artificial and natural means. Artificial discharge occurs at all pumping and flowing wells which screen the aquifer. The greatest amount of artificial discharge occurs at the municipal, industrial, and irrigation wells of the region. Natural discharge occurs through vertical interformational seepage, and through springs, seeps, and by evapotranspiration where the water table is near the land surface.

## Water Levels

Water levels in Region III are relatively close to the surface and flowing wells are common. There is no evidence of large-scale water-level declines throughout the region. However, water-level declines may be experienced locally in areas of heavy pumping.

## Water-Bearing Characteristics

The water-bearing characteristics of the Gulf Coast aquifer are highly variable. Permeabilities and thickness of the water-bearing sands differ greatly from place to place. On the basis of average permeabilities and the thickness of the sand beds of the aquifer containing water having less than 3,000 ppm dissolved solids, the coefficients of transmissibility range from a few thousand gpd/ft. to more than 200,000 gpd/ft. The largest transmissibilities occur where the net sand thickness of the aquifer is greatest.

Well yields and specific capacities differ greatly depending on the transmissibilities, the thickness and the lithologic characteristics of sand beds penetrated, and the well construction. Few wells penetrate the entire thickness of the aquifer.

In general the Goliad Sand, Willis Sand, and Lissie Formation unit is the most prolific part of the Gulf Coast aquifer.

## Chemical Quality

Ground Water of good to excellent quality may be obtained from the Gulf Coast aquifer throughout most of Region III. Table 6 lists a number of chemical analyses of water from the aquifer, their approximate location, and producing intervals from all parts of Region III. Except where indicated in the table, these analyses were selected from Wood, Gabrysch, and Marvin (1963). These analyses are representative of the quality of water in Region III in their respective location and producing interval.

Although water suitable for most purposes may be found in the aquifer throughout most of the region, some treatment may, in some instances, be advisable for public supplies and for some industrial uses where chemical quality is a critical factor. In general the softer waters are more likely to occur in the deeper zones. The iron content in some places exceeds 0.3 ppm, and the water may require treatment to reduce the concentration. Locally, the pH may be less than 7, and the water will tend to be corrosive.

The dissolved-solids content in the representative analyses shown in Table 6 ranges from 179 to 2,240 ppm. Ground water containing less than 900 ppm dissolved solids is obtained for all of the public supplies of the region.

The quality of water in some parts of Region III, especially the near coastal areas, may be threatened by salt-water encroachment. Heavy pumping may cause saline water to move up the formational dip to areas of discharge.

Table 6.--Representative chemical analyses of water from the Gulf Coast aquifer in Region III, Trinity River Basin

(Analyses by U. S. Geological Survey unless noted. Analyses expressed in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio.)

| Well of analysis No. [1] | Location of well | Screened interval (ft.) | Silica ($SiO_2$) | Iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium and potassium (Na + K) | Bicarbonate ($HCO_3$) [2] | Sulfate ($SO_4$) | Chloride (Cl) | Fluoride (F) | Nitrate ($NO_3$) | Dissolved solids | Total hardness as $CaCO_3$ | Percent sodium | Sodium adsorption ratio (SAR) | Specific conductance (micromhos at 25°C.) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 mi. N Anahuac, Chambers Co. | [3] 330- 387 | 19 | -- | 100 | 24 | 686 -- | 388 | 443 | 770 | -- | 2.5 | 2,240 | 348 | -- | 16 | 3,750 | 7.5 |
| 2 | Anahuac, Chambers Co. | 73- 113 | 21 | 1.0 | 70 | 15 | 212 2.3 | 526 | 18 | 172 | 0.5 | .0 | 770 | 236 | -- | 6.0 | 1,330 | 6.9 |
| 28 | 12 mi. NW Livingston, Polk Co. | 300- 320 | -- | [4] .50 | 141 | 13 | 656 | 560 | 2 | 970 | -- | 1.5 | 2,060 | 406 | -- | 14 | 3,680 | -- |
| 29 | Livingston, Polk Co. | ?- 610 | 32 | .04 | 16 | 1.0 | 155 4.6 | 362 | 3.8 | 62 | .3 | .0 | 453 | 44 | -- | 10 | 738 | 7.2 |
| 30 | 16 mi. SE Livingston, Polk Co. | ?-1,200 | -- | [4] .39 | 24 | 5.8 | 65 | 222 | 6 | 26 | -- | .2 | 236 | 84 | -- | 3.1 | 391 | -- |
| 31 | San Jacinto Co., 16 mi. SW Livingston | 350- 400 | 20 | .11 | 21 | 4.3 | 111 3.0 | 296 | 15 | 36 | .5 | .0 | 357 | 69 | -- | 5.8 | 579 | 8.0 |
| 32 | San Jacinto Co., 16 mi. SE Livingston | ?- 300 | -- | [4] .23 | 10 | 2.3 | 92 | 240 | 11 | 18 | -- | .0 | 253 | 34 | -- | 6.9 | -- | -- |
| 33 | San Jacinto Co., 13 mi. NW Livingston | 396- 411 | -- | [4] .11 | 31 | 1.9 | 317 | 585 | 1 | 208 | -- | .0 | 918 | 86 | -- | 15 | -- | -- |
| 34 | 26 mi. N Liberty, Liberty Co. | ?- 659 | -- | [4] .08 | 41 | 7.1 | 31 | 210 | 4 | 16 | -- | .0 | 268 | 132 | -- | 1.2 | -- | -- |
| 36 | 7 mi. NE Liberty, Liberty Co. | ?- 678 | 23 | -- | 144 | 10 | 84 2.6 | 257 | 22 | 250 | -- | .0 | 669 | 400 | -- | 1.8 | 1,240 | 6.9 |
| 37 | 4 mi. E Liberty, Liberty Co. | ?-1,180 | 21 | -- | 75 | 8.5 | 331 2.9 | 210 | 2.7 | 558 | -- | 2.0 | 1,100 | 222 | -- | 9.7 | 2,100 | 8.3 |
| 38 | Liberty, Liberty Co. | ?- 960 | 18 | .80 | 64 | 14 | 171 3.0 | 169 | .0 | 318 | .2 | 1.8 | 731 | 217 | -- | 5.0 | 1,290 | 7.6 |
| 60-07-801 | 12 mi. SE Trinity, Trinity Co. | 105- 109 | 93 | 4.9 | 6 | 2.7 | 20 3.5 | 50 | 6.8 | 20 | .2 | .0 | 181 | 26 | 54 | 1.7 | 170 | 5.6 |
| 60-13-301 | 13 mi. NE Huntsville, Walker Co. | 100- 395 | 46 | -- | 77 | 7.1 | 327 | 164 | 293 | 348 | -- | 2.2 | 1,180 | 221 | -- | -- | 1,850 | -- |
| [5] 60-20-202 | Huntsville, Walker Co. | [3] 300- 790 | 14 | .2 | 114 | 2.7 | 57 | 278 | 19 | 64 | -- | -- | 687 | 297 | -- | -- | -- | 7.1 |

[1] All analyses from wells in Chambers, Liberty, Polk, and San Jacinto Counties are from Wood, Gabrysch, and Marvin (1963).
[2] Includes equivalent of any carbonate ($CO_3$) present.
[3] Not screened throughout interval.
[4] Iron in solution at time of analysis.
[5] Analysis by Curtis Laboratories, Houston.

## Utilization and Development

On the basis of 1959 pumpage figures it is estimated that about 19,343 acre-feet of ground water per year is being withdrawn for municipal, industrial, and irrigation purposes from the Gulf Coast aquifer in Region III of the Trinity River Basin. About 16,000 acre-feet per year of this is being pumped for irrigation purposes. Pumpage for public supplies and industry total 2,223 and 1,120 acre-feet per year, respectively.

The greatest development of underground water in Region III occurs in south and central Liberty County where the water is used extensively for irrigation of rice. Ground water is the source for all public supplies in the region. Plate 3 shows the location and distribution of all municipal, industrial, and irrigation wells in Region III. It is estimated that the municipal, industrial, and irrigation pumpage figures listed above represent 90 percent of total production from the Gulf Coast aquifer, with domestic, livestock, and flowing wells accounting for the remaining pumpage. A number of wells in the region flow continuously. Not enough information is available at the present time to estimate the amount of water discharged through flowing wells in the region, or the quantities being utilized or wasted. Table 7 presents a summary of municipal, industrial, and irrigation pumpage from the Gulf Coast aquifer in Region III by major drainage subdivisions.

## Ground Water Available for Development

Approximately 19,000 acre-feet of water is presently being pumped from the Gulf Coast aquifer. It is estimated that under maximum gradients about 66,000 acre-feet of water per year could be withdrawn from the aquifer, or 47,000 acre-feet could be produced perenially in addition to that pumped in 1960, providing sufficient recharge is available. About 2 inches of the approximately 50 inches of annual rainfall would be needed as recharge to support maximum conditions of development. Outcrop conditions of the aquifer are such that even under conditions of maximum development, recharge probably will be greater than the amount needed to supply the withdrawals. Therefore, it should be possible to develop additional water supplies in the outcrop area.

There is 30,200,000 acre-feet of ground water available from storage during development from present to maximum conditions in subregion I of the Gulf Coast region (Wood, Gabrysch, and Marvin, 1963). The Trinity River Basin occupies approximately 28 percent of the area for which storage was calculated. Thus, it appears that approximately 8,500,000 acre-feet of ground water could be produced from storage in the Trinity River Basin during development from present to maximum conditions.

The reader is referred to Wood, Gabrysch, and Marvin (1963) for discussion on the methods used in determining the quantity of water available from the Gulf Coast aquifer.

Table 7.--1960 Ground-water pumpage from aquifers in Region III, Trinity River Basin 1/

(Pumpage expressed in acre-feet 2/ 3/ )

| Subdivision | 32 | 34 | 35 | Total |
|---|---|---|---|---|
| **Gulf Coast Aquifer** | | | | |
| Municipal | 1,002 | 437 | 784 | 2,223 |
| Industrial | -- | 168 | 952 | 1,120 |
| Irrigation | -- | -- | 16,000 | 16,000 |
| Total | 1,002 | 605 | 17,736 | 19,343 |
| **Other Aquifers 4/** | | | | |
| Municipal | 347 | -- | -- | 347 |
| Total | 347 | -- | -- | 347 |
| **Summary of Pumpage in Region III** | | | | |
| Municipal | 1,349 | 437 | 784 | 2,570 |
| Industrial | -- | 168 | 952 | 1,120 |
| Irrigation | -- | -- | 16,000 | 16,000 |
| Total | 1,349 | 605 | 17,736 | 19,690 |

1/ Some of the pumpage in the Gulf Coast aquifer was determined on the basis of pumpage in 1959.

2/ Municipal pumpage includes water supplied by privately owned systems.

3/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.

4/ Other aquifers include Yegua Formation and Jackson Group.

## Other Aquifers

### Yegua Formation

The Yegua Formation crops out across a small corner of Region III in the extreme northwestern part (Plate 3). The Yegua consists of a sequence of fine to medium-grained lenticular sand, sandy shale, shale, and a few beds of limestone and lignite. In Region III, the Yegua Formation supplies an estimated 6 acre-feet annually to a small community in Houston County and supplies numerous domestic and livestock wells in and near the outcrop. The Yegua contains water of varying quality, but generally the water in the Yegua contains less than 3,000 ppm dissolved solids in its outcrop and for a number of miles downdip in northern Walker County.

The quantity and quality of water available from the Yegua Formation differs from place to place owing to the lenticular nature of the sand beds. The aquifer is capable of supporting small communities in many locations in Region III, as well as supplying domestic and livestock wells.

### Jackson Group

The Jackson Group, consisting of sand, sandy shale, shale, and a few thin beds of limestone, crops out across the northern part of Region III and dips toward the coast at about 120 to 150 feet per mile (Plate 3). The Jackson ranges in thickness from zero at the northern extent of its outcrop to more than 1,200 feet in the downdip part. Small to moderate quantities of water are withdrawn from the Jackson Group for municipal, domestic, and livestock use in and near the outcrop.

The sand beds in the Jackson Group are lenticular and the quality of water differs from place to place, but generally the water contains less than 3,000 ppm dissolved solids in the outcrop and for a number of miles downdip. Analyses of water samples from 8 wells producing from the sands of the Jackson Group in Region III ranged from 457 to 1,133 ppm dissolved solids.

The municipal pumpage from the Jackson was approximately 341 acre-feet, all occurring in major drainage subdivision 32. The wells are all withdrawing water from sand beds between 166 and 465 feet below the land surface and have reported yields of between 100 and 300 gpm.

The Jackson is important as a source of small water supplies in and near its outcrop as it is located in an area of the region in which no other suitable ground-water supply is available. The aquifer has limited potential for large-scale development, but is capable of supplying water for small towns in many locations in Region III, as well as supplying domestic and livestock wells.

## Summary of Ground-Water Pumpage and Availability

Approximately 66,000 acre-feet of ground water is presently being pumped annually from the aquifers of the Trinity River Basin for municipal, industrial, and irrigation purposes. Most of this pumpage, approximately 40,000 acre-feet, occurs in Region I of the basin, where it is used primarily for municipal and industrial purposes. The pumpage in Region II is small in comparison with that of the other regions of the basin. Only about 6,000 acre-feet of ground water is pumped annually from aquifers in Region II, where it is used primarily for municipal purposes. Most of the approximately 20,000 acre-feet of water pumped in Region III is used for irrigation. Pumpage from the aquifers of the Trinity River Basin for 1960 is presented in Table 8.

On the order of 300,000 acre-feet of ground water is estimated to be available annually from the primary and secondary aquifers of the Trinity River Basin. The estimate is based on pumpage under assumed conditions and is related primarily to the ability of the aquifers to transmit water and on the availability of recharge in the outcrop areas. Under assumed conditions of pumpage, the effect of pumping is such that the static water level is drawn down to the top of the aquifer where this depth is 400 feet below land surface. An estimated 140,000 to 170,000 acre-feet of water is available perennially from the Carrizo-Wilcox, Sparta, and Queen City aquifers in Region II. This amount is more than double that calculated to be available in Region I or Region III. There is estimated to be 62,000 to 67,000 acre-feet available annually from the Trinity Group and Woodbine aquifers in Region I, and approximately 66,000 acre-feet from the Gulf Coast aquifer in Region III.

Additional quantities of water can be developed in the outcrop areas of the aquifers, where more water is available as recharge than can be transmitted by the aquifers to the areas of pumpage under the assumed conditions of development. In the course of establishing the assumed conditions of pumpage for which availability was computed, large quantities of water will be withdrawn from storage. However, this source of water is available only during the development and should not be considered as water available for development on a sustained basis.

## RECOMMENDATIONS FOR FUTURE STUDIES

For detailed water planning or for the planning of individual water supplies, more detailed information than is contained in this report is needed. Detailed ground-water investigations, as outlined in the report to the Fifty-Sixth Legislature (Texas Board of Water Engineers, 1958), should be made on the six primary and secondary aquifers of the Trinity River Basin to better define the geologic and water-bearing characteristics of the aquifers and to refine the estimates of ground water available for development that are presented in this report. These studies should not be limited only to the Trinity River Basin, but should include the entire aquifer, so as to determine the effects geology and pumping outside the basin will have on the availability of ground water within the basin. In addition to studies on the primary and secondary aquifers of the basin, investigations to define the occurrence, quality, and availability of water in the Nacatoch Formation, Yegua Formation, and Jackson Group are needed, as they are important as a source of supply to small communities, and they occur in areas in which no other ground water is available.

Ground-water studies should be made in the vicinity of towns needing additional water, to estimate the quantity of ground water available for development. These studies should be made as the need for a water supply or additional water arises in communities and municipalities.

Table 8.--1960 Ground-water pumpage from aquifers in the Trinity River Basin

(Pumpage expressed in acre-feet 1/)

| Aquifer 2/ | Municipal | Industrial | Irrigation | Total |
|---|---|---|---|---|
| REGION I | | | | |
| Trinity Group (P) | 21,467 | 12,755 | -- | 34,222 |
| Woodbine (S) | 4,393 | 1,346 | -- | 5,739 |
| Others 3/ | 137 | 165 | 160 | 462 |
| Subtotal | 25,997 | 14,266 | 160 | 40,423 |
| REGION II | | | | |
| Carrizo-Wilcox (P) | 3,447 | 220 | 839 | 4,506 |
| Queen City (S) | 107 | -- | -- | 107 |
| Sparta (P) | 995 | -- | 260 | 1,255 |
| Others 4/ | 111 | 13 | 41 | 165 |
| Subtotal | 4,660 | 233 | 1,140 | 6,033 |
| REGION III | | | | |
| Gulf Coast (P) 5/ | 2,223 | 1,120 | 16,000 | 19,343 |
| Others 6/ | 347 | -- | -- | 347 |
| Subtotal | 2,570 | 1,120 | 16,000 | 19,690 |
| TOTAL | 33,227 | 15,619 | 17,300 | 66,146 |

1/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.
2/ "P" indicates primary aquifer; "S" indicates secondary aquifer.
3/ Includes rocks of Pennsylvanian age, Nacatoch Formation, and alluvium.
4/ Includes Nacatoch Formation, Yegua Formation, and alluvium.
5/ Includes Catahoula Sandstone, Oakville Sandstone, Lagarto Clay, Goliad Sand, Willis Sand, Lissie Formation, and Beaumont Clay.
6/ Includes Yegua Formation and Jackson Group.

Continuing studies are needed to collect, compile, and periodically analyze records of pumpage, water levels, and chemical quality of water. Additional work is needed in the collection of water-use data to improve the quality of data received, and the program should be expanded to include irrigation pumpage. Additional water-level observation wells are needed in all of the primary and secondary aquifers of the Trinity River Basin. These wells should be spaced throughout the aquifer, and additional observation wells should be located in the areas of heavy pumping. Data from the continuing water-use and water-level programs will provide a means for determining the effects of present and future pumpage. A continuing observation program of the chemical quality of water in the primary and secondary aquifers should be established to determine changes in the chemical quality that may affect the quantity of fresh ground water available for development. Wells should be sampled periodically throughout the extent of the aquifers, with special attention given to areas of heavy withdrawals and in the vicinity of oil-field activities.

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# LIST OF GROUND-WATER PUBLICATIONS

The following is a list of ground-water publications pertaining to areas in the Trinity River Basin which have been published by the Texas Water Commission (formerly Texas Board of Water Engineers) or the United States Geological Survey.

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Coastal Plain near Houston, Texas, W. L. Broadhurst, 1953: U. S. Cong., House Comm. Interior and Insular Affairs, Physical and Economic Foundation of Natural Resources IV, p. 51-69.

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### Cooke

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### Dallas

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