BULLETIN 6307

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

By

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

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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 Sabine 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 SABINE RIVER BASIN, TEXAS


## ABSTRACT

The reconnaissance investigation of the Sabine 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 Sabine River Basin is in the eastern part of the State and covers approximately 7,400 square miles in Texas. The area of study includes all or parts of 20 counties and represents about 2.8 percent of the total area of Texas.

The physiographic expression of the Sabine River Basin ranges from treeless prairies to heavily forested hills with altitudes ranging from sea level at the mouth of the Sabine River to about 750 feet above sea level in the upper reaches of the basin. The mean annual precipitation ranges from 56 inches near the coast to 40 inches in the upper reaches of the basin. The population within the Sabine River Basin in 1960 was approximately 302,800 which represents about 3.2 percent of the State's population. The economy of the basin is highly diversified. Agriculture, livestock raising, dairying, wood products, oil and gas production and refining, plus a great variety of light manufacturing products, form the most important segments of the economy.

The Carrizo Formation and Wilcox Group, and the formations that comprise the Gulf Coast aquifer of this report are primary aquifers and are capable of supplying large quantities of water over large areas of the Sabine River Basin. The Queen City Formation is classified as a secondary aquifer because it is capable of supplying small quantities of water over large areas of the basin. In addition to the primary and secondary aquifers, the Woodbine Group, Nacatoch Formation, Paluxy Formation of the Comanche Series, Sparta Formation, Yegua Formation, and Jackson Group yield small to moderate quantities of water locally, but have limited potential.

In 1960, approximately 19,500 acre-feet of ground water was pumped from the aquifers of the Sabine River Basin for municipal, industrial, and irrigation purposes. Approximately 8,000 acre-feet of this total was from the Carrizo-Wilcox aquifer and approximately 11,000 acre-feet from the Gulf Coast aquifer. The remainder was obtained from the Queen City and other aquifers of the basin.

On the order of 150,000 acre-feet of usable quality ground water is estimated to be available annually from the primary aquifers of the Sabine 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 will be 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 100,000 acre-feet of water is available perennially from the Carrizo-Wilcox aquifer in the central part of the basin. In addition, a considerable amount of water will be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed. It is estimated that approximately 46,000 acre-feet of water is available perennially from the Gulf Coast aquifer in the southern part of the basin. During the time water levels are being lowered to a depth of 400 feet along the line of discharge, on the order of 6,000,000 acre-feet of ground water will also be obtained from storage in the Gulf Coast aquifer.

There are additional undetermined quantities of water available for development from the Queen City aquifer in its outcrop area. However, to obtain the ultimate amount of water available from the aquifer, it will be necessary to develop small well fields throughout the area.

For detailed water planning or for planning individual water supplies, more detailed information than is contained in this 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", December 1958, should be made on the three primary and secondary aquifers of the Sabine River Basin to better define the geologic and water-bearing characteristics of the aquifers and to refine the estimates presented in this report of ground water available for development.

# R E C O N N A I S S A N C E   I N V E S T I G A T I O N   O F   T H E   G R O U N D - W A T E R   R E S O U R C E S   O F   T H E   S A B I N E   R I V E R   B A S I N ,   T E X A S

## INTRODUCTION

### Purpose and Scope

The reconnaissance investigation of the Sabine 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 ground-water reconnaissance studies, the State was divided into 13 major river basin areas and a coastal region which embraces 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 Sabine 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 Sabine River Basin reconnaissance investigation provide a generalized evaluation of ground-water conditions over large areas. The amount of water available for development in the Sabine River Basin determined during this study is probably 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 Sabine River Basin as discussed in this report is that part of the Sabine River drainage area which lies in Texas.

The Sabine River Basin is in the eastern part of the State as shown on Figure 1. The basin, which includes the areas drained by the Sabine River and its tributaries, is bounded on the west by the Neches and Trinity River Basins and on the north by the Cypress and Sulphur drainage basins. From Shelby County south to the Gulf of Mexico, the Sabine River forms the State's eastern boundary. Consequently, the part of the drainage basin east of the Sabine River lies in Louisiana and is not considered or discussed in this report. The Sabine River Basin in Texas includes all or parts of 20 counties, has an areal extent of 7,386 square miles and represents 2.8 percent of the State's total area.

Because of its large areal extent, the Sabine River Basin has been divided into two 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 condition. The boundaries of the regions coincide with the topographic limits of the Sabine River Basin and the topographic limits of smaller drainage subdivisions which have been defined by the Planning Division of the Texas Water Commission. The location and extent of the two regions 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 selected wells for additional analyses.

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 affects 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.

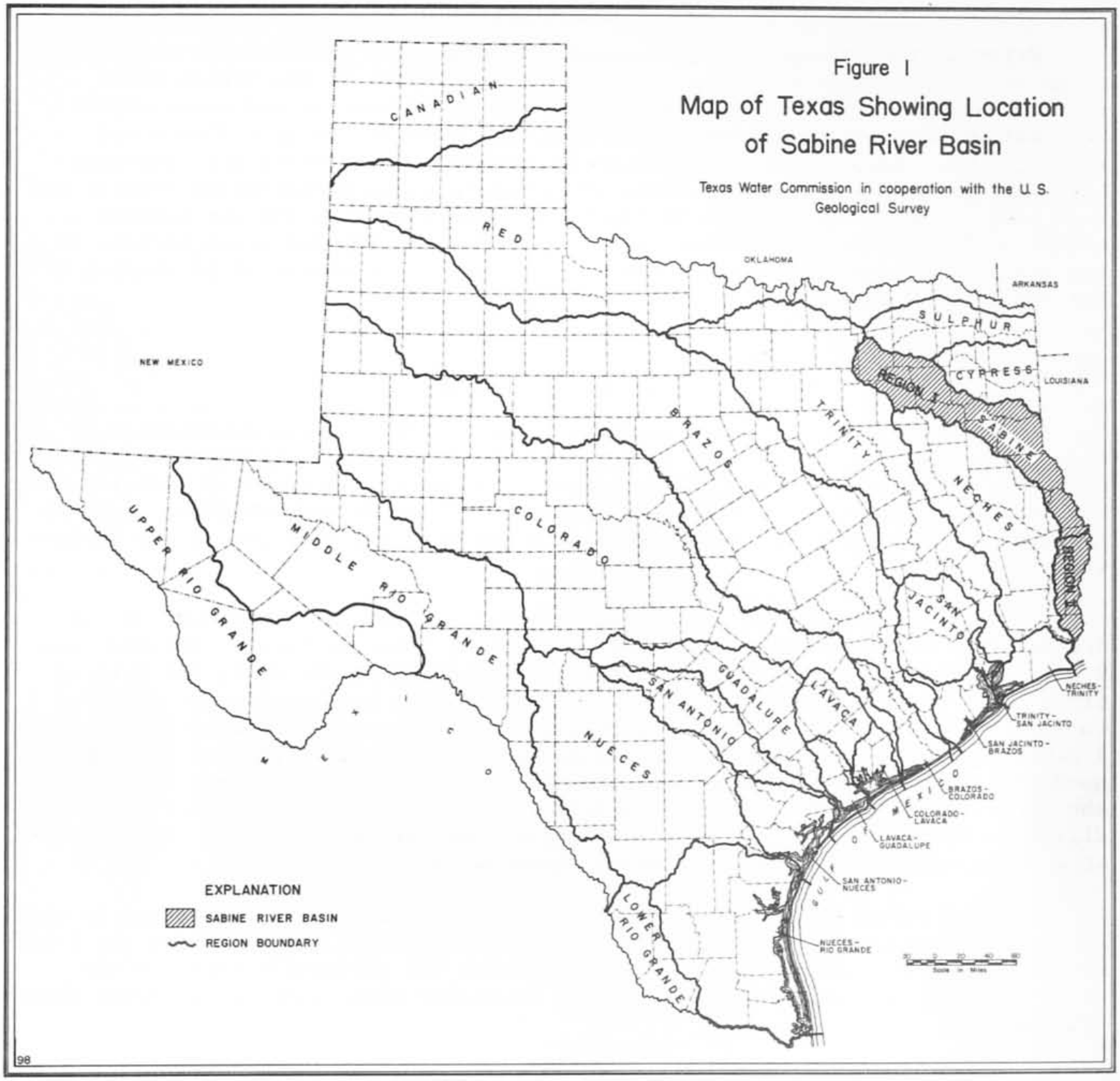



Figure 1

Map of Texas Showing Location of Sabine River Basin

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

## Previous Investigations

Prior to the present reconnaissance investigation, ground-water investigations had been conducted in all or parts of 15 counties of the Sabine River Basin. Available ground-water data range from comprehensive and out-of-date information to water-well inventories that were made in the late 1930's and early 1940's. None of the previous investigations in the basin are comprehensive and up-to-date. 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 which pertain to earlier work in the Sabine 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, measuring 1 degree of latitude and longitude, 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 individual well within the 2-1/2 minute quadrangle.

The individual wells used as control points on various illustrations in this report have not been identified by well numbers. 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, and 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 permitted the use of numerous electrical logs from their files which otherwise were not available.

The assistance and data furnished by members of the U. S. Geological Survey on parts of the Sabine River Basin is gratefully acknowledged.

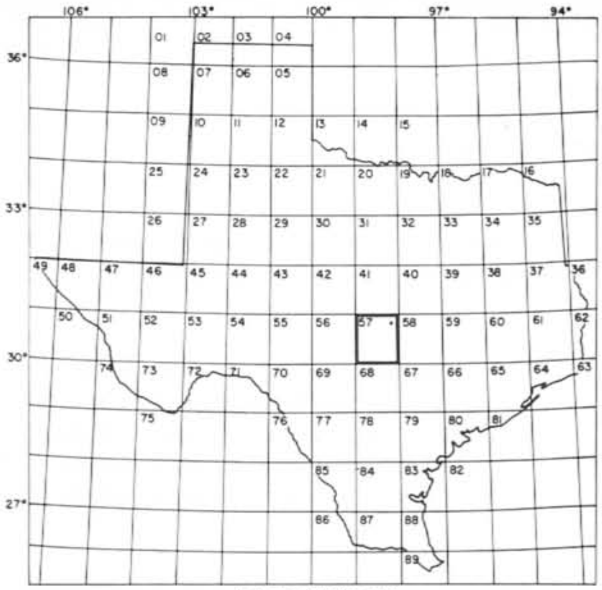
## Location of Well 57-15-701

57 1-degree quadrangle

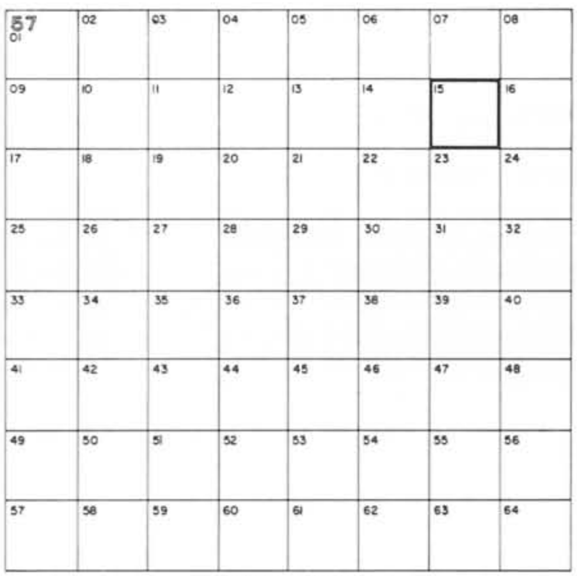
15 7 1/2 minute quadrangle

7 2 1/2 minute quadrangle

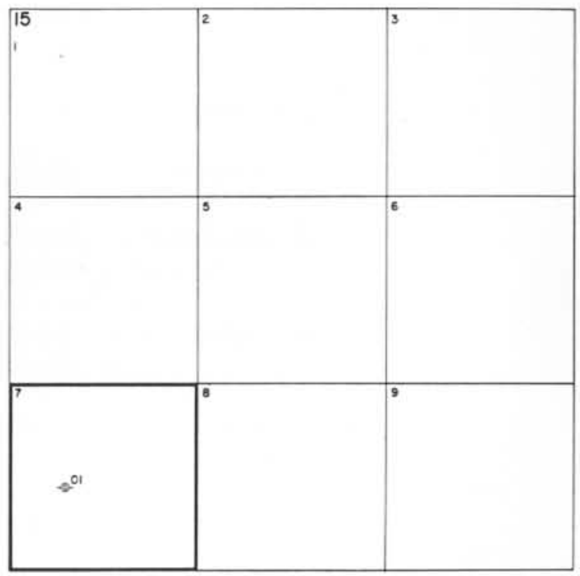
01 Well number within 2 1/2 minute quadrangle




1-degree Quadrangles



7 1/2-minute Quadrangles




2 1/2-minute Quadrangles

Special acknowledgment is expressed to W. F. Guyton and Associates who reviewed the manuscript for its technical adequacy and offered many helpful suggestions and criticisms.

## Personnel

Initial planning for the reconnaissance fieldwork and the resulting report on the Sabine 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 performed by Engineering Services, Texas Water Commission, by Ground Water Division personnel under the general supervision of John J. Vandertulip, Chief Engineer, L. G. McMillion, Director, Ground Water Division, and M. L. Klug, former Assistant Director, Ground Water Division. The Sabine River Basin report was prepared under the direction and supervision of R. C. Peckham, Assistant Director, Ground Water Division.

Fieldwork in the Sabine 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 |
|---|---|
| V. L. Souders | Collin, Hunt, Rockwall |
| J. W. Dillard | Kaufman, Rains, Smith, Gregg, Wood, Van Zandt, Upshur |
| B. B. Baker | Rusk, Sabine, San Augustine, Shelby, Panola |
| D. R. Curry | Rusk |

## GEOGRAPHY

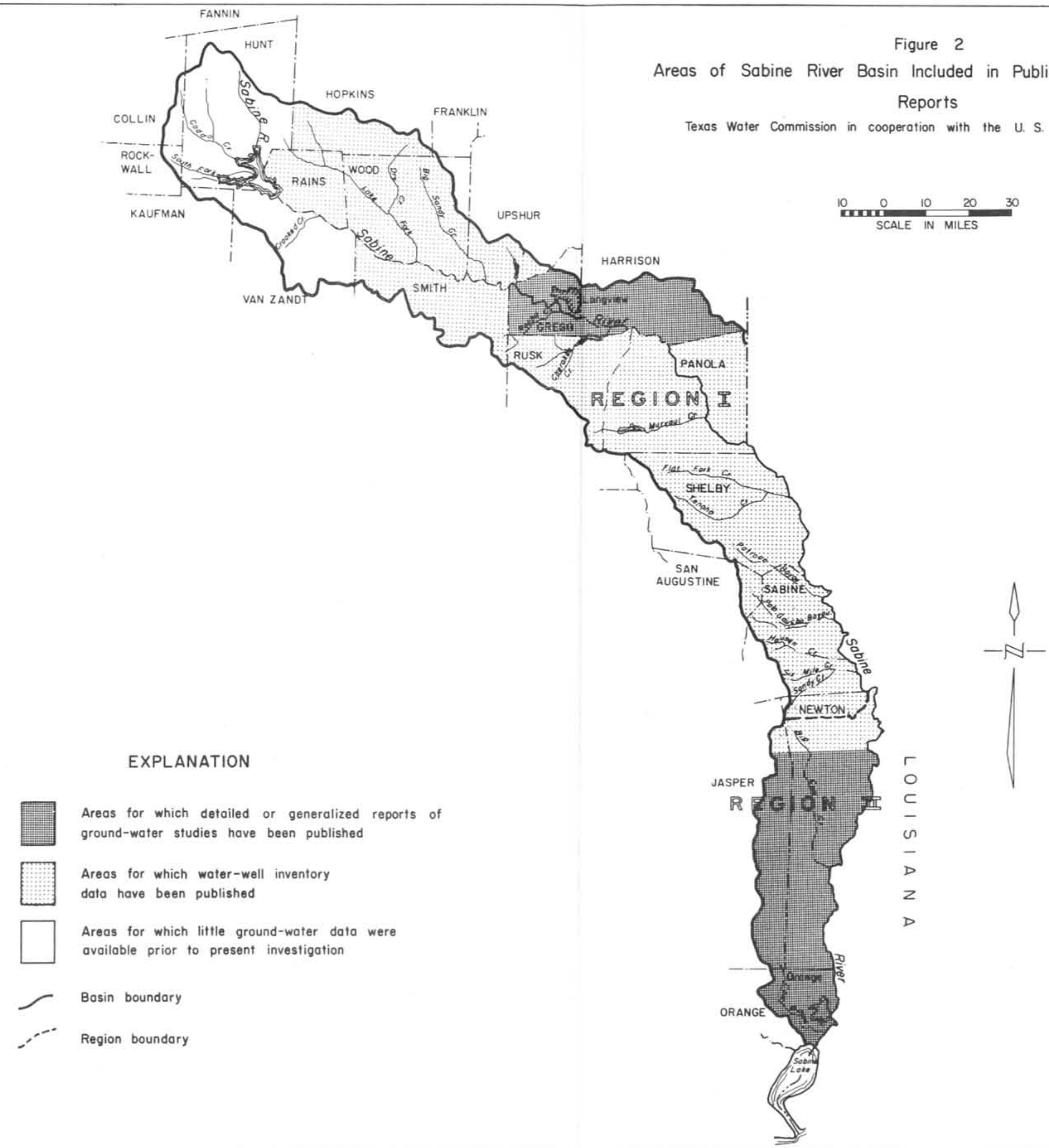
The Sabine River Basin in Texas lies in the Gulf Coastal Plain. The physiographic expression of the Sabine River Basin ranges from treeless prairies to heavily forested hills, with altitudes ranging from sea level at the mouth of the Sabine River to about 750 feet above sea level in the upper reaches of the basin. The Planning Division of the Texas Water Commission has subdivided the Sabine 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 and 2.

The climate of the Sabine River Basin is characterized by hot summers and mild winters. The mean annual precipitation ranges from about 40 inches in the upper reaches of the basin to more than 56 inches near the coast. Figure 3 illustrates the mean annual precipitation in the Sabine River Basin and the average monthly precipitation for the period of record at selected stations in the

Figure 2

Areas of Sabine River Basin Included in Published Ground-Water Reports

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



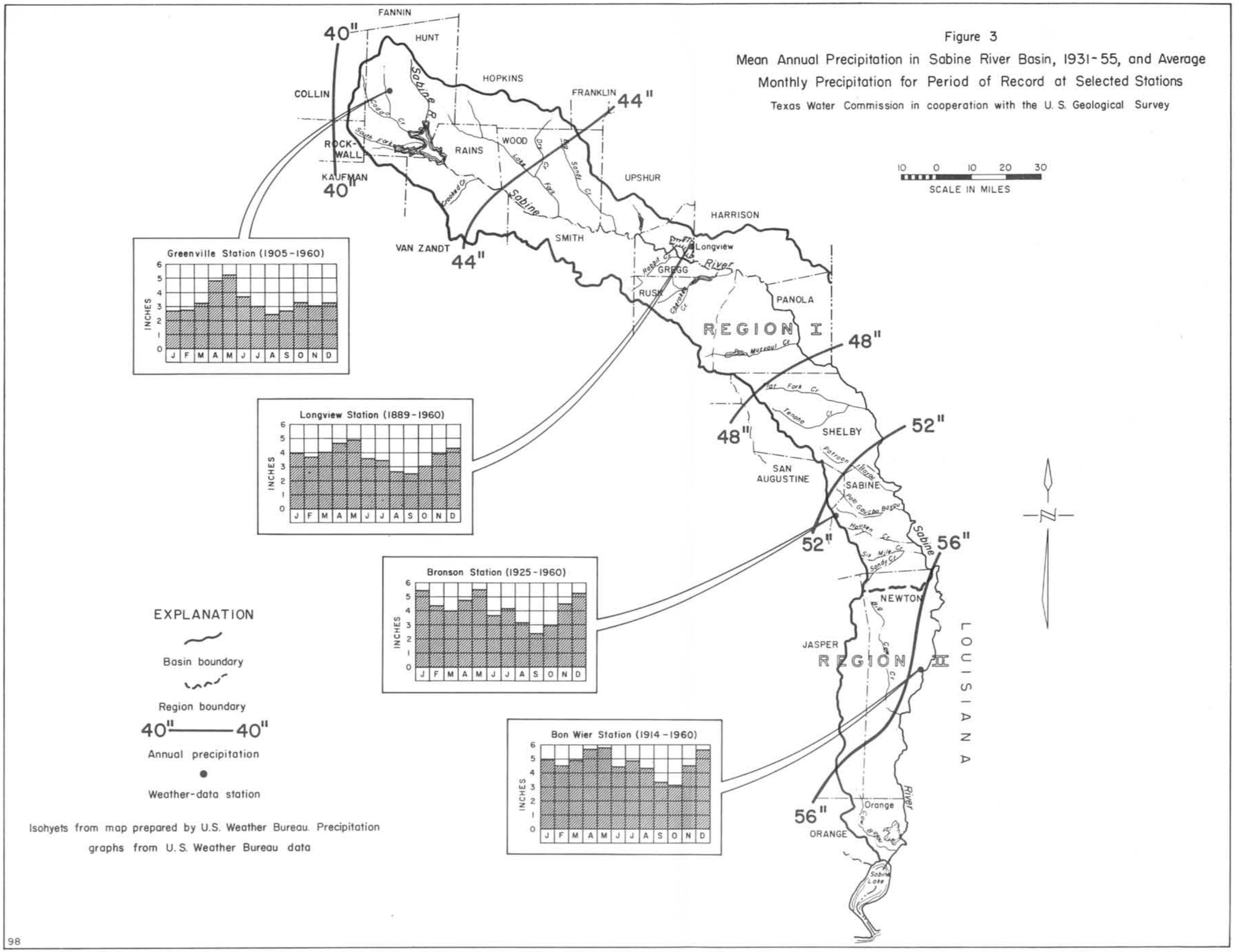



Figure 3
Mean Annual Precipitation in Sabine River Basin, 1931-55, and Average Monthly Precipitation for Period of Record at Selected Stations
Texas Water Commission in cooperation with the U. S. Geological Survey

basin. Figure 4 illustrates the annual precipitation for the period of record at selected stations in the Sabine River Basin.

The population of the Sabine River Basin in 1960 totaled approximately 302,800 people representing about 3.2 percent of the State's population. Approximately 46 percent of the inhabitants live in urban areas which are defined as towns or concentrated areas of 2,500 or more inhabitants. The remaining 54 percent of the population are classified as rural. There are 10 cities with populations of 2,500 or more which lie within or partly within the Sabine River Basin.

The economy of the basin is highly diversified. Agriculture, livestock raising, dairying, wood products, oil and gas production and refining, plus a large variety of light manufacturing products form the most important segments of the economy.

Because of the varying geographic conditions within the basin, the geography of each of the two regions are discussed in greater detail in the following paragraphs. The location of the two regions are shown on Figure 1.

## Region I

Region I of the Sabine River Basin extends from eastern Collin and Rockwall Counties in the westernmost part of the basin to northern Newton County in the south. The region covers about 5,986 square miles and represents about 81 percent of the basin's total area.

The topography of the region ranges from gently rolling to hilly and a flat flood plain occurs along the Sabine River and some of its major tributaries. Altitudes range from about 150 feet to about 750 feet above sea level. The region lies mostly in the heavily forested East Texas pine belt, but westward from central Smith and eastern Wood Counties the region extends across the post oak belt and into the edge of the Blackland Prairie.

The mean annual precipitation in Region I ranges from about 40 inches in the westernmost part of the region to about 56 inches in the extreme southern part of the region. Figure 4 shows the annual precipitation at the Greenville station for the years 1905 through 1960, at the Longview station for the years 1889 through 1960, and at the Bronson station for the years 1925 through 1959. The precipitation is fairly evenly distributed throughout the year with the drier months occurring in late summer and early fall. Figure 3 illustrates the average monthly precipitation in Region I for the period of record at the Greenville, Longview, and Bronson stations.

The population of Region I in 1960 was about 241,000 or about 80 percent of the basin's total. About 45 percent of the population lived in urban areas scattered throughout the region, and the remaining 55 percent were classified as rural dwellers.

Region I exhibits a highly diversified economy which is based mainly on agriculture, oil and gas, lumbering, and light manufacturing and processing. Manufacturing and processing industries are concentrated in and near the cities and towns of the region and include aluminum processing, aircraft, leather goods, textiles and garments, ceramics, oil-field supplies, meat packing, and flour

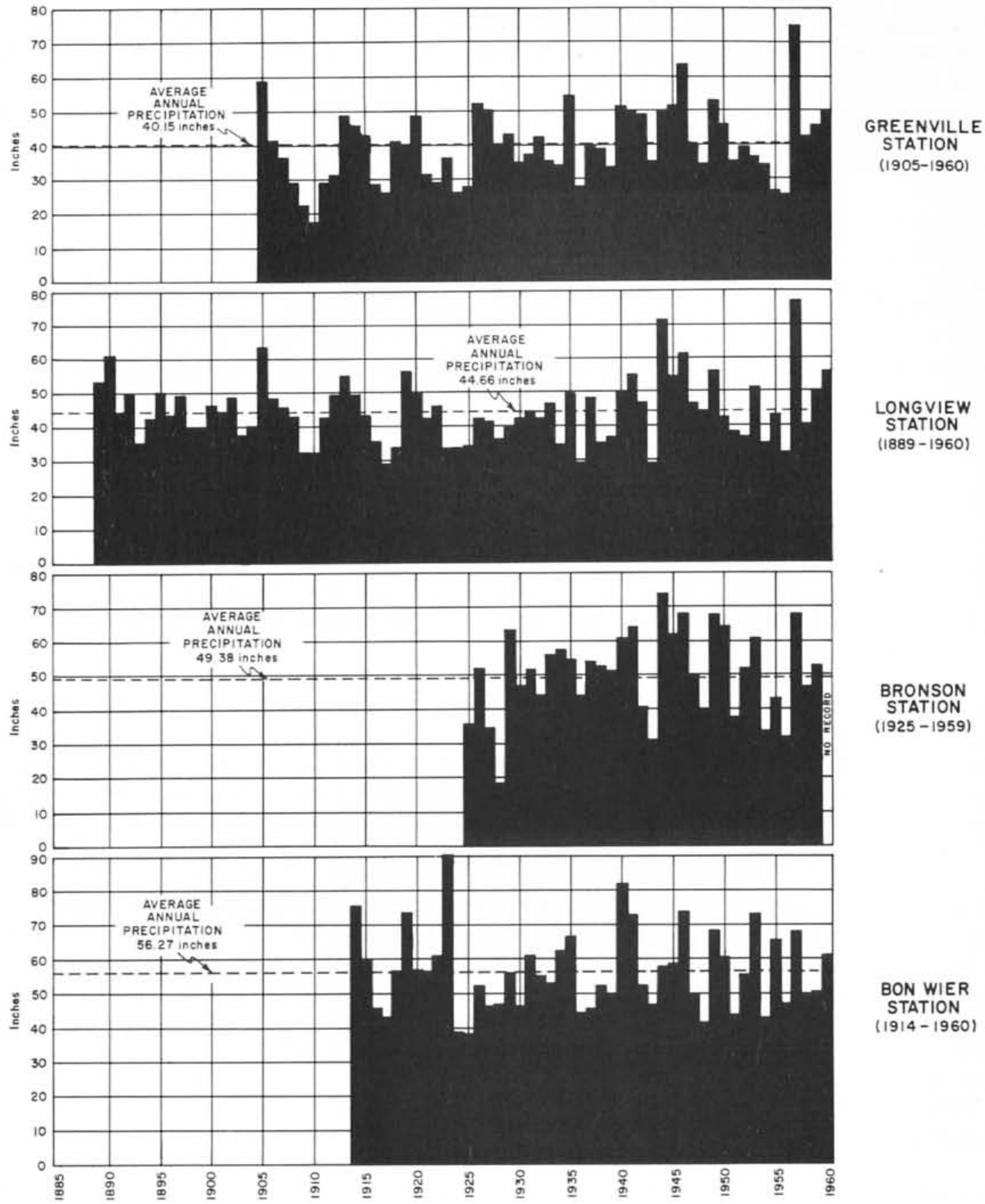



Figure 4

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

(From U. S. Weather Bureau data)

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

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milling. Agricultural products include cotton, wheat, corn, hay, and a large variety of vegetables and truck farming crops. Livestock raising includes beef cattle, swine, and poultry. The dairying industry is important in many parts of the region. Oil and gas production and processing forms one of the most important segments of the economy especially in the central part of the region including all or parts of Panola, Rusk, Harrison, Gregg, and Smith Counties. The lumbering industry, which also forms an important segment of the economy, is located in the pine woods area in the eastern and southern part of Region I.

### Region II

Region II occupies the lower part of the Sabine River Basin as shown on Figure 1. The region covers about 1,418 square miles and lies within Orange, Newton, and eastern Jasper Counties. The area is generally of low relief with altitudes ranging from sea level at the mouth of the Sabine River to about 300 feet above sea level in the northern part of the region. With the exception of a relatively open coastal prairie lying adjacent to the Gulf Coast, the region lies entirely within the East Texas pine woods belt and is heavily forested.

The mean annual precipitation ranges from about 54 inches to more than 56 inches, making Region II of the Sabine River Basin the wettest area in the State. The precipitation is fairly evenly distributed throughout the year with the driest months occurring in late summer and early fall. Figure 4 shows the annual precipitation at the Bon Wier station for the years 1914 through 1960. Figure 3 shows the average monthly precipitation at the Bon Wier station for the period of record.

The population of Region II in 1960 numbered about 62,000 or about 20 percent of the basin's total. About one half (30,000) of this population lived in the City of Orange and its suburbs. The remaining inhabitants of the region live on farms, ranches, and communities of less than 2,500 people and are classified as rural.

The economy of Region II is based on shipping, manufacturing, lumbering, and agriculture. Rice is the leading crop in the region, but a variety of garden crops and some small amounts of other grains are also produced commercially. Cattle, hogs, sheep, and poultry raising make up the livestock segment of the economy. The manufacturing and processing industries, most of which are located in and near Orange, include steel fabrication, chemicals, petrochemicals, cement, rice milling and food processing.

## GENERAL GEOLOGY

The present-day geology in the Sabine 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 Cretaceous, Tertiary, and Quaternary Periods.

During the Cretaceous Period, typical nearshore sand, and marine shale and limestone were deposited in the present-day Sabine River Basin on older pre-Cretaceous rocks. Rocks of Cretaceous age crop out at the surface in the extreme northwest part of the basin and dip in a general southeast direction.

Following the Cretaceous Period, which closed with the uplifting of the area where Cretaceous rocks are now exposed and with continued subsidence in most 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 transgressions and regressions of the sea. The marine deposits are characterized by clay, shale, marl, and minor amounts of sand, and the deposits possess relatively poor water-bearing properties. The continental and nearshore deposits consist of sand and lesser amounts of clay, shale, and lignite, and are the major water-bearing units in the basin. Rocks of Tertiary and Quaternary age crop out at the surface in Region I in the area southeast of Hunt County and in Region II. Since the beginning of the Tertiary Period, rocks in the Sabine 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 are in accordance with usage by The University of Texas Bureau of Economic Geology. The geographic name 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 sequence of geologic units in the Sabine River Basin are composed of rocks ranging in age from Cretaceous to Recent. Table 1 shows the geologic units of this sequence from youngest to oldest in age, their approximate thickness, a brief description of their lithology, and a brief summary of their water-bearing characteristics. The locations of the outcrop areas of various stratigraphic units listed in Table 1 are shown on Plates 1 and 2. Plate 3, a geologic section drawn generally along the axis of the Sabine River Basin, shows the stratigraphic position of these rocks in the subsurface.

## Structure

The major structural features of the Sabine River Basin are the Mexia-Talco fault zone, the East Texas embayment, and the Sabine uplift. In addition there are localized salt domes in the East Texas embayment area.

All of the major features of the structure as it exists in the Sabine River Basin are illustrated on the geologic section (Plate 3). The location of the Mexia-Talco fault zone also can be seen on the geologic map of Region I (Plate 1). The East Texas embayment and the Sabine uplift also are illustrated on Plate 4.

The axis of the East Texas embayment trends northeastward across Smith and eastern Wood Counties. In the area northwest of the embayment, rocks of Cretaceous and Eocene age dip to the southeast toward the axis of the trough. In eastern Hunt and Kaufman Counties, the rocks of Cretaceous and Eocene age are disrupted by faults along the Mexia-Talco fault zone which parallels the axis of the East Texas embayment. Southeast of the embayment axis, the formations dip northwestward from a large dome-shaped structural high located in East Texas and western Louisiana. This structure is known as the Sabine uplift. The uplift is centered in Panola County and covers a broad area which generally coincides with the outcrop of the Wilcox Group. On the southern flank of the Sabine uplift, the formations dip steeply to the south toward the Gulf of Mexico. Further to the south in Region II, the formations of late Tertiary and early Quaternary age also dip toward the Gulf of Mexico, but at a lesser rate than those on the south flank of the uplift.

Because ground water in the Sabine River Basin generally moves in the direction of the dip of the formations, the Sabine uplift and East Texas embayment have an important influence on the occurrence and movement of ground water in the basin. The fresh water-bearing units dip away from the center of the uplift in all directions and dip into the East Texas embayment from both the northwest and southeast.

There are numerous small faults and several salt domes in the East Texas embayment area. These structural features are of small areal extent, but may have some effect locally on the availability of fresh ground water.

## 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 quality as to constitute a usable supply. 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 principal 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. Four of the State's major aquifers, the Carrizo-Wilcox sands, the Catahoula-Oakville-Lagarto sands, the Goliad-Willis-Lissie sands, and the Beaumont sands, occur in the Sabine River Basin. A minor aquifer 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 aquifers of this classification occur in the Sabine River Basin. They are the Woodbine sands, Mount Selman sands, and the Sparta sands.

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 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 a limited areal extent or unfavorable hydrogeological characteristics that do not reflect its statewide importance. Therefore, for the purpose of discussion in this report, each aquifer has been classified as primary or secondary according to its importance within the Sabine 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 two primary aquifers of the Sabine River Basin are: (1) Carrizo

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

| System | Series | Group | Stratigraphic unit | Approximate thickness (feet) | Character of rocks | Water-bearing characteristics |
|---|---|---|---|---|---|---|
| Quaternary | Recent and Pleistocene | | Alluvium | 0- 50 | Unconsolidated gravel, sand, silt, and clay. | Yields only small amounts of water in stream valleys. |
| | Pleistocene | | Beaumont Clay | 0-1,500 | Unconsolidated sands, silts, and clays in upper part; thick basal sand, and clays with thin sand lenses in lower part. | Yields moderate to large amounts of water in Region II. |
| | | | Lissie Formation | 0-1,600 | Alternating thin to thick beds of sand, gravel, sandy clay, and clay. | Yields large amounts of water in Region II. |
| Tertiary | Pliocene(?) | | Willis Sand | 0- 400 | Sand and gravel interbedded with silt and clay. | Do. |
| | Pliocene | | Goliad Sand | 0- 500 | Sand, gravel, lime-cemented sandstone interbedded with variegated clay; overlapped by younger formations and does not crop out in the Sabine 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 II. |
| | Miocene | | Oakville Sandstone | 0-1,650 | Predominantly sand and sandstone interbedded with clay and silt. | Do. |
| | Miocene(?) | | Catahoula Sandstone | 0-1,500 | Sand and clay; some volcanic ash and fuller's earth. | Do. |
| | Eocene | Jackson | | 0-1,250 | Sand, sandy shale, and shale. | Yields small amounts of water in and near the outcrop. |
| | | Claiborne | Yegua Formation | 0- 900 | Sand, sandy shale, shale and clay. | Yields moderate amounts of water in and near the outcrop. |
| | | | Cook Mountain Formation | 0- 450 | Predominantly shale with some sand. | Yields only small amounts of water from the sand sections in and near the outcrop. |
| | | | Sparta Formation | 0- 290 | Sands interbedded with clay, shale, and sandy clay. | Yields small amounts of water in Region I. |
| | | | 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- 600 | Micaceous sand with shale and sandy shale lenses and thin glauconitic sand layers. | Yields moderate amounts of water in Region I. |
| | | | Mount Selman: Reklaw Formation | 0- 290 | Shale with thin sand layers in upper part; glauconitic sand and shaley sand in lower part. | Yields only small amounts of water from sands in and near the outcrop. |
| | | | Carrizo Formation | 0- 180 | Clean, fine to medium-grained sand with some thin interbedded shale. | Yields large amounts of water in Region I. |
| | | Wilcox | | 0-2,500+ | Interbedded sand and shale with stringers of lignite. | Do. |

(Continued on next page)

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

| System | Series | Group | Stratigraphic unit | Approximate thickness (feet) | Character of rocks | Water-bearing characteristics |
|---|---|---|---|---|---|---|
| Tertiary | Eocene | Midway | | 0- 960+ | Massive shale. | Not known to yield usable water in the basin. |
| Cretaceous | Gulf | Navarro | Kemp Formation | 0- 500 | Clay. | Do. |
| | | | Nacatoch Formation | 0- 150 | 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 | | 0-1,000 | Clay, marl, and chalk with some sand and sandy marl. | Do. |
| | | Austin | | 700 | Chalk, marl, and limestone. | Do. |
| | | Eagle Ford | | 500 | Shale with thin laminated beds of sandstone and limestone. | Do. |
| | | Woodbine | | 550- 650 | Ferruginous sand, sandstone, clay, and some lignite. | Yields small to moderate amounts of water in extreme western part of the basin. |
| | Comanche | Undifferentiated | | 800 | Alternating layers of limestone, marl, shale, clay, and sand. | Not known to yield usable water in the basin. |

Formation and Wilcox Group (Carrizo-Wilcox aquifer); and (2) 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 unit which makes up the only secondary aquifer of the Sabine River Basin is the Queen City Formation (Mount Selman sands).

Figure 5 is a map showing the areal relationship of the primary and secondary aquifers of the Sabine River Basin and the areas in which they produce 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.

In addition to the primary and secondary aquifers of the Sabine 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.

## 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 6 illustrates a number of the courses which the water may take in completing the cycle. All water occurring in the Sabine 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.

### 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, or 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.

Figure 5

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

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

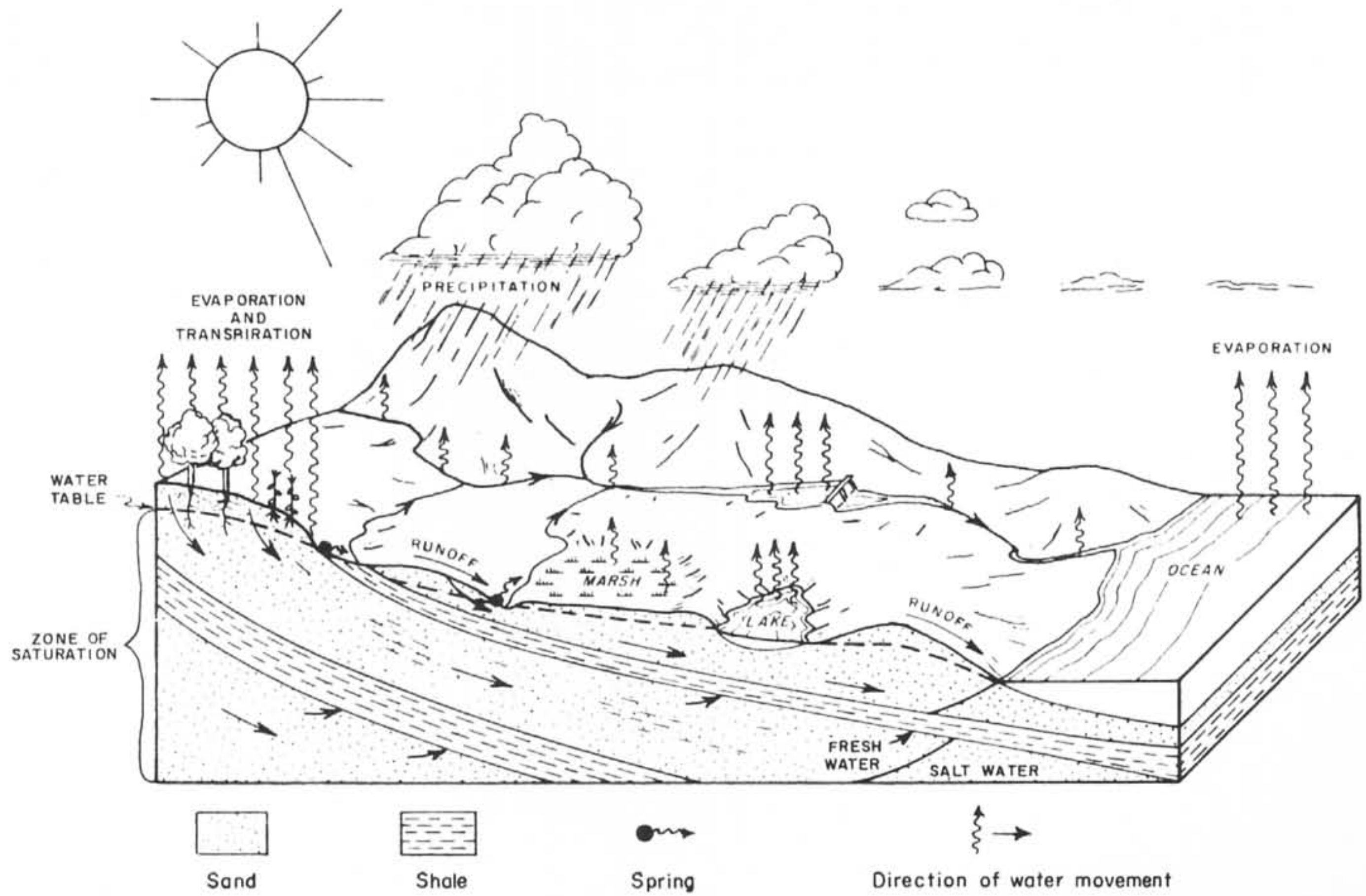


Figure 6

The Hydrologic Cycle in the Sabine River Basin

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

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Water which falls 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 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 artifically, and is subjected to other phases of the hydrologic cycle. Occasionally a local impermeable layer above the water table will intercept downward percolation of the water, creating a saturated zone above the main water table. This 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 depth at which the water-bearing stratum is encountered. 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 causes a loss in hydrostatic pressure downdip, so that the piezometric surface is at a progressively lower elevation in a downdip direction. The hydraulic gradient of an artesian aquifer is determined from 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 which 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 is usually determined by dividing the coefficient of transmissibility by the saturated thickness of the aquifer in feet.

The coefficients of storage and transmissibility are determined from pumping tests of wells which screen the water-bearing formation. The term "screen" is used to define the zone or zones in the casing which 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 an observation well. 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 Sabine 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 the limiting factor in the amount of water that can be developed from an aquifer, since it must balance the 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; 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 either be 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 often is closely related to the slope of the land surface. However, in the case of both artesian and water-table conditions, local cones of depression 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 while 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. In developing a ground-water supply, water-level declines in the vicinity of pumping wells are necessary to establish hydraulic gradients that permit sufficient quantities of water to move to the wells.

Water levels in some wells, especially those completed in artesian aquifers, have been known to fluctuate in response to such phenomena 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 stratagraphic 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 can also 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 quality of uncontaminated ground water, unlike surface water, remains relatively constant at all times. This, in addition to its 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, p. 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, p. 271) are presented by Hem (1959, p. 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, p. 69), the characteristics of water which 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 occurrence and availability of ground water in the Sabine River Basin is discussed by regions, beginning with Region I. The primary aquifers of each region are discussed first, the secondary aquifers next, and the other aquifers of limited significance are noted briefly at the end of the discussion for each region.

## Region I

The Carrizo Formation and Wilcox Group constitute the only aquifer in Region I of the Sabine River Basin which is classified as primary. The only aquifer occurring in Region I which is classified as secondary is the Queen City Formation. The location and extent of the primary and secondary aquifers of Region I are shown on Figure 5. Other aquifers occurring in Region I which are believed to have a limited potential for future development are the Woodbine Group, Nacotoch Formation, Paluxy Formation, Sparta Formation, Yegua Formation, and Jackson Group.

### 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 sand beds 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. The Carrizo-Wilcox aquifer is the primary source of ground water in Region I of the Sabine River Basin.

#### Geologic Characteristics

The Carrizo Formation consists of a white to gray, clean, fine to medium-grained, poorly cemented quartz sand. Thin shale beds may occur in the formation but they are of limited extent and importance. Where the entire section is present, the thickness of the Carrizo Formation ranges from less than 40 feet in northern Sabine and San Augustine Counties to about 180 feet in the trough of the East Texas embayment.

The Wilcox Group consists of interbedded, gray to brown, lenticular sand, sandy shale, shale, clay, and minor amounts of lignite. The sands of the Wilcox Group are fine to medium-grained, but are generally finer grained and less sorted than the sand of the Carrizo Formation. Approximately 40 to 50 percent of the thickness of the Wilcox Group consists of water-bearing sand.

In Region I of the Sabine River Basin, the Carrizo Formation and Wilcox Group have a total thickness ranging from zero at the Wilcox Group-Midway Group contact in central Rains and western Hopkins and Van Zandt Counties to more than 2,500 feet in southern Sabine County. The stratigraphic units do not contain usable water throughout their total thickness in some parts of Region I. Plate 5 is an isopachous map showing the thickness of the Carrizo-Wilcox aquifer where it contains water with less than 3,000 ppm dissolved solids. The isopachous map shows that the thickness of the aquifer ranges from zero to more than 1,600 feet, with the greatest thickness being in southern Shelby and eastern San Augustine Counties in the southern part of Region I. From its area of greatest thickness, the usable part of the Carrizo-Wilcox aquifer thins to zero as the quality of water becomes more mineralized downdip in the southern part of the region. The Carrizo-Wilcox aquifer attains a thickness of more than 1,200 feet in the trough of the East Texas embayment.

The Carrizo-Wilcox aquifer crops out over an extensive area of Region I in two separate areas. The first outcrop area is a northeastward trending belt across eastern Van Zandt, Rains, and Hopkins Counties and western Wood County. From this outcrop area, the aquifer dips southeastward into the East Texas embayment at a rate ranging from 20 to 50 feet per mile. The Carrizo-Wilcox aquifer also crops out over an extensive area on the flanks and crest of the Sabine uplift in the central and southern parts of Region I. From the Sabine uplift, which is centered in eastern Panola County, the aquifer dips westward into the East Texas embayment at about 20 feet per mile and southward toward the Gulf Coast at about 45 feet per mile near the crest of the uplift to as much as 150 feet per mile on the southern flank of the uplift. The outcrop areas and the altitude of the top of the aquifer are shown on Plate 4.

The depth to the top of the aquifer in Region I varies owing to land surface topography and geologic structure. The depth of the top of the aquifer ranges from zero in the outcrop areas to more than 500 feet in the East Texas embayment and in central Sabine County (Plate 4). Plate 3, a geologic section along the axis of the basin, also illustrates the general attitude of the aquifer, its thickness, and position.

## Occurrence and Movement of Ground Water

Water in the Carrizo-Wilcox aquifer, with the exception of the outcrop areas, is under artesian conditions. Consequently, where the top of the aquifer is penetrated by wells, the water will rise above the water-bearing sands. In the outcrop areas, water-table conditions normally exist. Locally, sand lenses interbedded with impermeable layers of shale create both perched water zones and localized artesian conditions within the outcrop areas. The outcrop areas of the Carrizo-Wilcox aquifer are shown on Plates 4 and 5.

The natural gradient of the confined water of the Carrizo-Wilcox aquifer is in the same direction as the formational dip, that is, from the structural highs to the structural lows. Consequently, the ground water moves outward in all directions from the Sabine uplift, which is centered in eastern Panola County. West of the axis of the East Texas embayment, the dip of the beds and direction of ground-water movement is toward the southeast. Ground water moves into the East Texas embayment from the northwest and southeast toward the axis of the trough and thence generally southward into the adjoining Neches River Basin. Because of the geographic location of the Sabine River Basin in relation to the geologic structure, large quantities of ground water move south and southwest from the Sabine uplift in the Sabine River Basin into the Neches River Basin.

Water-level measurements in Region I indicate that present hydraulic gradients range from about 5 to 8 feet per mile. Changes in the natural gradient may be expected to exist in the vicinity of well fields which supply the several municipalities and industries in the region. Cones of depression develop in the vicinity of the well fields causing water to move toward these points of discharge.

### Recharge and Discharge

Recharge occurs in the outcrop areas of the Carrizo-Wilcox aquifer. Conditions controlling recharge in the Carrizo-Wilcox outcrop are considered to be very favorable because the average annual precipitation is large and fairly evenly distributed throughout the year. The large outcrop areas have moderate topographic relief and are covered with loose sandy soils. It is estimated that approximately 1,000 square miles of the Carrizo-Wilcox outcrop constitute the recharge area in Texas for the aquifer in the Sabine River Basin. About 690 square miles of the outcrop are the recharge area for that part of the aquifer in the East Texas embayment. About 350 square miles of outcrop area in Texas and a small area in Louisiana constitute the recharge area for the downdip part of the aquifer in the southern part of the Sabine River Basin. In addition, approximately 1,200 square miles of outcrop area on the crest and flanks of the Sabine uplift make up a large part of the recharge area for the aquifer in the adjoining Neches River Basin.

Ground water is discharged naturally from the Carrizo-Wilcox aquifer by springs and seeps, and by evapotranspiration in the outcrop area. Downdip, where the aquifer is under artesian pressure, natural discharge occurs by means of upward leakage through the confining beds.

Pumping from water wells in the region constitute the artificial discharge from the Carrizo-Wilcox aquifer. The most important points of artificial discharge occur in the well fields of the various municipalities and industries which are distributed throughout the region.

### Water Levels

The depths at which water stands in the wells which penetrate the Carrizo-Wilcox aquifer range from zero to more than 300 feet below land surface. The deeper water levels occur in and around the well fields of the various municipalities and industries in Region I.

On the basis of information available, the water levels appear to have changed very little during the past 25 years except in areas of heavy concentrated pumpage. Near areas of extensive development and heavy pumping it is quite likely that water levels have declined as pumpage has increased. It must be emphasized that a decline in the water level does not mean that the water will be eventually depleted or that pumpage is exceeding recharge. Since water moves through an aquifer at a rate that is proportional to the hydraulic gradient, the water levels must decline in the vicinity of a pumped well in order to produce gradients sufficient to move the water to the well at a rate equal to the discharge. Fluctuations of water levels in a given area are usually related to the varying pumping rates in the area. In the outcrop area of the aquifer, which covers a large part of Region I, the water levels are likely to respond to seasonal variations in precipitation.

## Water-Bearing Characteristics

The water-bearing properties of the Carrizo Formation and Wilcox Group differ considerably. The Carrizo Formation, consisting of a massive, well-sorted, homogeneous sand, possesses the most favorable characteristics. Data from 5 pumping tests made on wells screening the Carrizo Formation in the East Texas embayment area show that coefficients of transmissibility ranged from 14,000 to 22,000 gallons per day per foot (gpd/ft.) and averaged about 18,000 gpd/ft. The coefficients of permeability ranged from 128 to 246 gpd/ft$^2$. Aquifer test data is not available for the Carrizo Formation in the southern part of Region I; however, the aquifer coefficients of transmissibility are likely to be lower than those in the northwestern part of the basin because the formation is much thinner.

The sands of the Wilcox Group exhibit relatively low coefficients of transmissibility and permeability. The coefficients of transmissibility obtained from a number of pumping tests on wells screening a part of the Wilcox group ranged from about 1,300 to 5,300 gpd/ft. Since these figures represent the coefficients of transmissibility of individual sand units in the Wilcox Group and not the total sand thickness, they are not comparable with each other, nor are they representative of the Wilcox Group as a whole. The coefficients of permeability ranged from 16 to 119 gpd/ft.$^2$ and averaged about 50 gpd/ft$^2$.

That part of the Wilcox Group containing water of usable quality in Region I ranges in thickness from zero to about 1,600 feet. It has been determined from electric logs that approximately 50 percent of this thickness is made up of water-bearing sands. Based on the average coefficient of permeability of the Wilcox sands and the total sand thickness, it is calculated that coefficients of transmissibility for the Wilcox part of the aquifer would range from zero to about 40,000 gpd/ft. Since the coefficients of transmissibility are dependent upon the aquifer's thickness, as well as permeability, the Wilcox part of the aquifer exhibits large coefficients of transmissibility in some places in the basin despite the relatively low permeability of its sands because of its great thickness. In the East Texas embayment area, where a full section of the Wilcox Group is present, calculated coefficients of transmissibility ranged from 15,000 to 21,000 gpd/ft. In this same area, where the Carrizo Formation is also present, the coefficients of transmissibility for the entire Carrizo-Wilcox aquifer are expected to range from 30,000 to 40,000 gpd/ft. In the southern part of the

Sabine River Basin, where the aquifer is thickest, coefficients of transmissibility up to 40,000 gpd/ft. may be expected. The aquifer's coefficients of transmissibility may be expected to be smallest on the outcrop of the Wilcox, west of the East Texas embayment where the aquifer thins to zero at the Wilcox-Midway contact and in eastern Panola County on the crest of the Sabine uplift.

Although the coefficients of transmissibility for the aquifer as a whole are very large in some places, it is not always practical to develop the entire sand thickness of the aquifer because of the cost of development and the more mineralized water in the lower part of the Wilcox. Therefore, the coefficients of transmissibility of the sand sections which are most commonly developed in the Wilcox part of the aquifer are considerably less than the figures given above.

Figure 7 is a distance-drawdown graph which shows the amount that water levels would be lowered at various distances from a pumped well after various periods of pumping. The distances are measured along a line parallel with the outcrop and passing through the pumped well. The distance-drawdown graph has been prepared based on coefficients believed to be generally applicable for the aquifer in the East Texas embayment area of Region I. A coefficient of transmissibility of 17,500 gpd/ft., a coefficient of storage of 0.0002, a pumping rate of 700 gallons per minute (gpm), and a distance to the outcrop of about 15 miles were used in preparation of the distance-drawdown graph.

## Chemical Quality

The chemical quality of water in the Carrizo-Wilcox aquifer varies from place to place and with depth. In general, water of good quality and suitable for most purposes may be found throughout most of Region I where the aquifer is present. Table 2 lists a number of selected analyses of water taken from the aquifer in different parts of Region I. Analyses of water taken from wells numbered 34-21-701, 35-41-702, and 37-40-302 are from wells which screen only the Carrizo part of the aquifer. The remainder of the analyses shown on Table 2 were of samples taken from wells which screen the Wilcox part of the aquifer. The location of wells from which the representative analyses listed in Table 2 were obtained may be determined by use of one of the grided maps, such as Plate 1, and the well numbers explained previously in this report.

In the outcrop, most wells take water only from the sands of the Wilcox Group. In those areas downdip where the Carrizo Formation is present, many wells screen only that part of the aquifer, or screen the Carrizo and the upper part of the Wilcox Group. The Carrizo Formation usually furnishes an adequate supply and, in most instances, contains water of superior quality to that of the underlying Wilcox sands.

Water that is relatively low in mineral content and suitable for most purposes is found in and near the outcrop areas. The water from the Carrizo-Wilcox aquifer is high in bicarbonates and locally has objectionable amounts of iron. The Wilcox sands in some places have lignite stringers which may impart an undesirable color to the water. The water from the aquifer is generally soft; however, in local areas moderately to very hard water may be encountered. In general the water in the aquifer becomes more mineralized downdip from the outcrop and also with depth. At a given locality, deeper sand bodies may be expected to

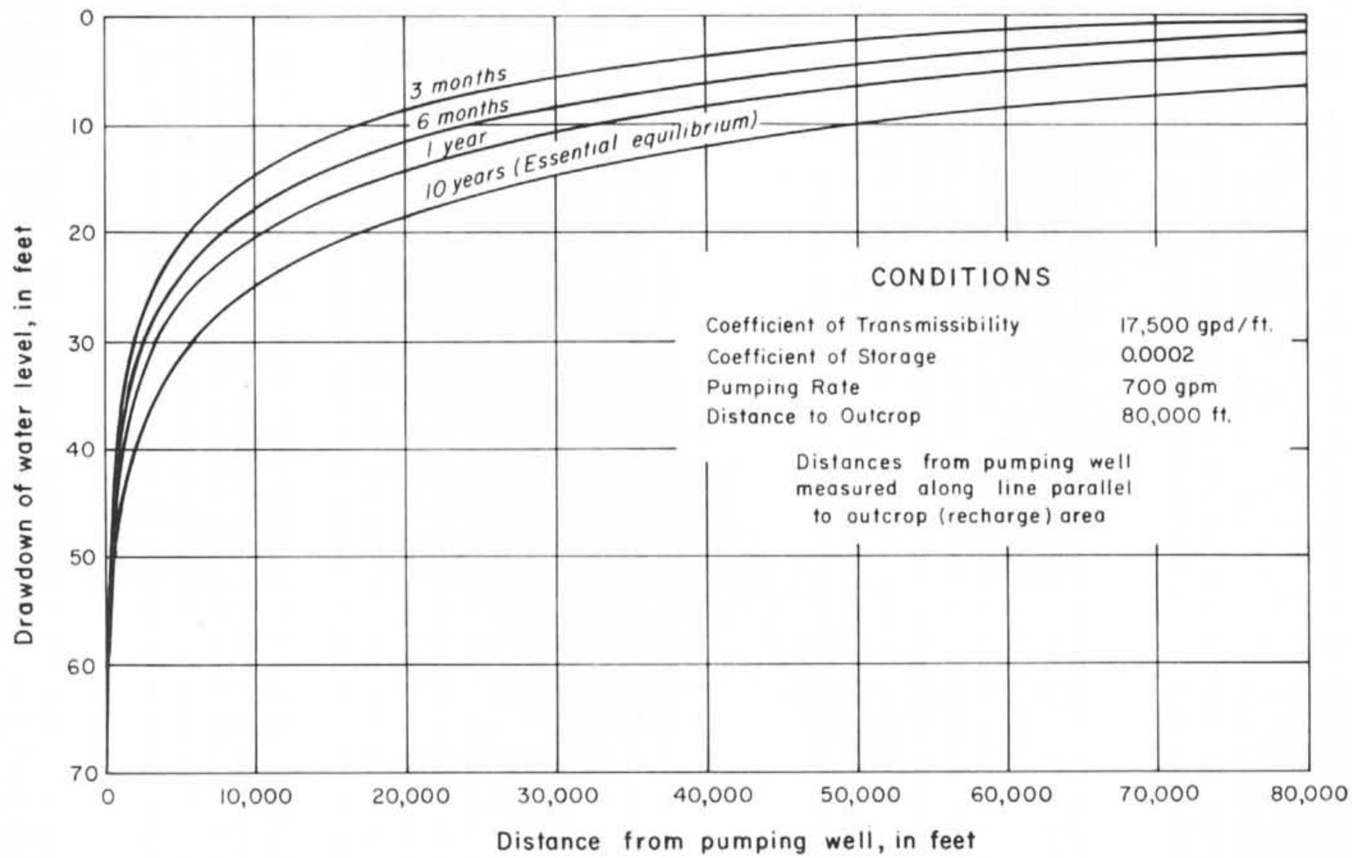


Figure 7

Distance-Drawdown Curves After Various Times of Pumping From the Carrizo-Wilcox Aquifer, Region I, Sabine 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, Sabine 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 | | | | | | | | | | | |
| 34-10-301 | City of Emory | 190 | 3-22-61 | 44 | 7.9 | 103 | 24 | 109 | 155 | 335 | 82 | 0.1 | 2.0 | 791 | 356 | 40 | 2.5 | 1,130 | 6.7 |
| 34-21-701 | City of Mineola | 469 | 1-12-61 | 11 | .14 | 4.2 | 1.4 | 62 | 125 | 30 | 12 | -- | .2 | 185 | 16 | 89 | 6.7 | 303 | 7.1 |
| 35-25-901 | Warren Petroleum Co. | 616 | 5-26-61 | 12 | .09 | 1.8 | .4 | 317 | 524 | 17 | 174 | .9 | .0 | 800 | 6 | 99 | 56 | 1,370 | 8.0 |
| 35-33-202 | Sinclair Oil Co. | 1,008 | 5-26-61 | 12 | .25 | 3.0 | .5 | 687 | 742 | 0 | 630 | 2.0 | .0 | 1,700 | 10 | 99 | 94 | 3,050 | 7.7 |
| 2/ 35-41-702 | City of Overton #4 | 319 | 4- -55 | -- | 2.3 | 15 | 4 | 42 | 49 | 64 | 28 | .2 | <.4 | 180 | 54 | -- | -- | -- | 6.7 |
| 35-41-901 | E. Texas Water Co. | 655 | 7- 6-61 | 13 | .19 | .5 | .0 | 154 | 366 | 21 | 8.2 | .2 | 2.2 | 379 | 1 | 100 | 67 | 607 | 8.1 |
| 35-44-101 | Council #585, Boy Scouts Am. | 421 | 8-10-49 | 15 | 0 | 1.6 | .3 | 250 4.0 | 628 | 4.1 | 22 | 0 | 3.0 | 621 | 5 | -- | -- | 1,020 | 8.5 |
| 35-48-102 | United Gas Pipeline Co. | 182 | 5-11-61 | 45 | 2.4 | 21 | 8.1 | 57 | 186 | 4.6 | 40 | .2 | .2 | 267 | 86 | 59 | 2.7 | 412 | 7.0 |
| 35-53-201 | City of Beckville | 280 | 7-28-49 | 22 | .32 | 1.1 | .6 | 89 17 | 279 | 19 | 13 | 0 | 2.0 | 307 | 5 | -- | -- | 502 | 7.7 |
| 35-61-302 | Cities Service Petroleum Co. #2 | 290 | 5-11-61 | 10 | 21 | 5.8 | 1.9 | 261 | 498 | 5.6 | 123 | .9 | 0 | 653 | 22 | 96 | 24 | 1,120 | 7.8 |
| 36-17-501 | U. S. Forest Service | 200 | 5-11-61 | 12 | .03 | 3.2 | 1.0 | 160 | 340 | 17 | 44 | .3 | .0 | 404 | 12 | 97 | 20 | 679 | 8.0 |
| 36-34-202 | U. S. Forest Service | 392 | 5-10-61 | 12 | .19 | 1.5 | .2 | 350 | 868 | .0 | 36 | .8 | .5 | 828 | 4 | 99 | 76 | 1,340 | 8.2 |
| 2/ 37-07-401 | City of Tenaha | 519 | 6-26-41 | 26 | .56 | 5.0 | 5.0 | 378 | 718 | 10 | 181 | 2.8 | .4 | 971 | 33 | -- | -- | -- | 8.8 |
| 37-08-601 | Texas Eastern Corp. | 330 | 5-11-61 | 12 | .19 | 3.0 | 1.2 | 802 | 894 | .6 | 720 | 2.8 | .8 | 1,980 | 12 | 99 | 101 | 3,450 | 8.0 |
| 37-15-101 | Center Country Club | 474 | 4- 5-60 | 12 | .11 | 5.0 | 1.5 | 282 1.8 | 658 | 51 | 34 | .5 | .0 | 712 | 18 | 97 | 29 | 1,150 | 8.6 |
| 3/ 37-23-301 | City of Center (Test hole) | 4/ 700-840 | 9-22-44 | -- | .4 | 1.4 | .3 | 374.2 | 791 | 93.5 | 48.0 | -- | -- | 1,335.2 | 4.7 | -- | -- | -- | 8.6 |
| 3/ 37-23-301 | City of Center (Test hole) | 4/ 985-1,019 | 9-22-44 | -- | -- | 2.4 | .4 | 533.4 | 694 | 10.5 | 15.0 | .7 | -- | 1,693.2 | 7.6 | -- | -- | -- | 8.5 |
| 3/ 37-23-301 | City of Center (Test hole) | 4/ 1,049-1,072 | 9-22-44 | -- | 1.2 | 6.2 | 1.0 | 842.5 | 838.8 | 0 | 825.0 | -- | -- | 2,580.7 | 19.6 | -- | -- | -- | 8.4 |
| 37-40-302 | J. C. Benedium | 219 | 5-11-61 | 17 | 1.0 | 24 | 8.6 | 73 | 216 | 60 | 10 | .1 | .2 | 299 | 96 | 62 | 3.2 | 474 | 7.6 |
| | | | | | | | | Queen City Aquifer | | | | | | | | | | | |
| 3/ 34-31-208 | Jarvis Christian College | 510 | 7-31-54 | 16 | 1.7 | 5.0 | 1.0 | 22 | 61 | 2 | 7 | -- | -- | 137 | -- | -- | -- | -- | 6.3 |

1/ Includes equivalent of any carbonate ($CO_3$) present.
2/ Analysis by Texas State Department of Health.
3/ Analysis by Curtis Laboratories, Houston.
4/ Interval indicates sand zone sampled.

carry more mineralized water than those near the surface. Three analyses of water taken at different depth intervals from a test hole located south of Center in Shelby County illustrate the typical decline in the quality of water with depth (See Table 2, well 37-23-301).

The quality of water in the Carrizo-Wilcox aquifer is variable, but water of usable quality may be expected throughout the entire thickness of the Carrizo Formation and Wilcox Group north and northwest of central Shelby County in Region I. South of central Shelby County the basal Wilcox sands contain water exceeding 3,000 ppm dissolved solids and further downdip the upper part of the aquifer becomes progressively more mineralized until the entire thickness contains water which exceeds 3,000 ppm dissolved solids. The approximate downdip extent of water containing less than 3,000 ppm dissolved solids is shown on Plates 4 and 5.

Although water containing up to 3,000 ppm dissolved solids is described in this report as usable, it must be emphasized that most water now being utilized from the aquifer seldom exceeds 1,000 ppm and it probably will not be necessary to use the less desirable water in the immediate future.

Region I has a large number of oil and gas fields located within its boundaries. Improperly cased or plugged wells are always a potential threat to fresh water-bearing formations. In addition, improper disposal of industrial wastes can also result in the contamination of fresh ground-water supplies.

## Utilization and Development

Most of the municipalities and industries of Region I obtain their ground water from the Carrizo-Wilcox aquifer. The size of the wells vary according to need. Construction of the major wells supplying the various municipalities and industries is usually of the gravel-wall type with the surface casing varying from 18 to 10 inches in diameter cemented in place and with an inside liner and screen ranging from 10 to 5 inches in diameter. The producing sand intervals are usually underreamed and gravel packed and a screen or perforated pipe is set opposite the producing zones. Most of the domestic and livestock wells are shallow hand-dug wells of various sizes, or 2- to 4-inch diameter drilled wells.

Specific capacities of the Carrizo-Wilcox wells range from less than 1 to 13 gpm per foot of drawdown. Production from the major wells range from less than 90 to 700 gpm.

Table 3 lists the reported 1960 pumpage from the Carrizo-Wilcox aquifer for municipal and industrial purposes by major drainage subdivisions. The municipal pumpage includes water supplied by privately owned systems for municipal purposes. The location of municipal, industrial, and irrigation wells and the major drainage subdivisions in Region I are shown on Plate 1. Table 3 shows that in 1960 approximately 8,000 acre-feet of ground water was pumped from the aquifer for municipal and industrial purposes. Of this total, about 5,000 acre-feet or 62 percent was pumped for industrial purposes. The remaining 3,000 acre-feet was pumped for municipal purposes. No irrigation pumpage was reported in Region I of the Sabine River Basin in 1960. The area of most intensive development occurs in subregion 6 where a total of 3,026 acre-feet was reported pumped for municipal and industrial purposes with pumpage for industrial purposes accounting for 2,323 acre-feet of the total.

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

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

| Subdivision | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Carrizo-Wilcox Aquifer** | | | | | | | | | | |
| Municipal | -- | 839 | 176 | 256 | 166 | 703 | 66 | 580 | 231 | 3,017 |
| Industrial | -- | 84 | 276 | 55 | 648 | 2,323 | 301 | 1,301 | -- | 4,988 |
| Total | -- | 923 | 452 | 311 | 814 | 3,026 | 367 | 1,881 | 231 | 8,005 |
| **Queen City Aquifer** | | | | | | | | | | |
| Municipal | -- | -- | -- | -- | 311 | -- | -- | -- | -- | 311 |
| Industrial | -- | -- | -- | -- | 56 | -- | -- | -- | -- | 56 |
| Total | -- | -- | -- | -- | 367 | -- | -- | -- | -- | 367 |
| **Other Aquifers 3/** | | | | | | | | | | |
| Municipal | 193 | -- | -- | -- | -- | -- | -- | -- | -- | 193 |
| Total | 193 | -- | -- | -- | -- | -- | -- | -- | -- | 193 |
| **Summary of Pumpage in Region I** | | | | | | | | | | |
| Municipal | 193 | 839 | 176 | 256 | 477 | 703 | 66 | 580 | 231 | 3,521 |
| Industrial | -- | 84 | 276 | 55 | 704 | 2,323 | 301 | 1,301 | -- | 5,044 |
| Total | 193 | 923 | 452 | 311 | 1,181 | 3,026 | 367 | 1,881 | 231 | 8,565 |

1/ Municipal pumpage includes water supplied by privately owned system.

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

3/ Includes Woodbine Group and Nacatoch Formation.

Little is known about the history of development of the aquifer in the Sabine River Basin. Most of the wells now being used have been drilled since 1940, although a few wells have been producing water since before 1925. Most of the present pumpage from the Carrizo-Wilcox aquifer is on or near the extensive outcrop areas, or in the area of the East Texas embayment. Very little development, other than domestic and livestock wells, has taken place in the aquifer in the southern part of the region south of the central part of Shelby County.

## Ground Water Available for Development

The amount of water available for development from the Carrizo-Wilcox aquifer determined during this study is an estimate based on pumpage under assumed conditions and is related primarily to the ability of the aquifer to transmit water to areas of pumping. It is not possible to determine precisely the amount of water that is present beneath the earth's surface or the quantity that may be produced. However, if certain aquifer conditions are known, it is possible to estimate the order of magnitude of water available by application of one of the fundamental laws of hydrology. It is known that the amount of water that will move through a segment of an aquifer is dependent upon three factors: the coefficient of transmissibility, the hydraulic gradient, and the width of the segment perpendicular to the flow. The relationship of the above factors are expressed by the formula $Q = TIL$ in which Q equals the quantity of water in gallons per day, T equals the coefficient of transmissibility, I equals the gradient in feet per mile, and L equals the length in miles of the segment of the aquifer under consideration. The above stated relationship is known as Darcy's Law. "T" can be determined from pumping tests, "L" can be measured, and "I" can be determined from water-level measurements. Therefore, this equation can be used to determine the amount of water being discharged from the aquifer under present conditions and to predict the quantity that would move through the aquifer under assumed conditions.

Under present existing gradients it is estimated that on the order of 15,000 acre-feet of ground water per year is being discharged from the aquifer in the East Texas embayment area. In the southern part of the basin, an additional 3,000 acre-feet of water per year is estimated being discharged from the aquifer. All of the municipal and industrial pumpage is located either on the outcrop or in the area of the East Texas embayment. Because the aquifer is essentially undeveloped in the southernmost part of the region, it is assumed that the total amount of water moving through that segment of the aquifer is being discharged through a few domestic and livestock wells, and through interformational leakage.

Under future conditions of development, the rate of flow through the aquifer may be greatly increased owing to increased gradients caused by pumping. For the purpose of estimating the amount of water available for development from the Carrizo-Wilcox aquifer, a future gradient is assumed, based on a static water level drawn down to the top of the aquifer where the aquifer is 400 feet below land surface. A gradient equal to the dip of the top of the aquifer was used as the maximum gradient that would be established by the development of the entire aquifer. The maximum gradient would therefore determine the rate of flow through the aquifer and would represent the maximum quantity of water that could be pumped perennially from the aquifer providing recharge is sufficient to supply this quantity. Under the foregoing assumed conditions, it is estimated that on the order of 100,000 acre-feet is perennially available from the aquifer in the Sabine River Basin. It is further estimated that on the order of 40,000 acre-feet per year of this quantity would move downdip into the East Texas embayment from the northwest, and on the order of 10,000 acre-feet would move into the embayment from the southeast. In the southern part of Region I, on the south flank of the Sabine uplift, it is estimated that on the order of 50,000 acre-feet per year would be available under the maximum gradient. This large quantity in a small area is possible because of the large thickness of the aquifer in this area and because of the steep dip of the beds which would allow maximum gradients of 100 feet per mile to be developed. The development of 50,000 acre-feet per year in the southern part of Region I assumes development of the total sand thickness of the aquifer. Although water containing up to 3,000 ppm dissolved solids is described as usable, it must emphasized that most water now being utilized from the aquifer seldom exceeds 1,000 ppm, and the less desirable water probably will not be used in the immediate future. The mineral content of a large quantity of the water available south of the uplift probably will exceed 1,000 ppm dissolved solids.

The outcrop areas of the Carrizo-Wilcox aquifer from which recharge is derived for the East Texas embayment area of the Sabine River Basin covers approximately 580,000 acres. Therefore, only a little more than 1 inch of the 45 inches of the annual precipitation would be required to supply the 50,000 acre-feet of water the aquifer is capable of transmitting under the assumed maximum conditions of development. The outcrop area of the aquifer from which recharge is derived for pumpage south of the Sabine uplift is approximately 220,000 acres. Three inches of recharge per year would be required in this area to support the conditions of assumed maximum development. Recharge to the Carrizo-Wilcox aquifer appears to be adequate to supply the quantity of water that would be discharged from the aquifer under the assumed conditions of development.

In addition to the perennial yields supported by recharge, a considerable amount of water will be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed.

## Secondary Aquifers

### Queen City Aquifer

#### Geologic Characteristics

The Queen City Formation consists of gray and brown, medium to very fine-grained micaceous sand with interbedded gray to brown shale and sandy shale. Minor amounts of glauconitic sand occur locally within the formation.

In Region I of the Sabine River Basin, the Queen City Formation crops out in in an area of approximately 980 square miles in Smith, Upshur, Wood, Harrison, Rusk, and Gregg Counties, in the trough of the East Texas embayment. The formation reaches its greatest thickness in northern Smith County where it is more than 600 feet thick. In general, the aquifer is thicker in the center and along the axis of the trough and thins to zero thickness both to the northwest and southeast at the Queen City-Reklaw contact. The location and extent of the outcrop area of the Queen City aquifer, as well as the thickness of the aquifer, is shown on Plate 6. The water-bearing sands constitute between 25 to 75 percent of the Queen City's total thickness.

The Queen City Formation is overlain locally by a few isolated outliers of younger formations. These outliers are most numerous and extensive along the axis of the East Texas embayment and consist of the Weches and Sparta Formations. The location and extent of these outliers are shown on Plate 1.

In general, the Queen City Formation dips both southeast and northwest toward the axis of the East Texas embayment. The general attitude of the aquifer in Region I is best illustrated on Plate 3.

### Occurrence and Movement of Ground Water

Water in the Queen City aquifer occurs generally under water-table conditions in Region I; however, artesian conditions and perched water-table conditions may exist locally where impermeable layers of clay and shale hinder the vertical movement of the water. Where the water is not confined by impermeable layers, water generally moves from areas of high elevation to areas of low elevation, that is, from the basin boundaries toward the Sabine River and its tributaries. Where the water is confined it moves in the direction of the formational dip toward the axis of the East Texas embayment.

### Recharge and Discharge

Conditions controlling recharge of ground water to the Queen City aquifer in Region I are considered good. The average annual rainfall of 45 inches per year on the 980 square miles of Queen City outcrop is fairly evenly distributed throughout the year. The aquifer outcrop area has moderate relief and is covered by a deep, sandy soil.

Ground water is discharged from the aquifer both naturally and artificially. Natural discharge occurs at seeps and springs, and by transpiration. Artificial discharge from the Queen City aquifer consists of pumpage by a few municipal and industrial wells, and a few domestic and livestock wells which screen the sands of the aquifer in Region I.

### Water Levels

The depths to water in wells which screen the Queen City aquifer in Region I range from a few feet to about 110 feet below the land surface. Fluctuations of the water level are caused mainly by variations in the amount of rainfall in the outcrop. Fluctuations of water level also occur in areas of development because of variations in the pumping rates.

### Water-Bearing Characteristics

The hydraulic characteristics of the Queen City aquifer are variable in Region I. Pumping tests on wells in Wood County showed the aquifer to have a coefficient of transmissibility of about 12,000 gpd/ft. and coefficients of permeability of 89 to 132 gpd/ft$^2$. The aquifer probably has its highest coefficient of transmissibility, and hence better development potential, in eastern Wood County and north-central Smith County where the aquifer is the thickest. Both northwestward and southeastward from eastern Wood County and north-central Smith County, the aquifer thins and the expected coefficients of transmissibility are correspondingly less. Pumping tests on wells which screened the aquifer in the adjoining Neches River Basin in Smith County showed the aquifer to have a coefficient of transmissibility of about 3,000 gpd/ft. and coefficients of permeability of 10 to 30 gpd/ft$^2$. The coefficients of transmissibility in the Sabine River Basin can be expected to be highly variable because of the aquifer's varying thickness, and also because of changes in the permeability of the sands.

### Chemical Quality

The water from the Queen City aquifer in Region I is of good quality in that it has a very low mineral content and is generally soft. Although the dissolved solids are not excessive, a combination of high iron content, low pH, and free carbon dioxide in many cases makes the water undesirable for many uses. Analyses indicate that water from the Queen City in Region I may be expected to have dissolved solids ranging from less than 100 up to 300 ppm. The iron content ranges from 0.03 up to 7.1 ppm. The quality of the Queen City water can be improved by simple treatment methods. A representative analysis of water from a well screening the Queen City aquifer is shown in Table 2.

### Utilization and Development

Development of the Queen City aquifer in Region I of the Sabine Basin is small. A total of 367 acre-feet of water was reported pumped from the Queen City aquifer in Region I in 1960. Of this total, 311 acre-feet was pumped for municipal purposes and the remaining 56 acre-feet was pumped for industrial purposes. All of the major pumpage presently takes place in major drainage subdivision 5. (See Table 3.) The remaining pumpage from the Queen City aquifer comes from small domestic and livestock wells in the region.

The construction of the municipal and industrial wells screening the Queen City aquifer is usually of the gravel-wall type. The wells generally have a large surface casing ranging in size from 10 to 16 inches in diameter, cemented in place, and a smaller liner ranging in size from 5 to 8 inches, inside the larger casing. Screen or slotted pipe is placed opposite the producing sands. The screen used in a well is 20 to 100 feet in length depending on the amount of sand present and the quantity of water needed. The domestic wells range in size from 48-inch dug wells to 2-inch drilled wells. Depths of the wells range from a few feet in the case of dug wells up to 650 feet in the case of some drilled wells.

Yields of the wells range from a few gallons to 400 gpm and the specific capacities range from 1.5 to 8 gpm per foot of drawdown. The quality of Queen City water results in considerable trouble to wells in the region. The highly corrosive action of the high iron content and low pH water causes damage to pumps, casings, storage tanks, and other metal objects in which it comes in contact.

## Ground Water Available for Development

The only occurrence of the Queen City aquifer in Region I of the Sabine River Basin is in its outcrop area. The outcrop area of the aquifer in Region I covers about 600,000 acres. The annual rainfall in this area of Region I is about 45 inches, and conditions on the outcrop of the aquifer are believed generally favorable for recharge. It is believed that relatively large quantities of water can be developed from the Queen City aquifer. The yields of the individual wells will be small to moderate, probably less than 500 gpm. It must be emphasized that in order to develop the ultimate amount of water available from the Queen City aquifer, it will be necessary to develop small well fields throughout the outcrop area. In addition to the perennial yields supported by recharge, some water also is available from storage.

The best area for additional development of the Queen City aquifer is in eastern Wood County and north-central Smith County where the aquifer is thickest and consequently where the aquifer's largest coefficients of transmissibility are believed to occur.

The quality of the water may be a limiting factor in the development of the Queen City aquifer because of the high iron content and the low pH which appears to be characteristic of the aquifer's water in Region I of the Sabine River Basin. Simple treatment methods, however, are available which can improve the quality of the water, and pumping equipment made of metals which are resistant to the corrosive characteristics of the water is available.

## Other Aquifers

### Woodbine Group

The Woodbine Group, where it contains water with less than 3,000 ppm dissolved solids, occurs in the extreme northwest part of the Sabine River Basin. The area of usable quality water forms a 2 to 9 mile wide belt adjacent to the northwest boundary of the basin extending from Rockwall County across northwest Hunt County. The top of the Woodbine in this area generally occurs at depths between 1,600 and 1,800 feet below the land surface and its thickness ranges between 550 and 650 feet. The outcrop of the Woodbine Group occurs in the Trinity River Basin to the west and in the Red River Basin to the north. The Woodbine Group is composed of lenticular, fine-grained ferruginous sand and sandstone interbedded with laminated clay and some lignite. The sands are more massive in the lower part of the Group than in the upper part where there is a higher percentage of clay. The sands make up approximately 50 to 60 percent of the Group's total thickness.

The only important pumpage from the aquifer in the Sabine River Basin is at the city of Celeste in northern Hunt County where about 40 acre-feet was pumped in 1960 for municipal use. The well is completed to a depth of 1,819 feet and yields 120 gpm. The water level in this well is reported to be about 380 feet below the land surface. An analysis of water obtained from this well showed the water to be very soft and it contained 880 ppm dissolved solids.

The potential for future development in the Woodbine in the Sabine River Basin is limited because of its small areal extent of usable water in the basin. Any large-scale development in this basin or in the adjacent basins could cause poorer quality water to move updip toward the pumpage.

## Nacatoch Formation

The Nacatoch Formation of the Navarro Group occurs at the surface in the northwest part of Region I in a northeastward trending belt, 1 to 4 miles wide, across central Hunt County. Its thickness downdip from the outcrop ranges from 100 to 150 feet. The Nacatoch is very limited as an aquifer because of a rapid change in water quality downdip and because of its poor transmission characteristics. Analyses of four wells producing from the Nacatoch Formation at depths to 400 feet below land surface showed that the dissolved solids ranged from 795 to 1,340 ppm.

Approximately 153 acre-feet of water was reported pumped from the Nacatoch Formation in 1960 for municipal use in the Sabine River Basin. Yields of the municipal wells ranged from 20 to 45 gpm. Domestic and livestock supplies also are obtained from the Nacatoch Formation.

## Paluxy Formation

The Paluxy Formation of the Comanche Series, where it contains water with less than 3,000 ppm dissolved solids, occurs in the subsurface, northwest of the Mexia-Talco fault zone. The Paluxy dips toward the southeast and occurs at depths of about 2,700 feet at the north end of the basin to a little more than 4,000 feet near the Mexia-Talco fault zone. The Paluxy Formation consists predominately of fine-grained sand with minor amounts of clay and sandy clay. Its thickness ranges between 100 and 300 feet.

There are no wells in the Sabine River Basin known to be producing from the Paluxy Formation. A study of electric logs indicates that the Paluxy Formation contains water of usable quality northwest of the Mexia-Talco fault zone. The dissolved solids probably range between 1,000 and 3,000 ppm. It is not likely that any future large-scale development of the Paluxy Formation will take place in the Sabine River Basin because of the depths at which the sands occur and because the water in the sands is rather highly mineralized.

## Sparta Formation

The Sparta Formation crops out in an eastward-trending belt across central Sabine County and a part of San Augustine County. The outcrop is from 1 to 3 miles in width and covers an area of about 50 square miles. The formation consists of gray and buff, loosely consolidated sands interbedded with clay, shale, and sandy clay strata. Good subsurface data are not available, but it appears that the formation ranges from about 200 to 260 feet in thickness and is made up of about 60 percent water-bearing sands.

Little is known about the water-bearing characteristics of the Sparta Formation in the Sabine River Basin, but aquifer tests conducted in the adjoining

Neches River Basin indicate that the formation's characteristics are highly variable within short distances.

The Sparta contains water of good chemical quality in and near the outcrop. However, the water quality may be expected to become more mineralized short distances downdip. A well, formerly supplying the city of Hemphill and reportedly screened in the Sparta Formation, yielded water containing 1,261 ppm dissolved solids. This well was located about 3 miles south of the outcrop.

At the present time, development of the Sparta Formation is confined to domestic and livestock use in or near the outcrop. The well formerly supplying the city of Hemphill has been abandoned and the city now has a surface-water supply.

The amount of water that could be developed from the Sparta Formation in the Sabine River Basin is believed small because of its limited extent within the basin and because of its limited quality of water.

In addition to the Sparta Formation in the south end of Region I, there are outliers of the Sparta Formation supplying good quality water to domestic and livestock wells in Smith and Wood Counties. The thickness of the Sparta on the outliers ranges from zero to 270 feet with approximately 70 percent of the total being sand. The water is under water-table or semiartesian conditions and the transmission characteristics of the sand are good. However, the Sparta's potential for large amounts of development is limited because of its small geographic extent. The outcrops of Sparta Formation are shown on Plate 1.

## Yegua Formation

The Yegua Formation crops out in an eastward-trending belt across central Sabine County, varying in width from 8 to 12 miles (Plate 1). The formation consists of a sequence of interbedded fine to medium-grained lenticular sand, sandy shale, shale, and clay. The Yegua ranges in thickness from zero at the Yegua-Cook Mountain contact to about 900 feet downdip. Approximately 50 percent of the formation is made up of sand.

Little is known about the water-bearing characteristics of the Yegua Formation in the Sabine River Basin. Aquifer tests and general development of the formation in the adjoining Neches River Basin indicate the permeability of the sands is relatively low. Chemical analyses of water from two wells in and near the Yegua outcrop showed 851 and 1,060 ppm dissolved solids.

At the present, development is confined to domestic and livestock wells in and near the outcrop. The Yegua Formation is believed to have a limited potential for development in the Sabine River Basin.

## Jackson Group

The Jackson Group crops out across southern Sabine County in an eastward-trending belt varying in width from 4 to 9 miles (Plate 1). The Group is made up of sand, sandy shale, and shale.

Little is known about the water-bearing properties of the Jackson Group in the Sabine River Basin; however, the Jackson Group generally contains less sand and more mineralized water than does the Yegua Formation. The present development of the Jackson Group in the basin is limited to domestic and livestock wells in and near the outcrop. The potential for development of the Jackson Group is believed to be very limited.

## Region II

The primary aquifer of Region II 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, Lagarto Clay; the Goliad Sand, Willis Sand, Lissie Formation; and the Beaumont Clay. The areal extent of the Gulf Coast aquifer is shown on Figure 5. There are no aquifers in Region II classified as secondary.

The statements and data on the following pages are a general summary of conditions occurring in Region II of the Sabine River Basin. Most of the data on Region II was taken from the report by Wood, Gabrysch, and Marvin (1963), prepared as a part of the statewide reconnaissance program. For a more comprehensive 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 II and extend a few miles into the southern part of Region I. The beds dip toward the Gulf Coast at a rate up to 100 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 overlie the Catahoula, Oakville, and Lagarto and crop out across the central part of Region II. 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 II 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 location of the outcrops of the various geologic formations in Region II are shown on Plate 2.

The sand beds in the Gulf Coast aquifer which 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 1,400 feet downdip where they occur to a depth of more than 3,000 feet below sea level in the vicinity of Kirbyville and in central Newton County. Southward from its deepest and thickest part, 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 bearing sand. These features are best illustrated on Plates 3, 7, and 8. The contours shown on Plates 7 and 8 are after Wood, Gabrysch, and Marvin (1963). Plate 3 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 II.

## 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 exist 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 exist, 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 pressure head than the younger and shallower formations owing to 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 pressure head.

## Recharge and Discharge

Conditions affecting recharge in the Sabine 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 II 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 generally where the net sand thickness of the aquifer is greatest.

Well yields and specific capacities differ greatly depending on the transmissibilities, the thickness and characteristics of the 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 comprise 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 II. Table 4 lists a number of chemical analyses of water from the aquifer, their approximate location, and producing intervals from all parts of Region II. These analyses were selected from Wood, Gabrysch, and Marvin (1963). These analyses are representative of the quality of water in Region II 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 4 range from 68 to 531 ppm.

Table 4.--Representative chemical analyses of water from the Gulf Coast aquifer in Region II, Sabine River Basin

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

| Analysis No. 1/ | Location of well | Screened interval | 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 $CaCO_3$ | Sodium adsorption ratio (SAR) | Specific conductance (micromhos at 25°C.) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | Orange, Orange County | 626- 706 | 50 | 0.07 | 16 | 5.4 | 167 2.9 | 189 | 0.0 | 196 | 0.3 | 0 | 531 | 62 | 9.2 | 927 | 7.0 |
| 9 | 8 mi. SW Orange, Orange County | 600- 672 | 34 | .08 | 2.0 | .5 | 135 1.0 | 225 | .0 | 83 | .4 | 0 | 372 | 7 | 22 | 610 | 7.4 |
| 10 | 20 mi. NE Newton, Newton County | ?- 225 | 50 | -- | 34 | .7 | 38 | 184 | 8.8 | 6.5 | .1 | 0 | 228 | 88 | 1.8 | 313 | 7.6 |
| 11 | Newton, Newton County | ?- 720 | 48 | .27 | 6.5 | 1.7 | 7.7 4.8 | 31 | 9.2 | 8.2 | .1 | 0 | 111 | 23 | .7 | 102 | 5.5 |
| 12 | 16 mi. SW Newton, Newton County | 489- 529 | -- | -- | 17 | 1.0 | 8.5 | 61 | 4 | 7.0 | .1 | 0 | 68 | 46 | .5 | -- | -- |
| 13 | 35 mi. S Newton, Newton County | 3/ 181- 432 | 56 | -- | 10 | 4.6 | 37 3.4 | 58 | 5.2 | 54 | -- | 0 | 210 | 44 | 2.4 | 279 | 6.3 |
| 15 | 20 mi. SE Jasper, Jasper County | 3/ 1,186-1,326 | -- | -- | 19 | 1.0 | 38 | 146 | 7 | 3.5 | .1 | 0 | 141 | 51 | 2.3 | -- | -- |

1/ All analyses are from Wood, Gabrysch, and Marvin (1963).
2/ Includes equivalent of any carbonate ($CO_3$) present.
3/ Not screened throughout interval.

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

Utilization and Development

On the basis of 1959 pumpage figures it is estimated that about 11,000 acre-feet of ground water per year is being withdrawn for municipal, industrial, and irrigation purposes from the Gulf Coast aquifer in Region II of the Sabine River Basin. About 2,000 acre-feet per year of this is being pumped for irrigation purposes and pumpage for public supplies and industrial use total about 1,000 and 8,000 acre-feet per year, respectively.

The greatest development of ground water in Region II occurs in the southern part of the region in major drainage subdivision 14, where 95 percent of the total pumpage occurs. Plate 2 shows the location and distribution of all municipal, industrial, and irrigation wells in Region II. It is estimated that the municipal, industrial, and irrigation pumpage figures listed above represent 90 percent of the total production from the Gulf Coast aquifer with domestic, livestock, and flowing wells accounting for the remaining discharge. 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 5 presents a summary of municipal, industrial, and irrigation pumpage from the Gulf Coast aquifer in Region II by major drainage subdivisions.

Table 5.--1960 Ground-water pumpage from the Gulf Coast aquifer in Region II, Sabine River Basin 1/

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

| Subdivision | 11 | 12 | 13 | 14 | Total |
|---|---|---|---|---|---|
| Municipal | 11 | 314 | -- | 840 | 1,165 |
| Industrial | -- | 67 | -- | 7,751 | 7,818 |
| Irrigation | -- | -- | -- | 2,000 | 2,000 |
| Total | 11 | 381 | -- | 10,591 | 10,983 |

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

Ground Water Available for Development

It is estimated on the basis of calculations made by Wood, Gabrysch, and Marvin (1963), that on the order of 46,000 acre-feet of water per year could be withdrawn from the aquifer under assumed maximum gradients. 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.

If the Gulf Coast aquifer is not developed to its maximum capacity in the Louisiana part of the Sabine River Basin, then additional water will be available for development in the Texas part of the basin.

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 Sabine River Basin occupies approximately 20 percent of the area for which storage was calculated. Thus, it appears that approximately 6,000,000 acre-feet of ground water could be produced from storage in the Sabine River Basin during development from present to maximum conditions.

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

## Summary of Ground-Water Pumpage and Availability

Approximately 19,500 acre-feet of ground water is presently being pumped annually from the aquifers of the Sabine River Basin for municipal, industrial, and irrigation purposes. Approximately 8,500 acre-feet of ground water is pumped in Region I of the basin where it is used primarily for industrial purposes and the approximately 11,000 acre-feet of ground water pumped in Region II is also used primarily for industrial purposes. Table 6 shows the distribution of pumpage in the basin by region, by use, and by aquifer.

On the order of 150,000 acre-feet of ground water is estimated to be available annually from the primary and secondary aquifers of the Sabine River Basin. The estimate is based on the ability of the aquifers to transmit water from the recharge areas to points of discharge, down the formational dip, under assumed maximum gradients.

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 the availability was computed, large quantities of water will be withdrawn from storage. However, this source of water is available only during the development of the assumed conditions and should not be considered as water available for development on a sustained basis. Additional quantities of water are also available for development from the "other" aquifers in the basin, but the amount is small in comparison to the primary and secondary aquifers.

Table 6.--1960 Ground-water pumpage from aquifers in the Sabine River Basin

(Pumpage expressed in acre-feet 1/)

| Aquifer 2/ | Municipal | Industrial | Irrigation | Total |
|---|---|---|---|---|
| REGION I | | | | |
| Carrizo-Wilcox (P) | 3,017 | 4,988 | -- | 8,005 |
| Queen City (S) | 311 | 56 | -- | 367 |
| Others 3/ | 193 | -- | -- | 193 |
| Subtotal | 3,521 | 5,044 | -- | 8,565 |
| REGION II 4/ | | | | |
| Gulf Coast (P) 5/ | 1,165 | 7,818 | 2,000 | 10,983 |
| Subtotal | 1,165 | 7,818 | 2,000 | 10,983 |
| TOTAL | 4,686 | 12,862 | 2,000 | 19,548 |

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 Woodbine Group and Nacatoch Formation.
4/ Pumpage for Region II based on 1959 figures.
5/ Includes Catahoula Sandstone, Oakville Sandstone, Lagarto Clay, Goliad Sand, Willis Sand, Lissie Formation, and Beaumont Clay.

## RECOMMENDATIONS FOR FUTURE STUDIES

The reconnaissance investigation has shown that large quantities of ground water are available for development in the Sabine River Basin. The reconnaissance investigations, however, are general in nature and are not suited for the planning of individual ground-water supplies.

Detailed ground-water investigations should be made on each of the two primary aquifers and the secondary aquifer of the basin to better define the aquifers' geologic and hydrologic characteristics, and the chemical quality of the water they contain. These detailed aquifer studies should not be limited to the Sabine River Basin, but should include the entire aquifer throughout their statewide extent.

Special, intensive ground-water studies should be made in the vicinity of towns needing additional water, in order 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.

The present water-level observation program in the basin is very inadequate and should be expanded as soon as possible. Observation wells should be located in all of the primary and secondary aquifers throughout the basin, especially in areas of intense pumpage, in order that the effects of present and future development may be determined.

A chemical quality of water program should be established and periodic water samples should be taken from all of the primary and secondary aquifers for chemical analysis to detect changes in chemical quality that may affect the quantity of usable ground water available for development. These periodic checks should be most frequent in areas of heavy withdrawals, in the vicinity of oil-field activities, and in areas of industrial waste disposal.

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## LIST OF GROUND-WATER PUBLICATIONS

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

### County Reports


Gregg

Records of wells, drillers' logs, and water analyses, and map showing location of wells in Gregg County, Texas, G. H. Shafer and W. M. Lyle, 1937: Texas Board Water Engineers duplicated rept.

Records of wells, drillers' logs, water analyses, and map showing locations of wells in Gregg County, Texas, W. L. Broadhurst, 1943: Texas Board Water Engineers duplicated rept.

Water resources of Gregg County, Texas, W. L. Broadhurst and S. D. Breeding, 1945: Texas Board Water Engineers duplicated rept.

Ground water resources of Gregg County, Texas, W. L. Broadhurst and S. D. Breeding, 1950: U. S. Geol. Survey Water-Supply Paper 1079-b.

Harrison

Records of wells and springs, drillers' logs, water analyses, and map showing locations of wells and springs in Harrison County, Texas, W. L. Broadhurst, 1942: Texas Board Water Engineers duplicated rept.

Water resources of Harrison County, Texas, W. L. Broadhurst and S. D. Breeding, 1943: Texas Board Water Engineers duplicated rept.

Hopkins

Records of wells, springs, drillers' logs, water analyses and map showing locations of wells and springs in Hopkins County, Texas, W. L. Broadhurst, 1943: Texas Board Water Engineers duplicated rept.

Hunt

Ground water in the Greenville area, Hunt County, Texas, N. A. Rose, 1945: Texas Board Water Engineers duplicated rept.

Jasper

Records of wells, drillers' logs, water analyses, and map showing locations of wells in Jasper and Newton Counties, Texas, G. H. Cromack, 1942: Texas Board Water Engineers duplicated rept.

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Records of wells, drillers' logs, water analyses, and map showing locations of wells in Jasper and Newton Counties, Texas, G. H. Cromack, 1942: Texas Board Water Engineers duplicated rept.

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Rains

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Records of wells, drillers' logs, and water analyses, and map showing location of wells in Rusk County, Texas, W. M. Lyle, 1937: Texas Board Water Engineers duplicated rept.

Records of wells, drillers' logs, water analyses, and map showing locations of wells in Rusk County (northwestern part), Texas, C. R. Follett, 1943: Texas Board Water Engineers duplicated rept.

Sabine

Records of wells and springs, drillers' logs, water analyses, and map showing locations of wells and springs in Sabine and San Augustine Counties, Texas, C. R. Follett, 1943: Texas Board Water Engineers duplicated rept.

San Augustine

Records of wells and springs, drillers' logs, water analyses, and map showing locations of wells and springs in Sabine and San Augustine Counties, Texas, C. R. Follett, 1943: Texas Board Water Engineers duplicated rept.

Shelby

Records of wells and springs, drillers' logs, and water analyses, and map showing location of wells and springs in Shelby County, Texas, W. M. Lyle, 1938: Texas Board Water Engineers duplicated rept.

Shelby (Cont'd.)

Memorandum report of preliminary ground water investigation of Shelby County, Texas, J. W. Dillard, 1960: Texas Board Water Engineers duplicated rept.

Smith

Records of wells, drillers' logs, water analyses, and map showing location of wells in Smith County, Texas, W. M. Lyle, 1937: Texas Board Water Engineers duplicated rept.

Results of pumping tests of municipal wells at Tyler, Texas, W. L. Broadhurst, 1944: Texas Board Water Engineers duplicated rept.

Upshur

Records of wells, drillers' logs, water analyses, and map showing locations of wells in Upshur County, Texas, W. L. Broadhurst, 1942: Texas Board Water Engineers duplicated rept.

Wood

Records of wells and springs, drillers' logs, water analyses and map showing locations of wells and springs in Wood County, Texas, C. R. Follett, 1942: Texas Board Water Engineers duplicated rept.

## OPEN-FILE REPORTS

Open-file reports are not available for distribution but may be reviewed in the office of the Texas Water Commission, 201 East 14th Street, or the U. S. Geological Survey, Ground Water Branch, 807 Brazos Street, Austin, Texas.

### Area or District Reports

Availability of ground water in the Gulf Coast region of Texas, L. A. Wood, 1956.

Ground water conditions in East Texas oil fields, S. F. Turner, 1932.

Ground water in the Gladewater-Big Sandy district, Texas, W. L. Broadhurst and C. R. Follett, 1942.

Water supply in the sandflat area and adjacent territory in Rusk, Nacogdoches, and Shelby Counties, Texas, W. L Broadhurst and Trigg Twichell, 1942.

## County Reports

### Harrison

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### Hunt

Development of ground water for public supply at Commerce, Texas, W. L. Broadhurst, 1944.

### Jasper

Ground water resources in the vicinity of Jasper, Jasper County, Texas, R. W. Sundstrom, 1941.

Ground water in the Beaumont area, Texas, with special reference to southeastern Hardin County and southwestern Jasper County, N. A. Rose, 1945.