TEXAS WATER COMMISSION

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BULLETIN 6308

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE NECHES 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 Neches 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 small 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 NECHES RIVER BASIN, TEXAS

ABSTRACT

The Neches River Basin is in the eastern part of Texas and covers approximately 10,000 square miles. The basin includes all or parts of 21 counties and represents about 3.8 percent of the total area of the State.

The physiographic expression of the Neches River Basin ranges from treeless prairies to rolling timbered hills with altitudes ranging from sea level at the mouth of the Neches River to about 600 feet above sea level in the upper reaches of the basin. The average annual precipitation ranges from approximately 44 inches at the upper end of the basin to about 56 inches near the coast. The population of the Neches River Basin in 1960 was approximately 354,500, or about 3.7 percent of the total population of Texas. The economy of the basin ranges from heavy and light industries in the urban areas to varying forms of agriculture in the rural areas. Forest and wood products, oil and gas production, and their associated industries also contribute to the economy in many parts of the basin.

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 Neches River Basin. The Queen City Formation and Sparta Formation are classified as secondary aquifers because they are capable of supplying small quantities of water over large areas of the basin. In addition to the primary and secondary aquifers, the Yegua Formation and the Jackson Group yield small to moderate quantities of water locally, but have limited potential.

On the order of 400,000 acre-feet of usable ground water is estimated to be available annually from the primary and secondary aquifers of the Neches 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 aquifers to transmit water and on the availability of recharge in the outcrops 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 200,000 acre-feet of water is available perennially from the Carrizo-Wilcox aquifer; 60,000 to 70,000 acre-feet from the

Sparta aquifer; 10,000 acre-feet from the Queen City aquifer; and approximately 123,000 acre-feet from the Gulf Coast aquifer. Additional quantities of water can be withdrawn from storage in the course of establishing the assumed conditions of pumpage for which availability was computed. However, this source of water is available only during the development of assumed conditions and should not be considered as water available for development on a sustained basis.

In 1960, approximately 73,000 acre-feet of ground water was reported pumped from the aquifers of the Neches River Basin for municipal, industrial, and irrigation purposes. About 32,000 acre-feet was reported pumped from the Carrizo-Wilcox aquifer; 75 acre-feet from the Sparta aquifer; 1,200 acre-feet from the Queen City aquifer; and 39,000 acre-feet from the Gulf Coast aquifer. In addition, about 850 acre-feet was reported pumped from the other aquifers of the basin for municipal and industrial purposes.

Large quantities of water of good quality, suitable for most municipal, industrial, and irrigation purposes, are available for additional development in all of the primary and secondary aquifers of the Neches River Basin. Additional small quantities of water of good quality are available for development from the other aquifers of the Basin.

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 four primary and secondary aquifers of the Neches 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.

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

INTRODUCTION

Purpose and Scope

The reconnaissance investigation of the Neches 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 basin areas 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 the 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 Neches 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 Neches River Basin reconnaissance investigation provide a generalized evaluation of ground-water conditions over large areas. The amount of water available for development in the Neches 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 Neches River Basin is in the eastern part of the State as shown by Figure 1. The Neches River Basin, which extends from southeastern Van Zandt County to the Gulf of Mexico, is bounded on the west by the Trinity River Basin, on the east and north by the Sabine River Basin, and is drained by the Neches River and its tributaries. The Neches River Basin includes all or parts of 21 counties, has an areal extent of approximately 10,000 square miles, and represents about 3.8 percent of the State's total area.

Because of the basin's large areal extent, the Neches 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 Neches River Basin and the topographic limits of smaller drainage subdivisions which have been defined by the Planning Division of the Texas Water Commission. The locations 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 effects of future pumping.

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

Previous Investigations

Prior to the present reconnaissance investigation, ground-water studies had been conducted in all or parts of 17 counties of the Neches River Basin.

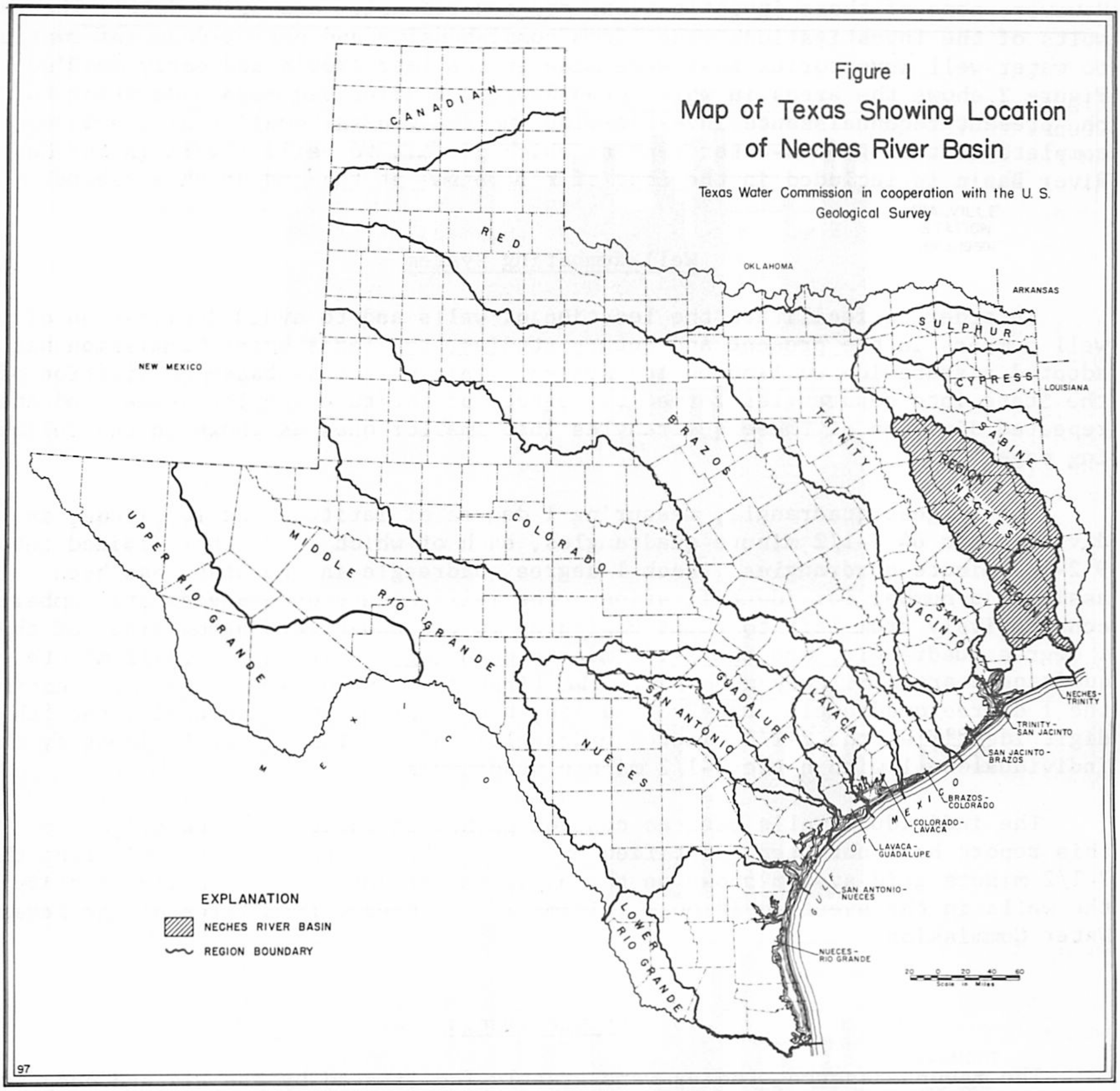


Figure 1

Map of Texas Showing Location of Neches River Basin

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

However, none of these investigations are comprehensive and up-to-date. The results of the investigations range from comprehensive and out-of-date information to water-well inventories that were made in the late 1930's and early 1940's. Figure 2 shows the areas in which ground-water studies had been made prior to the present reconnaissance investigation and the general quality of the data. A complete list of ground-water reports which pertain to earlier work in the Neches 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.

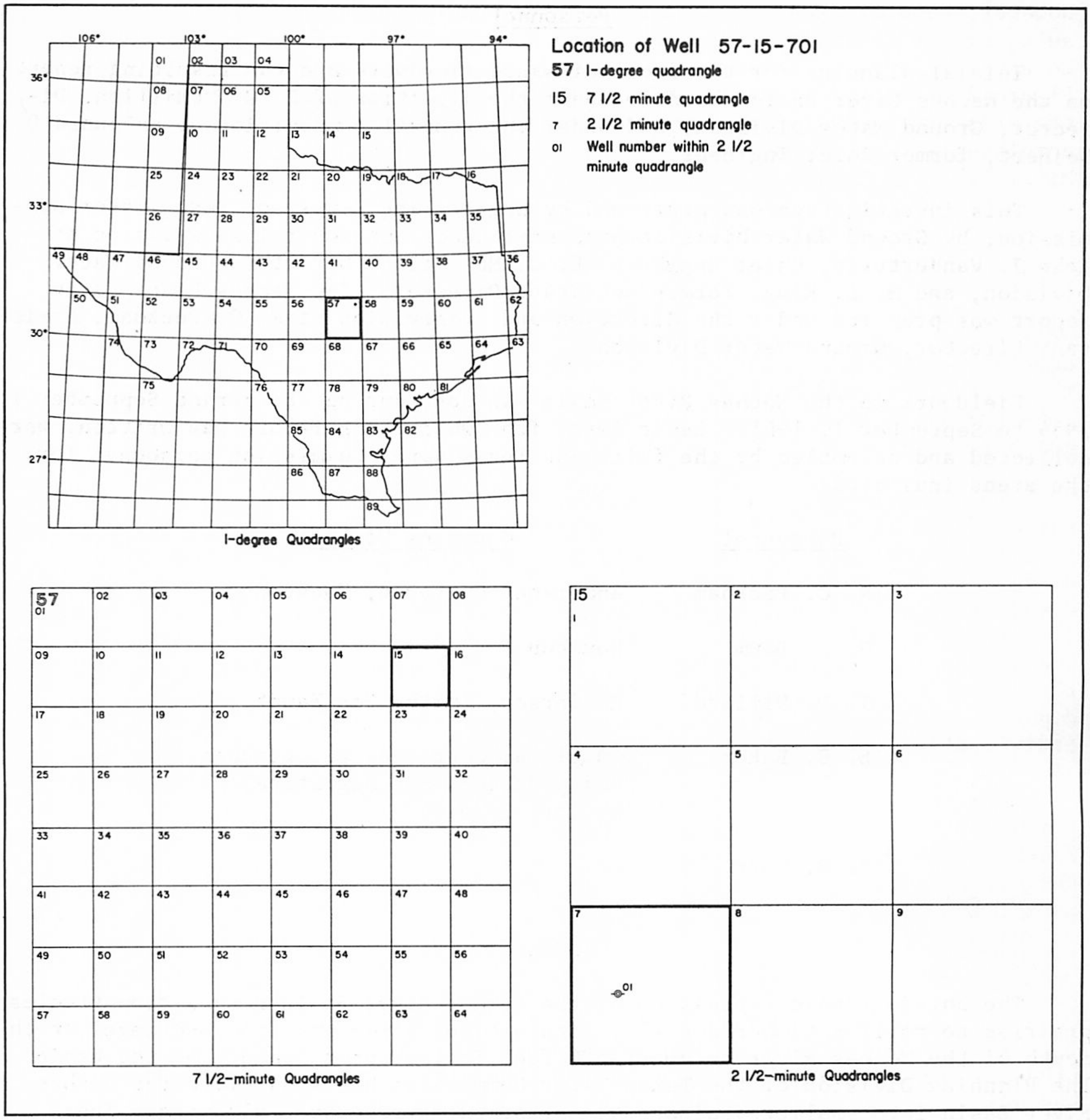
The individual wells used as control points on various illustrations in this report have not been identified by well numbers. However, by utilizing the 7-1/2 minute grid system shown on the maps, the reader can adequately identify the wells in the event additional information is needed from files of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

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

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.



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

Personnel

Initial planning for the reconnaissance fieldwork and the resulting report on the Neches 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. The Neches River Basin report was prepared under the direction and supervision of R. C. Peckham, Assistant Director, Ground Water Division.

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

Personnel	Counties Worked
R. C. Peckham	Anderson, Cherokee, Houston
G. H. Baum	Houston
J. W. Dillard	Henderson, Smith, Van Zandt
B. B. Baker	Angelina, Cherokee, Nacogdoches, Rusk, Sabine, San Augustine, Shelby, Trinity
D. R. Curry	Rusk

GEOGRAPHY

The physiographic expression of the Neches River Basin ranges from treeless prairies to rolling timbered hills, with altitudes ranging from sea level at the mouth of the Neches River to about 600 feet in the upper reaches of the basin. The Planning Division of the Texas Water Commission has subdivided the Neches 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 Neches River Basin is characterized by long hot summers and short mild winters. Mean annual precipitation ranges from about 44 inches in the upper reaches of the basin to 56 inches near the coast. Figure 3 illustrates the mean annual precipitation in the basin and the average monthly precipitation for the period of record at selected stations. Figure 4 shows the annual precipitation for the period of record at selected stations in different parts of the basin.

In 1960 approximately 354,500 inhabitants lived in the Neches River Basin representing about 3.7 percent of the State's population. Approximately one

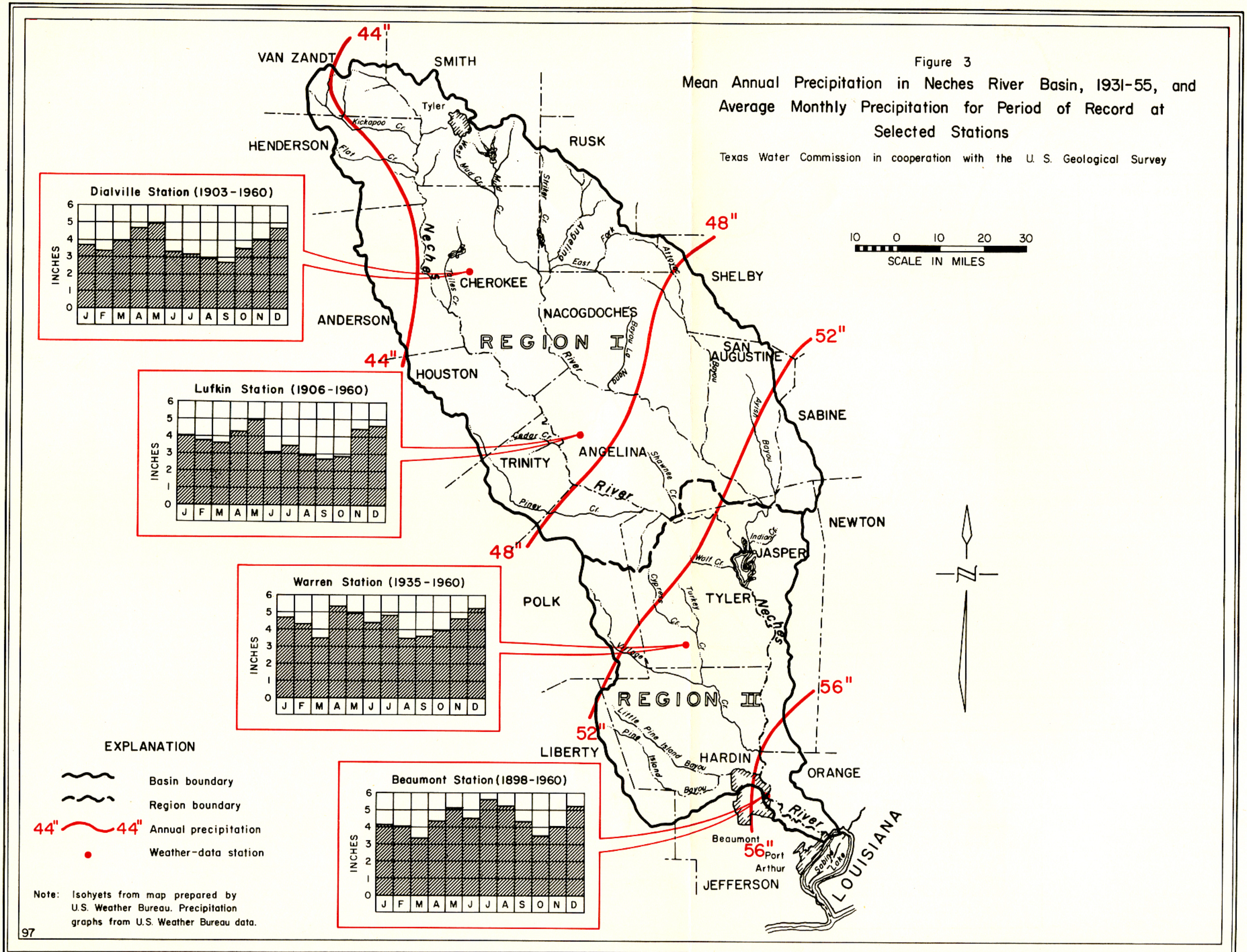


Figure 3

Mean Annual Precipitation in Neches 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

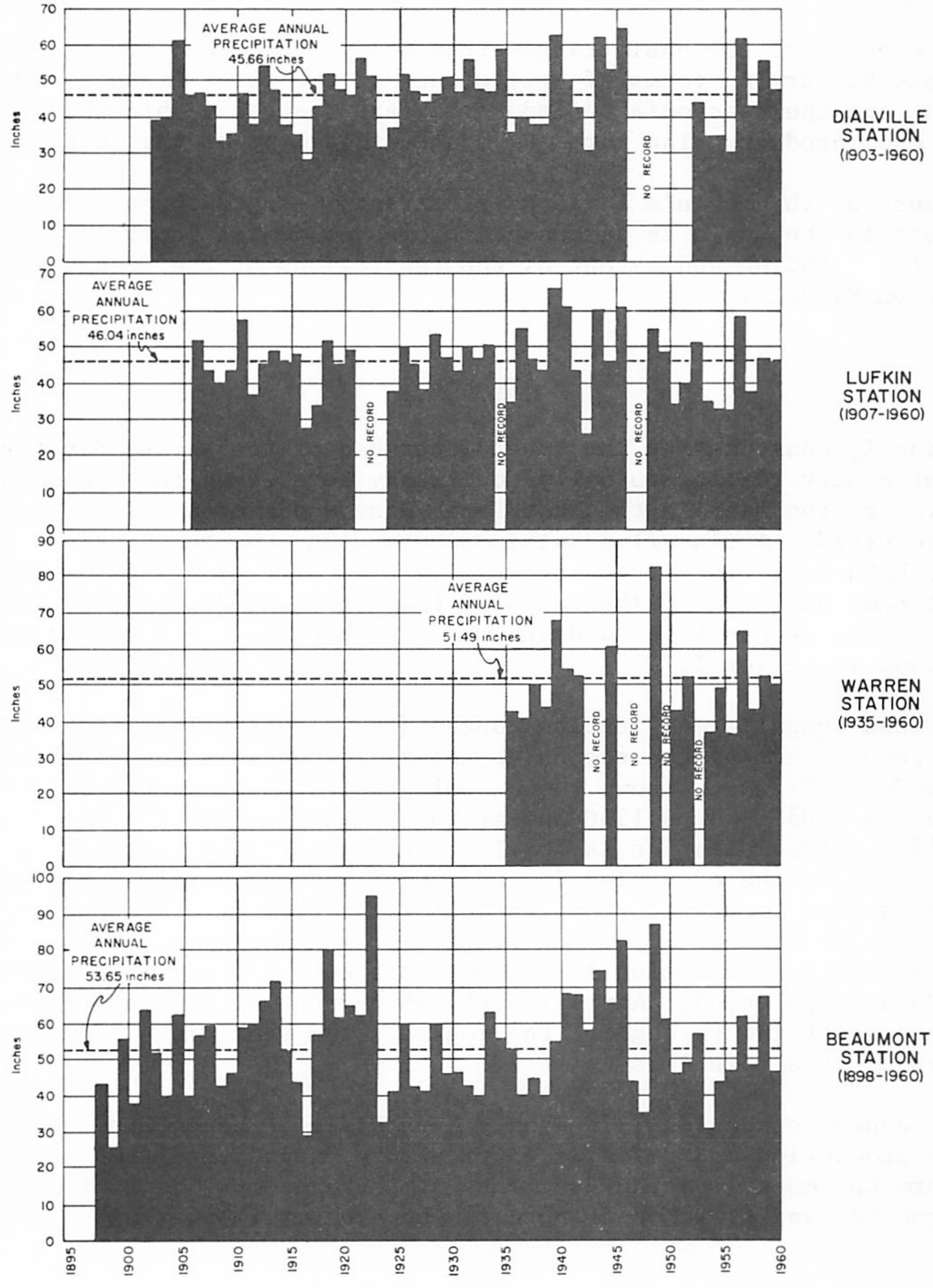


Figure 4

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

(From U. S. Weather Bureau data)

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

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half of the people live in urban areas which are defined as towns or concentrated areas of 2,500 or more inhabitants. The remainder of the population is classified as rural. There are 15 cities with populations of 2,500 or more which lie within or partly within the basin.

The economy of the basin ranges from heavy and light industries in the urban areas to varying forms of agriculture in the rural areas. Oil and gas production and their associated industries are scattered throughout the basin. Wood and wood products also form an important segment of the economy.

Because of the basin's large areal extent, the geography of each of the two regions in the basin is discussed in greater detail in the following paragraphs. The location and extent of the two regions of the Neches River Basin are shown on Figure 1.

Region I

Region I, constituting the upper watershed of the Neches River Basin, is an area of gently rolling to hilly topography located on the upper Gulf Coastal Plain. The region lies in the East Texas pine woods area and is typically heavily forested. A flat flood plain occurs along the Neches River and its larger tributaries. The 7,006-square-mile area of Region I is drained by numerous streams and major tributaries of the Neches River. Plate 1 shows the location of the Neches River and its major tributaries, and the major drainage subdivisions in Region I.

The mean annual precipitation ranges from slightly less than 44 inches in the westernmost part of the region to about 52 inches in the southeastern part of the region. Figure 4 shows the annual precipitation at the Dialville Station for the years 1903 through 1960 and at the Lufkin Station for the years 1907 through 1960. Precipitation is fairly evenly distributed throughout the year with the drier months occurring in the summer and early fall. Figure 3 illustrates the average monthly precipitation at the Dialville and Lufkin Stations.

The population of Region I in 1960 was about 253,800 or 70 percent of the basin's total population. Approximately 49 percent of this population lived in urban areas scattered throughout the region. The remaining 51 percent are classified as rural dwellers.

The economy of Region I is highly diversified. Forest and wood products, petroleum production and refining, agriculture, and diversified light manufacturing form the most important segments of the economy. Mineral production, mainly iron ore and clay, contribute to the economy locally.

Region II

Region II constitutes the lower drainage area of the Neches River Basin. Most of the region lies in the hilly and heavily forested East Texas pine belt. The part of the region near the coast, however, consists of relatively open and level coastal prairie. The 3,005 square miles of Region II are drained by the Neches River and its tributaries. Plate 2 shows the location of the Neches River and its major tributaries, and the major drainage subdivisions in Region II.

The average yearly precipitation ranges from about 52 to 56 inches, making Region II one of the wettest areas in the State. Figure 4 shows the annual precipitation at the Warren Station for the years 1936 through 1960 and at the Beaumont Station for the years 1898 through 1960. Precipitation is fairly evenly distributed throughout the year with the driest months occurring in late summer and early fall. Figure 3 illustrates the average monthly precipitation at the Warren and Beaumont Stations.

The population of Region II in 1960 was about 100,700, which represents approximately 30 percent of the basin's total. About 51 percent lived in urban areas and the remaining 49 percent are classified as rural. The greater part of the urban population lived in or near the heavily industralized Beaumont and Port Arthur areas.

The economy of Region II is highly diversified. Forest and wood products, petroleum production, and livestock raising form important segments of the economy. Rice, hay crops, sorghum, soybean, and various truck crops are major agricultural products of the region. The Beaumont-Port Arthur metropolitan area contains a great variety of both light and heavy industries. Some of the more important industries and products include petroleum refining, oil-field equipment, petrochemicals, synthetic rubber, iron and steel, and ship building.

GENERAL GEOLOGY

Rocks of the Quaternary and Tertiary systems are exposed throughout the Neches River Basin and range in age from Eocene to Recent. A few small isolated outcrops of older rocks of Cretaceous age are exposed on the crest of some salt domes in the basin. Older rocks underlie the Neches River Basin but do not contain usable ground water and are not described or discussed in this report.

The history of the Tertiary and Quaternary Periods in the Gulf Coast area is one or repeated marine transgressions and regressions resulting in the deposition of an alternating sequence of marine and continental sediments. The marine sediments, typically characterized by clay, shale, marl, and minor amounts of sand, possess relatively poor water-bearing properties. The continental deposits consist mainly of sand with lesser amounts of shale, clay, and lignite and are the major water-bearing units in the basin.

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 Neches River Basin are shown in Table 1. This table lists the geologic units from youngest to oldest, their approximate thickness, a brief description of their lithology, and a brief summary of their water-bearing properties. The location of the outcrop areas of various stratigraphic units listed in Table 1 are shown on Plates 1 and 2. Plate 3, a geologic section drawn

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

System	Series	Group		Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing properties
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, and lime-cemented sandstone interbedded with variegated clay; overlapped by younger formations and does not crop out in the Neches 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			0-1,200	Sand, sandy shale, shale, and a few thin beds of limestone.	Yields small to moderate amounts of water in and near the outcrop.
		Claiborne		Yegua Formation	0-1,100	Sand, sandy shale, shale, and a few beds of limestone and lignite.	Yields moderate amounts of water in and near the outcrop.
				Cook Mountain Formation	0- 520	Predominantly shale with some sand.	Yields small amounts of water from the sand sections in and near the outcrop.
				Sparta Formation	0- 345	Massive, poorly cemented sand in lower part; sands in upper part interbedded with clays and shales.	Yields moderate amounts of water in Region I.
			Mount Selman	Weches Formation	0- 250	Glauconitic sandstone and shale.	Not known to yield usable water in the basin.
				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.
				Reklaw Formation	0- 310	Shale with thin sand layers in upper part; glauconitic sand and shaley sand in lower part.	Yields only small amounts of water from the sands in and near the outcrop.
				Carrizo Formation	0- 180	Clean, fine to medium-grained sand with some thin interbedded shales.	Yields large amounts of water in Region I.
		Wilcox			0-3,500+	Interbedded sand, sandy shale, shale and	Do.
		Midway			0- 900+	Massive shale.	Not known to yield usable water in the basin.
Cretaceous	Undifferentiated				6,000+	Alternating layers of limestone, chalk, marl, shale, and sand.	Do.

generally along the axis of the Neches River Basin, illustrates the stratigraphic position of these rocks in the subsurface.

Structure

Throughout most of the Neches River Basin the geologic formations dip generally south and southeast toward the Gulf Coast. The rate of dip is substantially greater than that of the land surface and as a result the older formations crop out to the north of younger formations at progressively higher elevations.

The general attitude of the geologic formations occurring in the northern part of the Neches River Basin is controlled by two major structures. The formations dip eastward and westward toward the axis of a structural trough known as the East Texas syncline. The axis of this trough strikes generally northward across the Neches River Basin in eastern Anderson and western Smith Counties. On the eastern flank of the trough, the formations dip westward and southwestward from a dome-shaped structural high located in East Texas and western Louisiana. This structure is known as the Sabine uplift. Because of subsequent erosion on the Sabine uplift, the oldest rocks of the Tertiary system cropping out in the Neches River Basin occur along the basin's northeast boundary in Nacogdoches, Shelby, and Rusk Counties. These geologic structures have a primary influence on the occurrence and movement of ground water in the basin.

Several major faults are present in the basin. The most important and extensive is a fault zone known as the Mount Enterprise fault system, which strikes generally westward from the northwest corner of Shelby County across southern Rusk County and northern Cherokee County. The structural features of the Neches River Basin are best illustrated on Plate 4 showing the top of the Carrizo Formation. Insufficient data is available at this time to determine the full effect of the faults on the movement of ground water in the basin. The general structural trends occurring in the Neches Basin are sharply interrupted locally by salt domes which occur in the East Texas syncline and the lower Gulf Coast.

Fresh-Water Aquifers

An aquifer is defined by Meinzer (1923 p. 30) as a geologic formation, group of formations, or part of a formation that is water bearing. General usage, however, has restricted the application of the term to those water-bearing units which yield water in sufficient quantities to constitute a usable supply. A geologic unit 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 that 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 Neches River Basin. A minor aquifer has been defined as one which yields large quantities of water in small areas

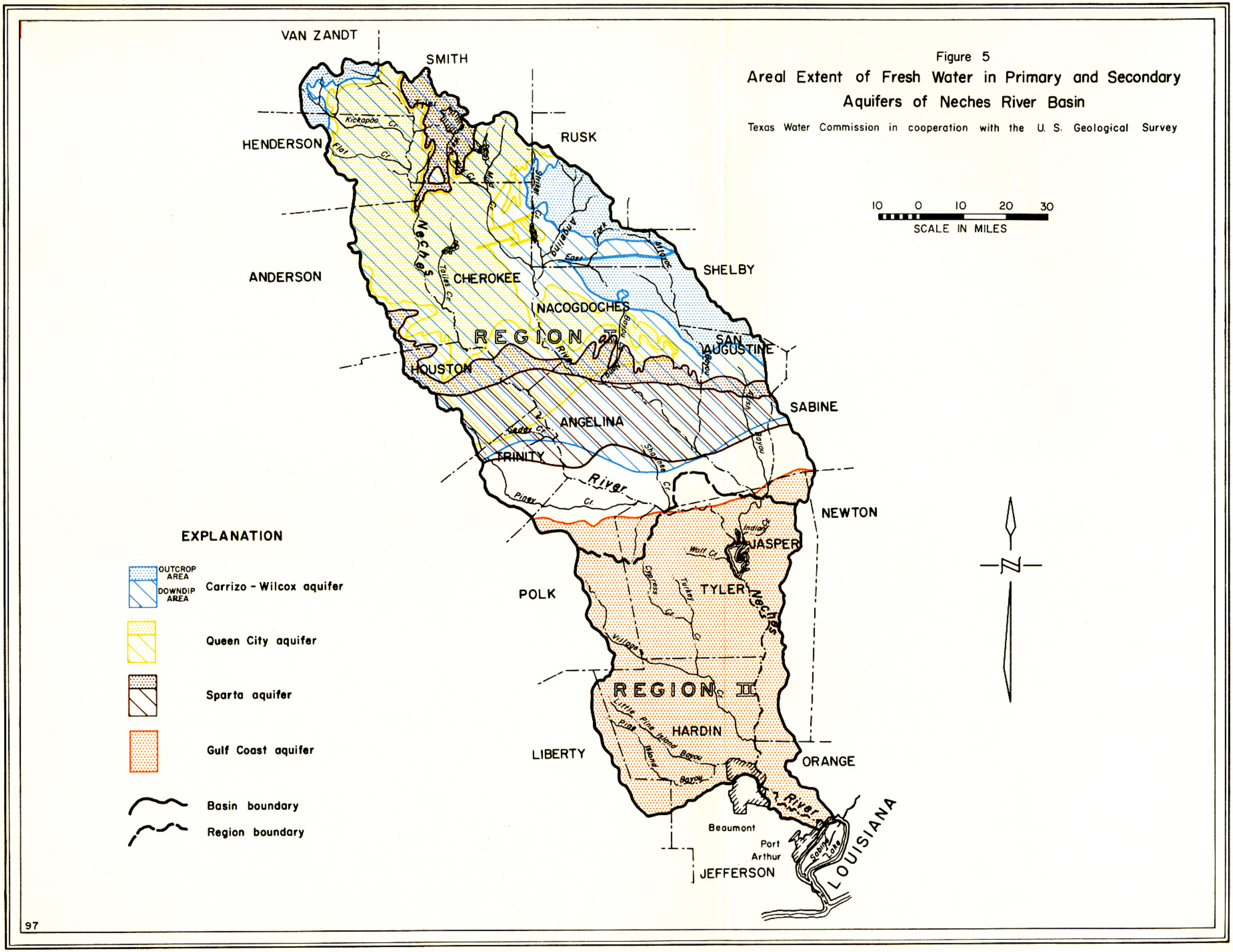

Figure 5
Areal Extent of Fresh Water in Primary and Secondary Aquifers of Neches River Basin
Texas Water Commission in cooperation with the U. S. Geological Survey

or relatively small quantities in large areas of the State. Two aquifers of this classification occur in the Neches River Basin. They are the Sparta sands and Mount Selman sands.

Aquifers which 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, 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 Neches 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 Neches River Basin are: (1) Carrizo 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 units which make up the two secondary aquifers of the Neches River Basin are: (1) Queen City Formation (Mount Selman sands) and (2) Sparta Formation.

It must be emphasized that the terms primary and secondary as applied to the aquifers of the basin do not necessarily correspond with the major and minor aquifers of the State. Also, because of the varying geologic and hydrologic characteristics, primary and secondary aquifers of the Neches River Basin do not necessarily bear the same classification in adjacent basins.

The areal relationship of the primary and the secondary aquifers of the Neches River Basin and the areas in which they produce fresh water are shown on Figure 5. 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 Neches 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 provide 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 Neches 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.

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 from the soil and returned to the atmosphere by transpiration. Some of the water will run off the land surface into streams and thus return to the sea. A small percentage of the rainfall will percolate downward under the force of gravity to a zone in which all rock voids are saturated. This zone is known as the zone of saturation and the upper surface of the zone is called the water table. Water entering the zone of saturation moves to points of lower elevation where it is discharged naturally or artificially, and is subjected to other phases of the hydrologic cycle. Occasionally a local impermeable layer above the water table will intercept 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

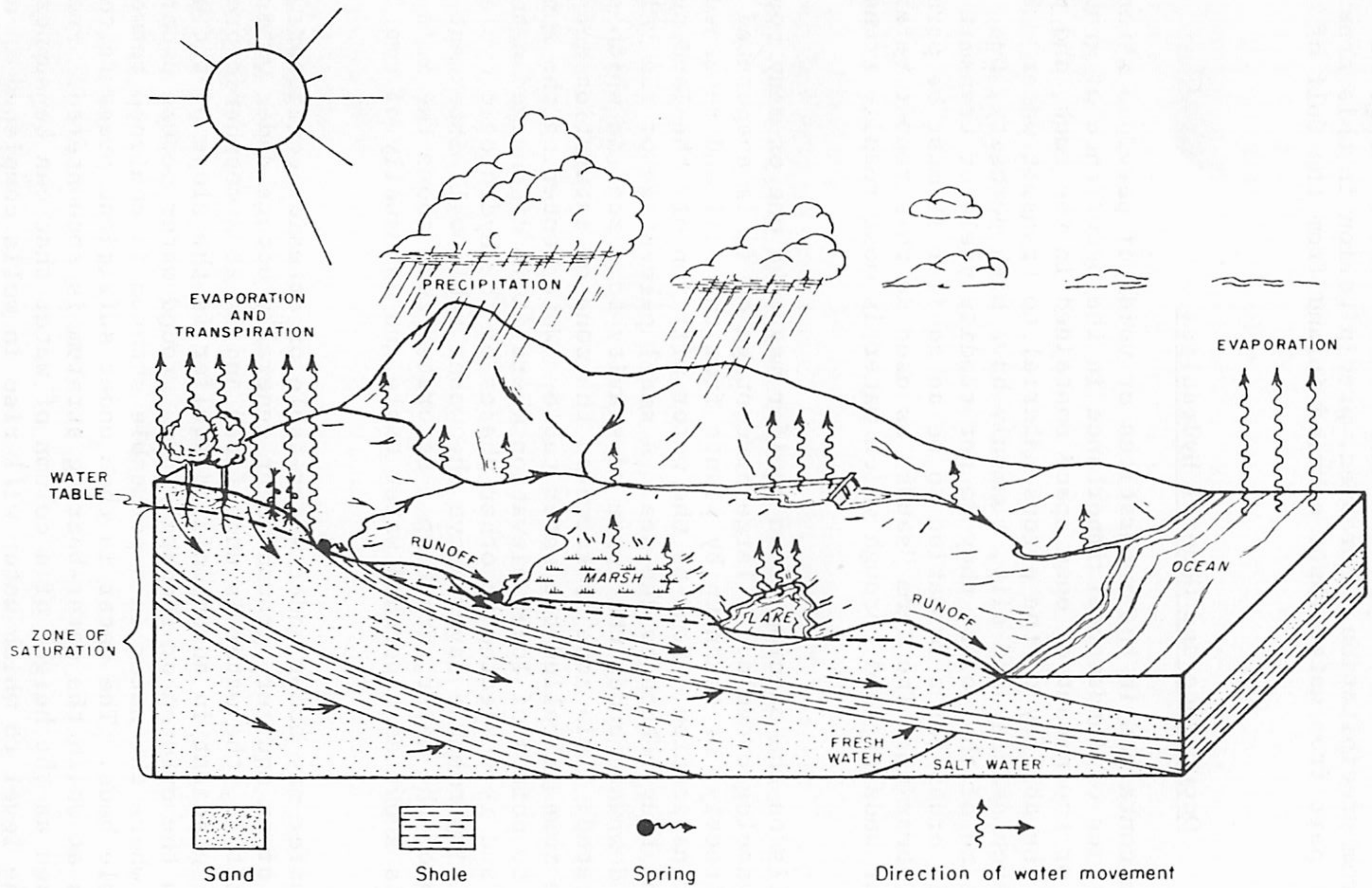

Figure 6

The Hydrologic Cycle in the Neches River Basin

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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 Neches River Basin is precipitation which falls on the outcrops 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 stratigraphic units where ground-water circulation is restricted. In most stratigraphic units whose sediments were deposited in brackish water, the flushing action of fresh water moving through the aquifers has not been complete throughout the strata. Therefore, at some distance downdip and in some cases in limited areas, highly mineralized water is encountered.

In addition to natural mineralization of water, the quality of water 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 Neches River Basin is discussed by regions, beginning with Region I. The primary aquifers of each region are discussed first, the secondary aquifers next, and other aquifers of limited significance are noted briefly at the end of the discussion for each region.

Region I

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

Geologic Characteristics

The Carrizo Formation consists of a clean, fine to medium-grained, poorly cemented quartz sand. Thin shale beds occur in the formation but they are of limited extent and make up a minor part of the formation. The total thickness of the Carrizo Formation ranges from 70 to 180 feet and averages about 120.

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. The sands of the Wilcox make up about 40 to 50 percent of the total thickness of the group.

In Region I, the Carrizo Formation and Wilcox Group have a total thickness ranging from about 400 feet in the outcrop to more than 3,500 feet in the southernmost part of the region; however, the stratigraphic units do not contain usable water throughout their total thickness over a large part 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 400 feet in the outcrop to more than 2,400 feet in southern Cherokee and northern Houston Counties, and finally thins to zero as the quality of water becomes more mineralized in the southern part of the region.

The Carrizo-Wilcox aquifer crops out over a rather extensive area on the crest and flanks of the Sabine uplift along the northeast boundary of Region I and in the adjacent Sabine River Basin. In addition, the aquifer crops out in the extreme northwest part of the region. From its outcrop areas, the aquifer dips toward the axis of the East Texas syncline and toward the Gulf Coast. The rate of dip is variable and ranges from 12 to 100 feet per mile. 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 the geologic structure. The depth to the top of the aquifer ranges from zero in the outcrop area to more than 2,000 feet below the land surface (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 confined by overlying impermeable strata and 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 is generally downdip, that is, the gradient is in the same direction as the formational dip. North of the Mt. Enterprise fault system the water apparently moves into the East Texas syncline from the Carrizo-Wilcox outcrop areas, which are located on both the east and west sides of the basin. South of the fault zone the water moves generally toward the south and southeast. Variations from the natural gradient may be expected to exist in the vicinity of well fields which supply water to the several municipalities and industries of the region. Cones of depression develop in the vicinity of the well fields causing water to move toward these points of discharge.

Water-level measurements in Region I indicate that present gradients range from 3 to 25 feet per mile. The steeper gradients are in areas of intensive development.

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 evenly distributed throughout the year over a large intake area. The outcrop areas have moderate topographic relief and are covered with loose sandy soils. It is estimated that approximately 2,600 square miles of the Carrizo-Wilcox outcrop constitute the recharge area for this basin. The largest part of this recharge area, however, lies in the adjoining Sabine and Trinity River Basins.

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 head, natural discharge occurs by means of upward leakage through the confining beds.

Flowing wells, and pumping from wells 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 wells which penetrate the Carrizo-Wilcox aquifer range from 0 to 450 feet below land surface. The deeper water levels occur north of Lufkin in Angelina County where large quantities of water are pumped from the well fields of the Southland Paper Mill and the city of Lufkin.

Where the Carrizo-Wilcox aquifer has been developed and pumpage increased, the water levels have declined. The declines are especially noticeable in areas of large pumpage and have caused concern among the residents of these areas. It must be emphasized that a decline in water levels does not mean that the water eventually will be depleted or that pumping 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 the well in order to produce gradients sufficient to move the water to the well at a rate equal to the discharge. Fluctuation of water levels observable in wells penetrating the aquifer are usually related to the varying rates of withdrawal in the area.

A general decline in water levels has occurred in the Nacogdoches-Angelina County area during the past 20 years due to periodic increases in pumpage. In 1940, the Carrizo-Wilcox water levels in southern Nacogdoches and northern Angelina Counties stood very near the surface and several flowing wells were reported. At present, nearly all wells penetrating the aquifer have ceased to flow. Hydrographs on Figure 7 illustrate the decline in water levels during the past 10 years in six selected wells completed in the Carrizo Formation in Nacogdoches and Angelina Counties.

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, homogenous sand, possesses the most favorable characteristics. Data from 25 pumping tests made on wells completed in the Carrizo Formation in different parts of the basin show that the coefficients of transmissibility ranged from 12,000 to 41,000 gallons per day per foot (gpd/ft.) and averaged about 26,600 gpd/ft. The coefficients of permeability ranged from 120 to 300 gpd/ft.^{2} and averaged 220 gpd/ft^2. Storage coefficients are available from 11 pumping tests and ranged from 0.000061 to 0.000185 and averaged 0.000133.

The sands of the Wilcox Group exhibit rather low coefficients of transmissibility; those obtained from seven pumping tests on wells completed in the Wilcox Group in or near the outcrop ranged from about 1,300 to 7,700 gpd/ft. These figures, however, are not comparable with each other nor are they

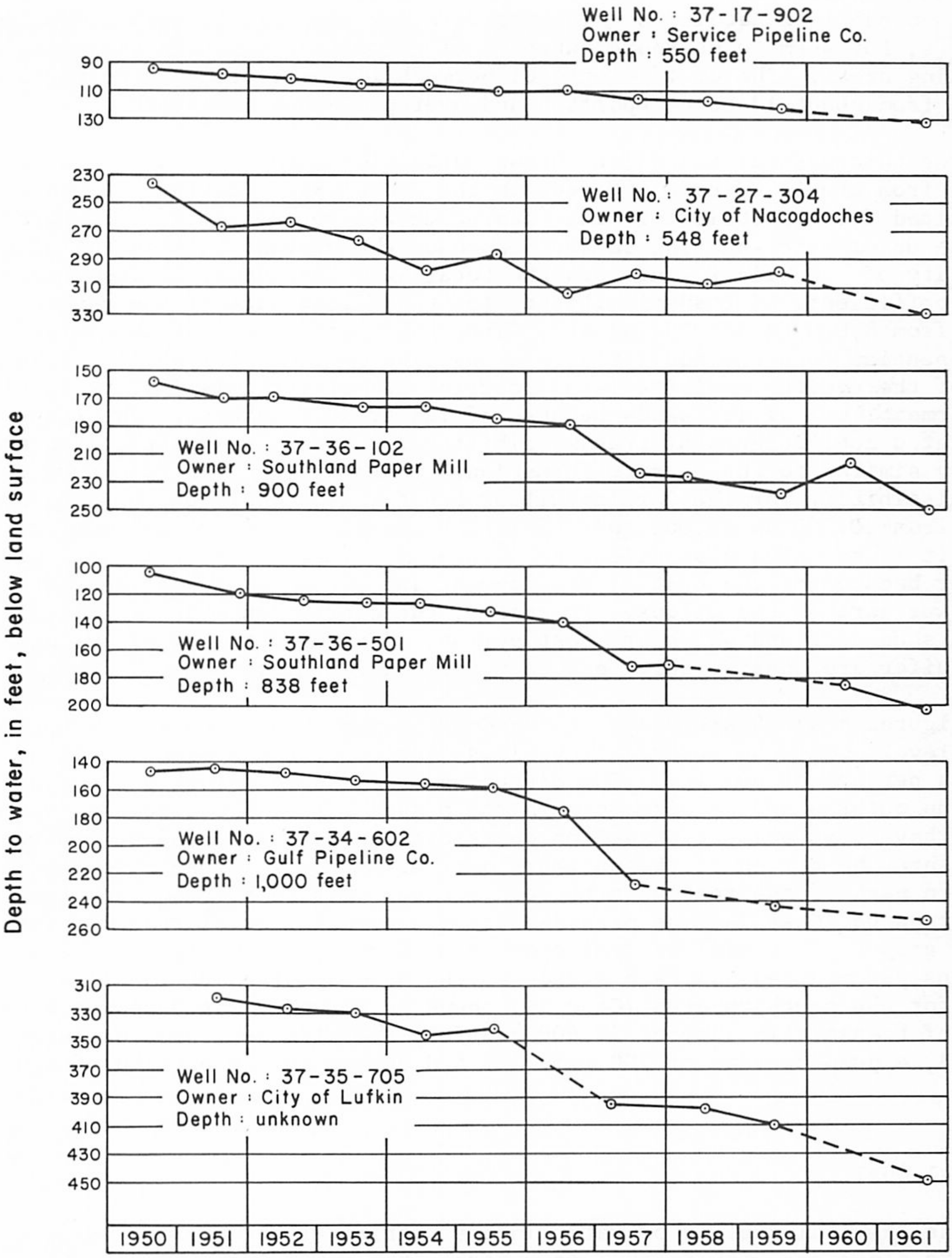

Figure 7

Hydrographs of Wells Screened in the Carrizo-Wilcox Aquifer, Region I, Neches River Basin

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representative of the Wilcox Group as a whole, because they are coefficients of transmissibility of individual sand beds within the Wilcox Group and not the total sand thickness. The coefficients of permeability of the Wilcox, which are independent of aquifer's thickness, are low compared to most productive aquifers, but seem to be representative of the Wilcox sands in the basin and adjoining areas. The coefficients of permeability calculated from three tests ranged from about 13 to 60 gpd/ft.^{2} and averaged about 40 gpd/ft^2.

The thickness of the Wilcox Group containing water of usable quality ranges from about 400 to 2,400 feet in the Neches River Basin. 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 8,000 to 48,000 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 despite the low permeability of its sands because of its great thickness. The range of calculated coefficients of transmissibility for the Wilcox part of the aquifer is very similar to the Carrizo Formation. Therefore, the coefficients of transmissibility for the Carrizo-Wilcox aquifer as a whole can be expected to range from 20,000 to 89,000 gpd/ft. in the downdip areas of the aquifer. However, 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.

Figures 8 and 9 are distance-drawdown graphs which show 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 graphs have been prepared based on coefficients believed to be generally applicable throughout much of the northern part of Region I in one case and to the southern part of the region in the other case. Figure 8, the graph for the northern area (Case I), was prepared using a coefficient of transmissibility of 17,500 gpd/ft., a coefficient of storage of 0.0002, a pumping rate of 700 gpm (gallons per minute), and a distance to the outcrop of about 15 miles. The graph for the southern area (Case II) shown on Figure 9 was based on a coefficient of transmissibility of 26,600 gpd/ft., a coefficient of storage of 0.00013, a pumping rate of 700 gpm, and a distance to the outcrop of about 10 miles.

Chemical Quality

The chemical quality of water in the Carrizo-Wilcox aquifer varies from place to place and with depth. In general, the water is of good quality and suitable for most purposes throughout most of Region I. Table 2 lists a number of selected analyses of water taken from the aquifer in different parts of Region I.

In the outcrop, most wells take water only from the sands of the Wilcox. Downdip, the majority of the wells screen the Carrizo Formation and seldom

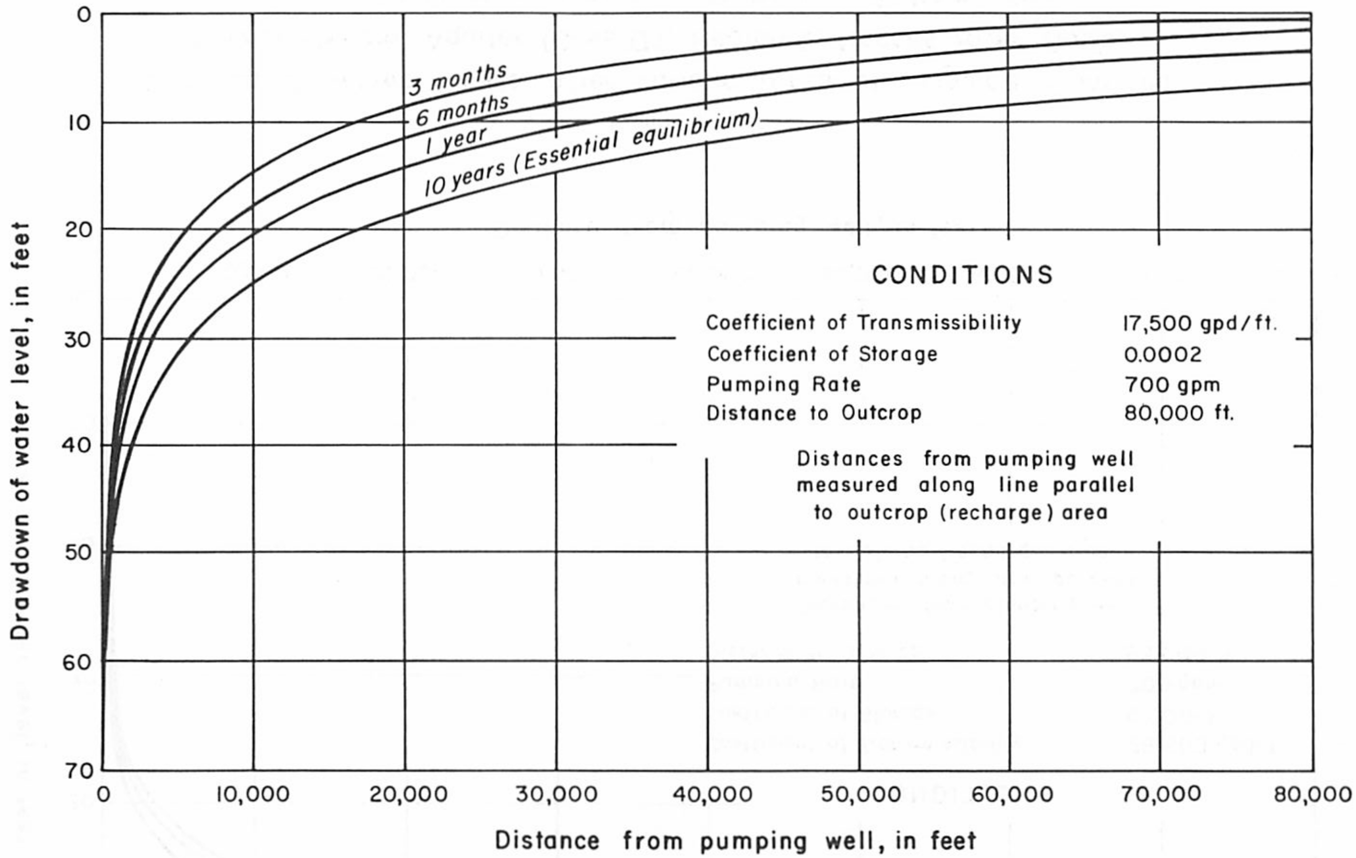

Figure 8

Distance-Drawdown Curves After Various Times of Pumping From the Carrizo-Wilcox Aquifer (Case I), Region I, Neches River Basin

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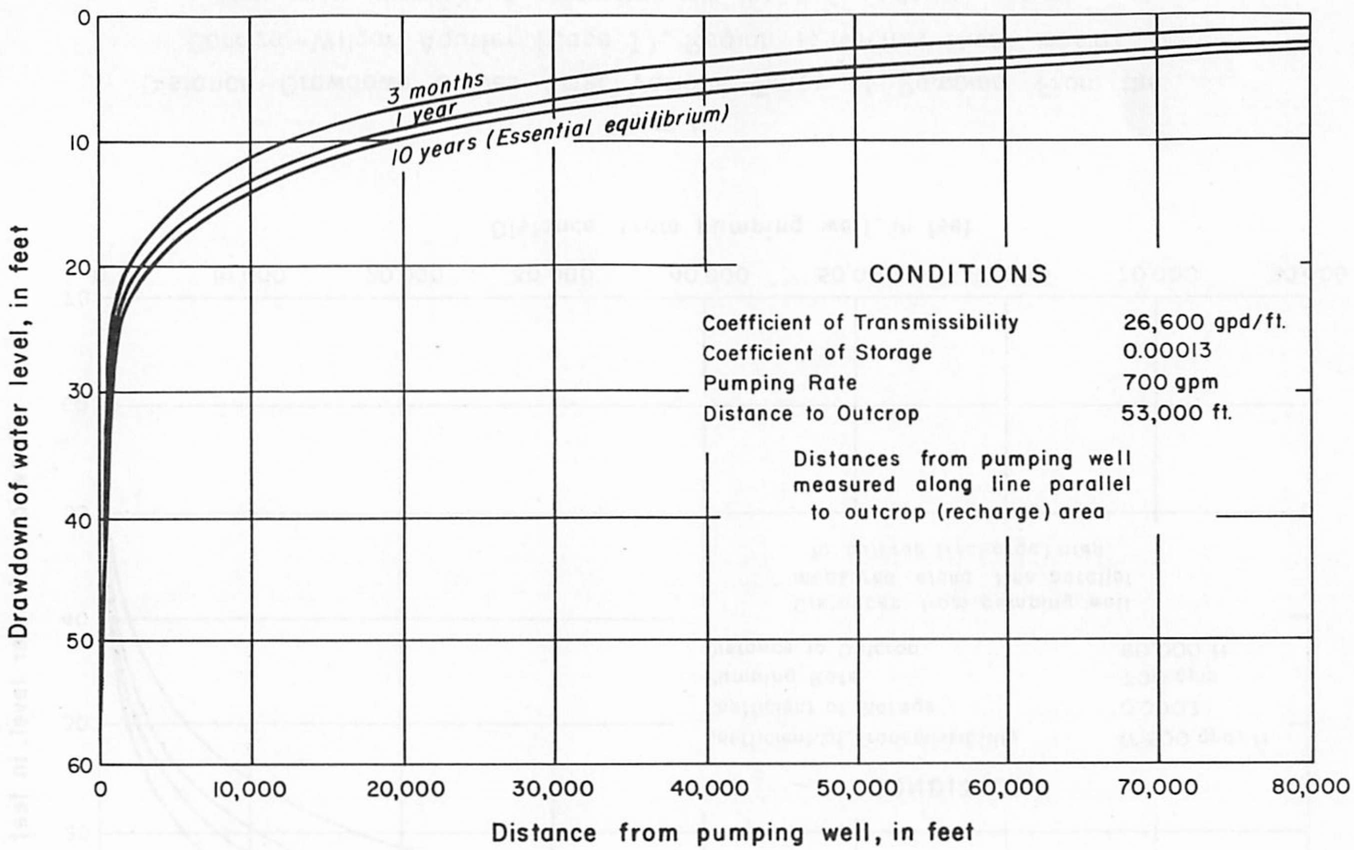

Figure 9

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

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Table 2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, Neches 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											
34-34-601	Willard Sides	451	3-22-61	23	1.6	17	1.8	36	115	15	12	0.2	0.0	162	50	61	2.2	261	7.1
[2] 34-43-501	Lone Star Gas	795	10-26-55	20	.2	1.4	.3	128	285	8	28	--	--	489	--	--	--	--	8.5
[3] 34-46-502	City of Tyler	1,042	8-26-54	16	2.6	23	8.0	44	92	48	43	.2	.4	225	91	--	--	--	7.5
[2] 34-55-903	City of Troup	1,100	10- -57	14	.4	12	.3	374	746	--	130	--	--	1,307	--	--	--	1,537	8.5
34-61-601	C. L. Newberne	745	7-31-61	11	.2	1.5	.3	55	126	11	--	.3	0	148	5	96	11	246	7.3
[3] 35-50-906	City of Henderson #2	752	11- 3-59	--	.76	2	<1	99	249	15	10	.1	< .4	261	5	---	--	435	8.7
37-02-201	J. H. Walker	144	7- 6-61	18	4.6	16	2.8	5.4 1.6	58	8.4	5.0	.2	0	87	51	18	.3	136	5.8
37-10-402	City of Cushing	320	6-15-44	21	1.0	12	4.3	8.0 2.2	16	37	11	.2	.2	115	48	--	--	--	6.8
[2] 37-11-802	Nacogdoches Ind.	[4] 765-779	2-12-60	20	.5	2	.3	333	866	0	13	--	--	1,170	6	--	--	1,200	8.7
[2]	Foundation test	[4] 1,105-1,126	2-13-60	23	.6	.5	.1	418	1,057	0	30	--	--	1,449	2	--	--	1,565	8.7
[2]	hole; Caro Town-	[4] 1,350-1,370	2-16-60	14	4.0	4.0	1.7	704	1,079	0	470	--	--	2,226	17	--	--	--	8.5
[2]	site, Nacogdoches County	[4] 1,465-1,485	2-17-60	14	3.6	2.0	1.0	842	1,098	0	665	--	--	2,556	9	--	--	3,515	8.55
37-13-401	City of Garrison #1	340	9- 4-44	15	.08	2.2	.5	157 1.8	391	7.0	14	.2	2.2	399	8	--	--	--	8.4
37-20-101	Appleby Water Co.	303	6- 3-61	23	.63	.5	1.4	3.1 1.4	7	3.6	3.5	.2	.4	40	7	43	.5	36.5	5.9
37-26-401	Ben Stripling	530	6- 2-61	10	.62	6.2	2.8	92	183	58	12	.2	.0	271	27	88	7.7	449	9.1
37-27-304	City of Nacogdoches #4	548	11-28-51	13	.13	1.6	1.4	50 .4	102	21	7.8	.2	1.5	152	10	--	--	240	6.8
37-28-801	DeWitts Hatchery	520	8- 1-61	12	.04	.8	.0	151	361	20	8.0	.6	.5	371	2	99	46	609	7.9
37-29-202	J. O. Justice	270	7- 5-61	19	3.2	12	5.3	109	273	48	11	.1	.0	338	52	82	6.6	547	7.1
37-32-702	City of San Augustine #2	560	5- 6-42	13	1.0	.4	.9	385	980	20	10	1.1	.0	931	4	--	--	--	--
[2] 37-33-202	City of Wells	[4] 880-958	6-18-55	--	.3	3.0	1	154	326	49	18	--	--	581	11.6	--	--	--	8.95
37-34-501	USAF Radar Sta.	1,277	5-12-60	14	1.0	.8	0	187	313	118	20	.3	--	494	2	100	--	786	8.3
37-35-503	Southland Paper	1,050	8- 1-61	14	.05	.2	0	118	226	52	12	.3	0	308	0	100	73	503	8.0
37-38-501	Ray Horton	510	3- 6-61	11	.4	2.0	.1	368	796	0	109	--	--	881	6	99	65	1,470	8.6
37-44-801	City of Huntington test well	[4] 1,772-1,797	7- 3-59	16	1.5	3	1	677	804	--	580	--	--	2,066	11	--	--	3,080	8.7
38-05-401	W. T. Todd	720	4-21-49	12	.2	5.6	2.1	321 4.8	618	.7	163	.9	.8	847	22	--	--	1,420	8.3
38-05-903	Humble O. & R.	350	7-31-61	11	.16	.8	0	80	186	9.4	9.8	.2	--	202	2	99	25	338	7.6

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

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3) [1]	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
38-06-303	City of Jacksonville #1	[4] 623-645	10-31-48	18	0.2	2.0	0.6	167.5	431	0.0	11.0	--	--	633.7	7.5	--	--	--	--
38-15-602	City of Rusk #2	750	7-31-61	11	.04	.8	0	190	399	55	21	.5	0	474	2	100	58	772	8.1
[2] 38-20-103	Calhoun Packing Plant	764	12-17-56	--	.8	4.5	1.5	62.7	159	11.3	8	--	--	285	17	--	--	--	7.1
38-24-802	City of Alto #2	545	7-31-61	12	.05	1.0	0	264	586	3.2	64	.7	0	633	2	100	81	1,060	8.1
38-37-103	City of Grapeland #3	783	11- -46	10	.06	5	2	129	--	29	21	.2	< .04	333	21	--	--	--	7.6

Queen City Aquifer

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
34-52-502	Central High School	71	5- 1-61	31	0.02	24	9.1	107 12	34	38	189	0.1	15	486	98	67	4.7	815	5.4
34-62-901	E. Hendricks	[4] 248-290 [4] 329-366	7-29-61	41	3.0	3.2	5.0	12	10	31	10	.1	0	107	29	48	1.0	119	4.7
37-26-601	M. L. Christopher	272	7- 5-61	11	.04	1.5	.7	227	508	51	17	1.4	3.5	563	6	99	40	908	7.8
38-04-801	C. D. Davis	90+	7-12-60	22	1.2	52	20	48 5.9	25	36	168	.1	28	392	212	32	1.4	738	6.1
38-11-905	Palestine Ice Co.	381	4-21-49	20	24.0	21	12	21 4.4	57	48	42	.1	.2	234	102	--	--	350	6.2
38-29-603	O. C. Daniels	250	7-25-61	28	2.4	17	7.8	44	121	47	15	.2	.0	219	74	56	2.2	338	6.5
38-31-401	Mission State Park	43	7-24-61	35	.07	13	5.3	13	35	4.6	26	.1	16	130	54	35	.8	182	6.0
38-32-201	H. A. Lindsey	245	7-29-61	18	1.9	30	10	48	200	13	30	.2	.2	248	116	47	1.9	414	6.7

Sparta Aquifer

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
[2] 34-46-205	Richardson Co.	220	5-25-45	--	0.5	4	2.4	21	18	6.7	28	--	--	192	20	--	--	--	6.1
37-34-502	Central School	464	3- 7-61	11	.10	3.5	.9	435 3.0	572	336	110	1.1	0	1,180	12	98	55	1,880	8.1
37-35-404	I. W. Sowell	348	5-10-61	11	.12	1.2	.6	418	918	0.0	108	3.1	.5	993	6	99	74	1,640	8.0
37-37-801	A. H. Munk	492	6- 2-61	14	.23	.2	.3	177	446	.0	12	1.4	.5	424	2	100	54	712	8.1
37-38-401	Plus-Tex Poultry	165	6- 2-61	16	--	4.2	2.3	113	161	109	12	.6	2.0	338	20	92	11	543	7.0
37-39-901	Bill Goynes	210	3- 7-61	21	.1	0	0	95	196	23	16	--	.0	251	0	100	--	396	8.4
[2] 37-44-801	City of Huntington	[4] 1,153-1,178	7-25-59	16	.1	116	63	5,433	464	--	8,500	--	--	14,596	549	--	--	24,500	7.9
37-47-301	Lonnie Skinner	250	3- 7-61	11	.09	1.2	.1	319	780	22	24	--	--	761	4	99	69	1,230	8.5
38-29-401	Travis Mosely	109	7-13-60	24	.32	5.0	1.9	15	13	.4	14	.0	28	94	20	62	1.5	137	6.0
38-32-901	Mrs. C. A. Odom	298	7-28-61	25	.05	.5	0	78	164	21	10	.2	0	216	1	99	34	341	6.7

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

penetrate the Wilcox part of the aquifer. The Carrizo furnishes an adequate water supply and, in most instances, contains water of superior quality to that of the underlying Wilcox sands.

In and near the outcrop, sands of the Wilcox Group furnish water that is soft, relatively low in mineral content, and suitable for most purposes. The water is high in bicarbonates and locally has objectionable amounts of iron. The Wilcox sands in some places have lignite stringers and, where present, these may impart an undesirable color to the water. The water in the Wilcox becomes more mineralized downdip from the outcrop and also with depth. At a given locality, deeper sand bodies may be expected to carry more mineralized water than those nearer the surface. Four analyses of water taken at different depth intervals from a test hole in northern Nacogdoches County illustrate the typical decline in the quality of water with depth (See Table 2, well 37-11-802).

The sand of the Carrizo, unlike the lenticular sands of the Wilcox, is a more or less uniform massive continuous sand which permits the free percolation and circulation of ground water. Ground water in the Carrizo Formation is soft and of the bicarbonate type. In and near the outcrop the iron content is commonly very high and locally hydrogen sulphide gas gives the water of the Carrizo Formation a disagreeable odor. The Carrizo part of the aquifer varies in quality from place to place. In and near the outcrop the water is very soft and very low in mineral content and in many instances contains less than 100 ppm dissolved solids. (See Table 2, wells 37-02-201 and 37-20-101.) Downdip from the outcrop, the mineral content of water in the Carrizo Formation gradually increases. A test well drilled in the city of Huntington in Angelina County, 28 miles downdip from the outcrop, showed the Carrizo to contain a mineral concentration of 2,066 ppm dissolved solids. (See Table 2, well 37-44-801.) Electric logs indicate that the Carrizo may carry fresh water as far downdip as southern Angelina and northern Trinity Counties. The approximate downdip extent of water containing less than 3,000 ppm dissolved solids is shown on Plates 4 and 5. The approximate downdip extent of water which contains less than 3,000 ppm dissolved solids was determined from a study of numerous electric logs of oil tests and water wells. The accuracy of the method used in calculating dissolved solids from electric logs is limited. Therefore, the location of the 3,000 ppm dissolved solids line should be viewed only as an approximation and not as absolute.

Salt-water contamination of the Carrizo-Wilcox aquifer appears to be a significant problem in some areas of Region I. A large number of oil and gas fields as well as innumerable test holes are located in the region. Improperly cased and plugged wells are a potential threat to fresh water-bearing formations. In addition, improper disposal of industrial wastes, especially disposal of brine into unlined open pits, is a potential source of contamination to fresh ground-water supplies.

The location of wells, from which the representative analyses listed in Table 2 were obtained, may be determined by use of one of the gridded maps, such as Plate 1, and use of the well numbers explained earlier in this report.

Utilization and Development

The Carrizo-Wilcox is the most important aquifer in Region I. Most of the larger municipalities and industries of the region obtain their ground water from this aquifer.

The size of the wells vary according to need. The large municipal and industrial wells have surface casing ranging from 20 inches to 16 inches in diameter with an inside liner ranging in size from 12-3/4 to 8-5/8 inches in diameter. Wells supplying the small industries and municipalities usually have surface casing 10-3/4 inches in diameter with inside liners ranging from 6-5/8 to 4-1/2 inches in diameter. All of the known major wells in the region have screen set opposite the producing horizons. The amount of screen in the municipal and industrial wells ranges from 210 feet to as little as 40 feet. Most major wells are underreamed and gravel walled, and their surface casings are cemented to prevent the entry of poor quality water from other formations.

The performance of the wells is as varied as their sizes. Specific capacities range from 30 gpm per foot of drawdown to less than 1 gpm per foot of drawdown. The quantity of water produced by the municipal and industrial wells of Region I ranges between 100 and 1,200 gpm.

Table 3 lists the reported 1960 pumpage from the Carrizo-Wilcox aquifer for municipal, industrial, and irrigation purposes, by major drainage subdivisions. Table 3 shows that 31,937 acre-feet of ground water was pumped from the aquifer for municipal, industrial, and irrigation purposes. Of this total, 20,691 acre-feet or about 65 percent was pumped for industrial purposes. The table further shows that 11,222 acre-feet was pumped for municipal purposes and only 24 acre-feet was pumped for irrigation purposes. The location of the municipal, industrial, and irrigation wells and the major drainage subdivisions are shown on Plate 1.

Little is known about the early history of development of the Carrizo-Wilcox aquifer, but it is known that the most extensive development has taken place in the past 25 years. Most of the industrial and many of the municipal wells now operating have been drilled since 1940. Most of the present pumpage from the Carrizo-Wilcox aquifer occurs in the western part of subdivision 13 where more than 23,000 acre-feet of water is pumped annually for municipal and industrial purposes. The remainder of the pumpage is distributed throughout the region. The largest single development of ground water in the Carrizo-Wilcox aquifer has been by the Southland Paper Mills in northern Angelina and southern Nacogdoches Counties. This development, consisting of 14 production wells, was started in 1939 with 5 wells and increased to 9 wells in 1947. Five more wells were drilled in 1956 and 1957.

At the present time, most of the development of the Wilcox part of the aquifer has taken place on or very near the outcrop areas. Downdip from the Wilcox outcrop, the Wilcox is practically undeveloped because of the superior quality and larger quantities of water obtainable from the Carrizo Formation. The largest amount of water pumped from the Carrizo-Wilcox aquifer at the present time is pumped from the Carrizo part of the aquifer.

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

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

Subdivision	1	3	4	5	6	8	9	11	12	13	Total
Carrizo-Wilcox Aquifer											
Municipal	964	1,422	1,089	192	--	1,586	1,282	--	77	4,610	11,222
Industrial	609	214	--	--	--	52	511	--	--	19,305	20,691
Irrigation	--	24	--	--	--	--	--	--	--	--	24
Total	1,573	1,660	1,089	192	--	1,638	1,793	--	77	23,915	31,937
Gulf Coast Aquifer											
Industrial	--	--	--	--	--	--	--	--	--	133 [4]	133
Total	--	--	--	--	--	--	--	--	--	133	133
Queen City Aquifer											
Municipal	--	3	--	--	--	--	--	--	--	--	3
Industrial	1,120	6	--	--	--	--	--	--	--	--	1,126
Irrigation	--	--	84	--	--	--	--	--	--	--	84
Total	1,120	9	84	--	--	--	--	--	--	--	1,213
Sparta Aquifer											
Municipal	--	57	--	--	--	--	--	--	--	--	57
Industrial	18	--	--	--	--	--	--	--	--	--	18
Total	18	57	--	--	--	--	--	--	--	--	75
Other Aquifers [3]											
Municipal	--	--	--	--	74	--	--	--	--	23	97
Industrial	--	--	--	--	585 [4]	--	--	--	--	167 [4]	751
Total	--	--	--	--	658	--	--	--	--	190	848
Summary of Pumpage in Region I											
Municipal	964	1,482	1,089	192	74	1,586	1,282	--	77	4,633	11,379
Industrial	1,747	220	--	--	584	52	511	--	--	19,605	22,719
Irrigation	--	24	84	--	--	--	--	--	--	--	108
Total	2,711	1,726	1,173	192	658	1,638	1,793	--	77	24,238	34,206

[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] Other aquifers include the Yegua Formation and Jackson Group.
[4] Includes water supplied to some municipalities by industry owned wells.

Ground Water Available for Development

The amount of water available 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 segment of 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 conditions it is estimated that on the order of 70,000 to 80,000 acre-feet of water per year is being discharged from the aquifer. Of this total, about 37,000 acre-feet per year is being discharged from the Carrizo Formation alone. Municipal, industrial, and irrigation pumpage accounts for about 32,000 acre-feet of the total discharge.

Approximately 2,600 square miles of the Carrizo-Wilcox outcrop in the Neches River Basin and in the adjoining Sabine and Trinity River Basins constitute the recharge area for the Carrizo-Wilcox aquifer in Region I. It is estimated that approximately 2,000 square miles of the recharge area occurs in the northeastern part of the Neches River Basin and in the adjoining Sabine River Basin on the crest of the Sabine uplift. The remaining 600 square miles of the outcrop or recharge area occurs in the extreme northwestern part of the Neches River Basin and in the adjoining Trinity River Basin.

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. Because of the aquifer's great thickness and extensive outcrop area, gradients that would be established between the outcrop and the line where the top of the Carrizo is 400 feet below the land surface, by the development of the entire aquifer, will vary greatly between the upper and lower sands of the aquifer. The lower sands of the Wilcox Group crop out at great distances from the assumed 400-foot line; therefore, their gradients will be low in comparison to the Carrizo Formation and the upper Wilcox sands. For the purpose of computing the quantity of water available under the assumed conditions, a gradient equal to the dip of the top of the aquifer was used for the Carrizo Formation. An average gradient between the dip of the top of the aquifer and the lowest sand was used for the Wilcox part of the aquifer. Under the foregoing assumed conditions, it is estimated that on the order of 200,000 acre-feet per year would be transmitted from the outcrop areas of the Carrizo-Wilcox aquifer to the areas of pumpage.

The outcrop areas from which recharge is supplied for pumpage from the aquifer cover about 1,200,000 acres. It would require less than 2 inches of recharge annually in the outcrop areas to supply the 200,000 acre-feet of water that can be transmitted by the aquifer under the assumed conditions of development. The actual quantity of recharge received by the aquifer is not known; however, it appears adequate to support the present and future withdrawals from the aquifer.

The above availability figure assumes development of the total sand thickness of the aquifer. While water containing up to 3,000 ppm dissolved solids is described 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.

In addition to the perennial yields supported by recharge, a considerable amount of water is available from storage. It is estimated that on the order of 40,000 to 50,000 acre-feet of water can be pumped from storage during development of the aquifer from the present to the assumed conditions. It must be emphasized, however, that development of water from storage is a one-time operation, since that water removed from storage is not recharged.

It should be emphasized that the quantity of water calculated to be available for development from the aquifer is for the entire basin and under assumed conditions. Although the quantity is large, it is possible to overdevelop the aquifer in local areas by intensive pumpage.

Secondary Aquifers

Queen City Aquifer

Geologic Characteristics

The Queen City Formation overlies the Reklaw Formation and underlies the Weches Formation. The Queen City consists of gray and brown, medium to very fine-grained micaceous sand with interbedded shale and sandy shale. Minor amounts of lignite and glauconitic sand layers occur locally within the formation. The formation ranges in thickness from 0 to 600 feet. The greatest thickness occurs in the East Texas syncline. Eastward from the area of the East Texas syncline, the formation thins and finally pinches out, loosing its identity as a geologic unit, in the eastern part of Nacogdoches and Angelina Counties. Water-bearing sands constitute between 25 and 85 percent of the Queen City's total thickness. Plate 6 is an isopachous map of the Queen City Formation which illustrates the thickness of the aquifer in Region I, where it contains water of 3,000 ppm or less dissolved solids.

The Queen City outcrop covers an extensive area of the northwest part of Region I. To the east, the outcrop becomes narrow and forms an eastward-trending belt across Nacogdoches County. The outcrop area ranges in width from zero in eastern Nacogdoches County to more than 40 miles in the trough of the East Texas syncline. There are numerous outliers of Weches and Sparta Formations in the Queen City outcrop area which are shown on Plate 1. With the exception of the large one in Smith County, the outliers of Weches and Sparta Formations are relatively thin and limited in extent. To more clearly illustrate the outcrop area of the Queen City aquifer, the outliers have been omitted on the Plates 6 and 7.

Downdip from the outcrop area, the formation strikes generally eastward and dips toward the Gulf Coast at approximately 60 to 70 feet per mile. Plate 7 shows the extent of the Queen City outcrop, the attitude of the top of the aquifer, and the downdip extent of water which contains less than 3,000 ppm dissolved solids.

The depth to the top of the Queen City aquifer in the Neches River Basin varies owing to topography and structure, and ranges from zero at the edge of the outcrop to more than 1,000 feet in southern Houston and northern Trinity Counties. The Queen City Formation extends to greater depths downdip, but does not contain water of usable quality. A geologic section along the axis of the Neches River Basin, shown on Plate 3, illustrates the general attitude of the aquifer and its thickness.

Occurrence and Movement of Ground Water

Water in the Queen City aquifer occurs under water-table and artesian conditions. In the outcrop, water in the Queen City aquifer occurs under water-table conditions. Downdip, however, the water is beneath a confining layer and is under artesian pressure. In the outcrop area, the movement of water is controlled largely by the elevation of the land surface. Therefore, the water in the Queen City aquifer moves from the basin boundaries toward the Neches River and its tributaries. Downdip where artesian conditions exist, the movement of ground water is generally in the direction of the dip of the formation.

Recharge and Discharge

Conditions controlling recharge of ground water to the Queen City aquifer are considered good. Annual rainfall in the region is large and evenly distributed throughout the year. Relief of the outcrop area is moderate, and the soils are generally loose, sandy, and well covered with vegetation. The recharge area in the Neches River Basin consists of more than 1,400 square miles.

Ground water is discharged from the aquifer naturally and artificially. Artificial discharge from the Queen City aquifer consists of pumpage from a few industrial, municipal, and irrigation wells, and a number of domestic and livestock wells in and near the outcrop. Only a few domestic and livestock wells are completed in the aquifer downdip from the outcrop. The greatest amount of water-supply development from the aquifer occurs in the outcrop where the water is under water-table conditions.

Water Levels

Depths to water in wells screening the Queen City aquifer are variable because of differences in the land surface topography and geologic structure, and range from a few feet to about 150 feet below the land surface. Variations in the amount of rainfall in the outcrop, as well as evapotranspiration, cause some fluctuations in the water level. Larger fluctuations in water levels may be expected in areas immediately adjacent to wells which screen the aquifer because of variations in pumping rates.

There is little past data on water levels in the Queen City aquifer; however, it is doubtful that water levels have changed much over the years except for minor natural fluctuations.

Water-Bearing Characteristics

Since few wells screen the Queen City aquifer in the Neches River Basin, little can be determined about the aquifer's water-bearing characteristics; however, available data indicate that the aquifer has only fair to poor hydrologic characteristics. Pumping tests on two wells in Smith County showed the aquifer to have coefficients of transmissibility of 3,000 and 3,100 gpd/ft., and a coefficient of permeability of 10 to 30 gpd/ft^2. Coefficients of transmissibility reported from tests in the adjoining Trinity and Sabine River Basins ranged from 2,500 to 12,700 gpd/ft. Coefficients of transmissibility of the Queen City aquifer in the Neches River Basin can be expected to vary widely because of the differences in the sand thickness of the aquifer. The largest coefficients of transmissibility can be expected in the area of the East Texas syncline where the formation is thickest. The smaller values can be expected in the eastern part of the basin where the Queen City Formation becomes thin and finally looses its identity as a separate stratigraphic unit. The coefficients of permeability, which are independent of the aquifer's sand thickness, can be expected to range from 10 to 165 gpd/ft^2. It is believed that a coefficient of permeability of 50 gpd/ft.^{2} probably would be representative for the aquifer as a whole. Higher coefficients of transmissibilities than were obtained on the pumping tests can be expected if the entire thickness of the Queen City sands is screened in those areas where the aquifer is thickest.

Figure 10 is a distance-drawdown graph which shows the amount that water levels would be lowered at various distances from a pumped well after the well has been pumped for various periods of time. The assumed values of coefficients of transmissibility and storage, and the rate of pumpage that were used in constructing the distance-drawdown graph are believed to be typical of wells screening the Queen City aquifer in the Neches River Basin. The distances on the distance-drawdown graph were measured along a line parallel with the outcrop and passing through the pumped well. The pumped well is located approximately 8 miles from the outcrop and pumps at a rate of 200 gpm.

Chemical Quality

Analyses of water samples from the Queen City aquifer indicate that water of reasonably good quality can be obtained from the aquifer in and near the outcrop. Table 2 lists analyses from 8 wells which screen the Queen City aquifer.

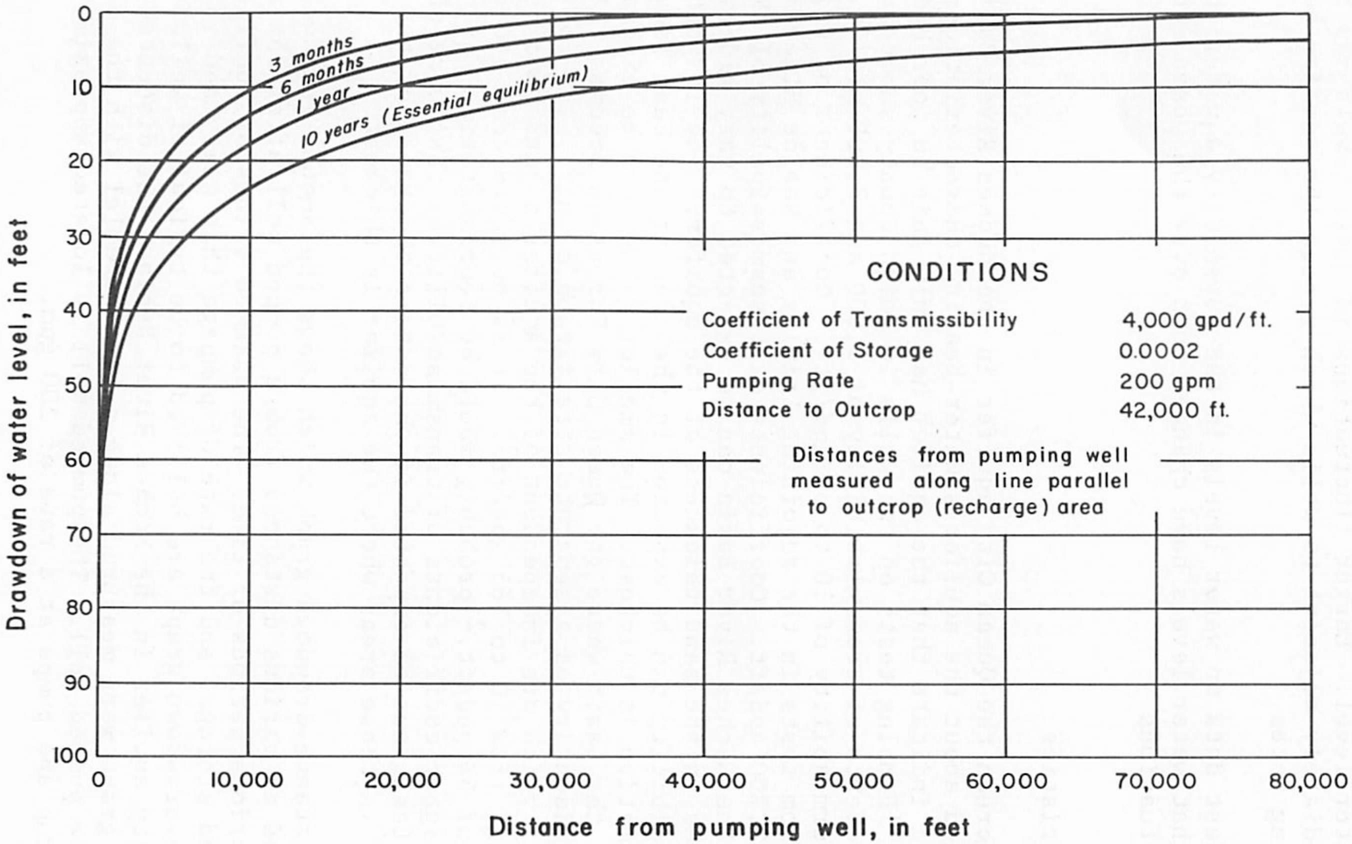

Figure 10

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

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All of these analyses are from wells in or very near the outcrop. Even though the total dissolved solids are not excessive, in many cases a combination of high iron content, low pH, and free carbon dioxide makes the water undesirable for many uses. These factors appear to be widespread throughout the outcrop, causing people in the outcrop to consider this aquifer for a water supply only if there is nothing better available. Analysis of water from well 38-11-905 listed in the table of analyses shows an iron content of 24 ppm. This iron content is very high and may be due to water entering the well from the overlying Weches Formation which has an extremely high iron content. The low pH of the water indicates that the water is acidic and will tend to be corrosive. The quality of the water from the Queen City aquifer, however, can be improved by simple treatment methods.

Little is known about the quality of water downdip from the outcrop since few wells screen the formation downdip from the outcrop. The approximate downdip extent of water containing 3,000 ppm or less dissolved solids was determined by interpretation of electric logs. A well formerly completed in the Queen City Formation, located in northern Angelina County, was reported by W. N. White, et al. (1941, p. 37) to have yielded highly mineralized water containing 780 ppm bicarbonate and 1,400 ppm chloride.

Some of the shallow wells in the outcrop also contain nitrate in amounts slightly over the recommended limit. It is common to find shallow wells that have high nitrate content, which indicates possible pollution from surface sources.

Utilization and Development

Development of the Queen City aquifer by wells is small. Two irrigation, two industrial, and two public-supply wells constitute the major development of the aquifer in the Neches River Basin. One of the industrial wells is located in the vicinity of Tyler and the other in the vicinity of Palestine. The two wells used for irrigation purposes are located just off the outcrop in northern Houston County. The major pumpage from the Queen City aquifer in Region I of the Neches River Basin totals 1,213 acre-feet per year. The largest part of this pumpage is industrial and occurs in the vicinity of Tyler. The total industrial pumpage is 1,126 acre-feet per year, irrigation pumpage is 84 acre-feet per year, and municipal pumpage amounts to only 3 acre-feet per year. Pumpage from the Queen City aquifer in 1960 is presented by major drainage subdivisions in Table 3. In addition, there are a large number of domestic and livestock wells which screen the Queen City aquifer in and near the outcrop. The affects of pumpage in the Queen City sands is small, and probably natural discharge exceeds pumpage.

The size of the casing in the major wells ranges from 10 to 6 inches in diameter. The size of domestic and livestock wells ranges from 2 inches in drilled wells to 48 inches in dug wells. The depth of the wells varies as greatly as their size, ranging from a few feet in the case of hand dug wells to as much as 600 feet in some of the drilled wells. The thickness of the formation screened ranges from 20 to 165 feet. The amount of screen placed in a well depends on the water requirement of the owner and the amount of sand section present in the formation. The yields of the wells range from a few gallons to 400 gpm and the specific capacities range from less than 1 to 9.4 gpm per foot of drawdown.

Because of the low transmissibilities of the Queen City sands, large drawdowns are required to obtain large amounts of water. Where large quantities of water are required, care should be taken that individual wells and well fields are properly spaced so as to avoid severe water-level declines in local areas. It appears that the Queen City aquifer in the Neches River Basin is capable of supplying water for small municipalities and industries in and near the outcrop.

Ground Water Available for Development

The estimate of water available for development from the Queen City aquifer is based on pumpage under assumed conditions and is related to the ability of the aquifer to transmit water from the outcrop to areas of pumpage. It is assumed that the effect of pumping is such that the static water level is drawn down to the top of the aquifer where its depth is 400 feet below the land surface. The gradient thus established determines the amount of water that will move through the aquifer. Under the assumed conditions, it is estimated that approximately 10,000 acre-feet of water would be transmitted annually from the outcrop to the areas of pumpage. This relatively small quantity of water is due to the generally low permeability of the sands. The largest quantity of water moving through the aquifer would occur in the westernmost part of the basin where the Queen City aquifer is the thickest. In Angelina County and the eastern part of Nacogdoches County, the sand thickness of the Queen City Formation is only a few feet and contributes very little to the overall quantity of water moving downdip.

The Queen City Formation crops out over a rather extensive area in Region I of the Neches River Basin, especially in the East Texas syncline area. The area of recharge is about 1,400 square miles or 896,000 acres. Less than 1 inch of recharge annually would be required to supply the 10,000 acre-feet of water that could be transmitted by the aquifer under the assumed conditions of development. Recharge to the Queen City aquifer appears to be more than adequate to supply this quantity of water. Therefore, it is believed that large quantities of additional water would be available for development in the outcrop area.

The most promising area for future development is in the western part of Region I where the aquifer is thickest and consequently transmissibilities are the greatest. Also, the development potential in or very near the outcrop appears to be best since analyses and electric logs indicate that the water becomes highly mineralized short distances downdip from the outcrop. Quality of the water may be a limiting factor in the development of the aquifer because of the rather high iron content and low pH which commonly occur in the aquifer. However, simple treatment methods are available which can improve the water quality.

Sparta Aquifer

Geologic Characteristics

The Sparta Formation consists chiefly of unconsolidated, fine to medium-grained sand, gray to buff in color. The sand in the lower part of the formation is more massive than in the upper part which is interbedded with lenses of clay and shale. Small particles of carbonaceous material are common throughout the formation and small amounts of glauconite occur locally.

The Sparta Formation crops out in an irregular eastward-trending belt across southern Nacogdoches and Cherokee Counties, northern Angelina and Houston Counties, and central San Augustine County in Region I of the Neches River Basin. The outcrop varies in width from 3 to 15 miles and covers an area of approximately 550 square miles. Downdip from the outcrop area the Sparta dips toward the south and southeast at a rate ranging from 60 to 100 feet per mile. Numerous outliers, parts of the formation separated from the main body of the formation by erosion, occur north of the main outcrop area. These outliers are most numerous and extensive in Cherokee, Anderson and Smith Counties. The largest of these outliers occurs in the western portion of Smith County and covers an area of approximately 240 miles. Plate 1, the geology map, shows the location of the Sparta outcrop and its relation to the outcrops of other geologic formations in Region I. The general attitude of the formation, the approximate depths to the top of the Sparta aquifer below the land surface, and the geographic extent of the area in which the formation contains ground water of usable quality are shown on Plate 8.

The thickness of the Sparta Formation in the outcrop ranges from zero at the Sparta-Weches contact to about 260 feet. Downdip from the outcrop, the formation ranges in thickness from about 260 to 345 feet. Water-bearing sand makes up 60 to 70 percent of the formation's total thickness. Plate 9 is an isopachous map which shows the thickness of the Sparta aquifer in the Neches River Basin. Plate 3, a geologic section along the axis of the Neches River Basin, illustrates the aquifer's thickness and attitude and the position of usable water in the aquifer.

Occurrence and Movement of Ground Water

In the outcrop of the Sparta Formation, including the numerous Sparta outliers, the water occurs under water-table conditions; immediately downdip from the outcrop, water occurs under artesian conditions. The outcrop area of the Sparta aquifer is shown on Plates 8 and 9.

A number of water levels measured in wells screening the Sparta aquifer indicate that the water occurring under artesian conditions is moving south and southeast down the dip of the formation. The water-level gradient ranges from about 4 to 8 feet per mile.

Recharge and Discharge

The Sparta aquifer is recharged by precipitation falling on its outcrop. Conditions in the Sparta outcrop appear to be very favorable for recharge to the aquifer. The amount and distribution of rainfall, size of the intake area, moderate relief, and loose, sandy soils favor maximum recharge to aquifer.

Natural discharge occurs at springs and seeps and by evapotranspiration in the outcrop area. Downdip, natural discharge takes place by interformational leakage. Artificial discharge from the Sparta aquifer occurs at a few municipal and industrial wells, and numerous small domestic and livestock wells. In addition, a number of flowing wells located in southern Nacogdoches and northern Angelina Counties discharge water from the Sparta sand.

Water Levels

The depth at which water stands in wells which screen the Sparta aquifer in Region I ranges from about 10 feet above the land surface to about 300 feet below land surface. The great differences in depths to water primarily are due to the differences in surface elevations. Water levels less than 200 feet below land surface may be expected in the Sparta aquifer over most of the area. Some wells which penetrated the aquifer in the Angelina River Valley of northern Angelina County and southern Nacogdoches County flow. Pumpage from wells which screen the aquifer have little affect on water levels in the region because the pumpage is small. Water-level fluctuations are small and are due primarily to varying rates of recharge in the outcrop area.

Water-Bearing Characteristics

Presently available data indicate that water-bearing characteristics of the Sparta aquifer are highly variable throughout Region I.

A number of pumping tests were conducted by the Southland Paper Mills in 1942 and 1943 at several locations in northern Angelina County and southern Nacogdoches County. The data from the tests were analyzed by the U. S. Geological Survey (Guyton and Rose, 1943). Although some of these tests did not screen the entire Sparta aquifer, it is estimated that the coefficients of transmissibility of the entire aquifer will range from about 3,200 gpd/ft. to 58,000 gpd/ft. and the coefficients of storage range from 0.00026 to 0.00052.

A pumping test run on a well screening the Sparta Formation in the vicinity of Tyler in Smith County showed the Sparta to have a coefficient of transmissibility of 10,900 gpd/ft. This test was conducted on a well which screened one of the more extensive outliers of the Sparta Formation and is not connected with the main body of the Sparta Formation. Coefficients of transmissibility obtained from pumping tests conducted on wells screening the Sparta aquifer in the adjoining Trinity River Basin ranged from 16,500 gpd/ft. to 21,000 gpd/ft. These wells however, did not screen the entire thickness of the aquifer. Therefore, coefficients of transmissibility for the entire aquifer thickness probably would be as high as 40,000 gpd/ft. in some places.

Figure 11 is a distance-drawdown graph showing the amount water levels would be lowered at different distances from a pumped well along a line passing through the pumped well and parallel with the outcrop, after pumping the well for various periods of time. For the purpose of constructing the graph, a coefficient of transmissibility of 20,000 gpd/ft. and a coefficient of storage of 0.0002 was used. A pumping rate of 700 gpm and a distance of 8 miles from the pumped well to the outcrop were also assumed. The aquifer coefficients used in constructing the distance-drawdown graph are believed to be representative of the Sparta aquifer where the total sand section of the aquifer has been screened.

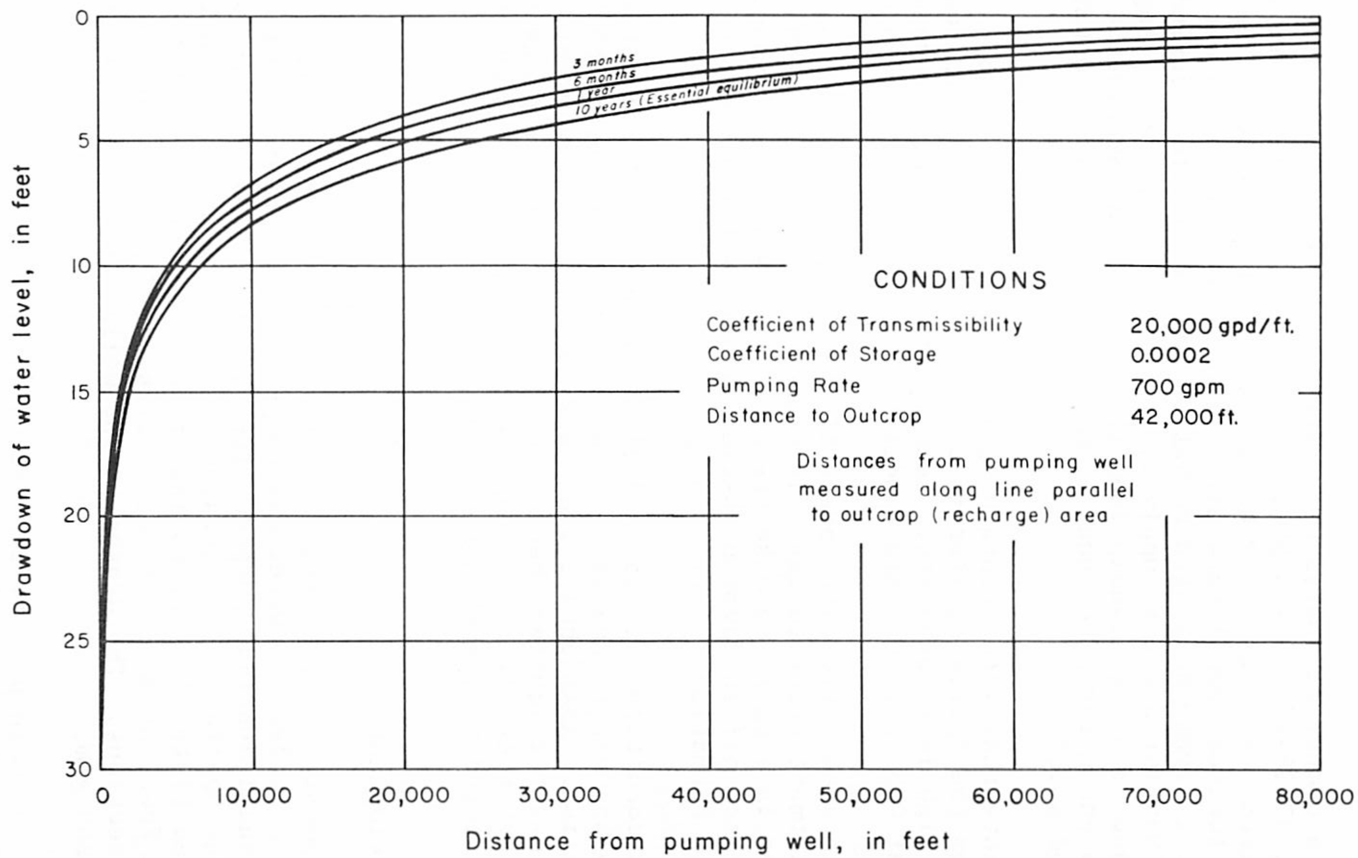

Figure 11

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

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Chemical Quality

Chemical analyses indicate that water low in mineral content, suitable for most purposes, may be obtained from the Sparta aquifer in and near the outcrop. However, in relatively short distances downdip water of marginal and unsuitable quality is encountered.

Table 2 lists a number of analyses of water from the Sparta aquifer. Wells numbered 34-46-205, 37-38-401, 37-39-901, 38-29-401, and 38-32-901 are located in or near the outcrop. The remainder of the wells, with the exception of number 37-44-801, are located from 1 to 4 miles from the outcrop. The water taken from well 37-44-801 is from the Sparta Formation and was obtained during exploratory drilling in 1959 for a water supply at the city of Huntington, Angelina County, located about 13 miles downdip from the outcrop. At Huntington, the Sparta Formation is encountered at about 1,060 feet and the water contains 14,596 ppm dissolved solids.

Analyses indicate that water containing less than 500 ppm dissolved solids may be expected from the Sparta aquifer in and near the outcrop. The water is generally soft and high in bicarbonate. Locally, the iron content exceeds the recommended limit of 0.3 ppm, but this condition does not seem to be widespread.

As far as it is known, the water presently being used from the Sparta aquifer receives no treatment prior to use. In those areas where the chemical quality of Sparta water is such as to make treatment necessary, the formation has been bypassed and cased off in favor of better quality water present in the deeper-lying Carrizo Formation.

Under present conditions, it is unlikely that the quality of water in the Sparta will undergo any marked changes. No obvious areas of future contamination are known to exist. Abandoned oil and gas test holes are commonly a potential threat to fresh-water aquifers because of possible improper plugging and inadequate casing, but there is no evidence that the water quality of the Sparta aquifer is being affected from such a source at the present time.

Utilization and Development

Present development of the Sparta aquifer is small in the Neches River Basin. A total of 75 acre-feet of water was pumped from the Sparta aquifer in 1960 for municipal and industrial purposes (See Table 3). All of this water was pumped from the large Sparta outlier located in Smith County in the northern part of Region I (See Plate 1). The casing of the major wells is 10 to 6 inches in diameter, and 50 feet, or more, of screen or slotted pipe is set opposite the producing sand sections. The depths of the wells range up to 200 feet and yields range up to 280 gpm.

Development of the main part of the Sparta aquifer is confined to small domestic and livestock wells. A well screening the Sparta aquifer formerly supplied water for the city of Wells in southern Cherokee County, but this well was abandoned and destroyed when a Carrizo well was drilled to supply the town.

There are numerous flowing Sparta wells along the Angelina River Valley in southern Nacogdoches and northern Angelina Counties. The flow from individual wells is usually small, ranging from 2 to 4 gpm. A portion of this water is piped into cisterns, chicken houses, and livestock ponds, but for the most part is wasted in that it is allowed to flow into nearby streams.

Ground Water Available for Development

Because of wide variations in the water-bearing properties of the Sparta Formation in relatively short distances, it is difficult to estimate the availability of water. However, it is believed, on the basis of data available, that a coefficient of transmissibility of 20,000 gpd/ft. is representative of the aquifer as a whole.

If the estimated coefficient of transmissibility of 20,000 gpd/ft. is representative of the aquifer, then under the present water-level gradients about 7,000 acre-feet of water per year is being discharged from the aquifer. The rate of flow through the aquifer would be increased with an increase in pumpage downdip, because the added pumpage would cause steeper water-level gradients. Using the gradient that would be established by development under the assumed conditions of pumpage, it is estimated that on the order of 60,000 to 70,000 acre-feet of water per year would be transmitted from the outcrop to the areas of pumping, providing recharge is sufficient to supply this much water.

The recharge area of the Sparta aquifer is about 550 square miles or 352,000 acres. Less than 0.3 inch of recharge in the Sparta outcrop is required to support present discharge from the aquifer. Under the assumed conditions of development postulated above, it would require less than 3 inches of recharge per year to supply the quantity of water that the aquifer is capable of transmitting. The amount of recharge received by the aquifer is not known, but the conditions in the Sparta outcrop are such that it does not appear unreasonable to assume that sufficient recharge would be available to support the assumed conditions of development.

In addition to the perennially available water, it is estimated that 10,000 to 20,000 acre-feet of water could be obtained from storage during the development of the aquifer from present to the assumed conditions. This quantity would not be replenished, however, and would not constitute part of the perennial yield.

In addition to the quantity of water available for development from the main body of the Sparta aquifer, large outliers of the Sparta Formation also are capable of yielding water. The most extensive of these outliers, located in the northern part of Region I in the western part of Smith County, covers approximately 240 square miles or 153,600 acres. A large part of this Sparta outlier is relatively thin and is not favorable for development; therefore, future development of this part of the aquifer should take place in the thicker part of the outlier and wells should be properly spaced in order to achieve optimum development.

Other Aquifers

Yegua Formation

The Yegua Formation crops out in an eastward-trending belt across central San Augustine and Angelina, southern Houston, and northern Trinity Counties, varying in width from 9 to 16 miles (See Plate 1). The formation ranges in thickness from zero at the Yegua-Cook Mountain contact to 1,100 feet in the southernmost part of Region I. The formation dips toward the Gulf Coast at a rate of about 60 to 80 feet per mile. The formation is composed of a sequence of fine to medium-grained, poorly sorted, lenticular sand, sandy shale, chocolate colored shale and a few beds of limestone. Stringers of lignite and bentonite occur locally. Approximately 40 to 50 percent of the Yegua's total thickness consists of water-bearing sand.

Conditions in the outcrop which affect recharge are generally good. The outcrop area of the Yegua Formation covers about 800 square miles in the Neches River Basin, and hence the recharge area is extensive. The relief is relatively low and, where the sand units outcrop, the soils are generally a loose sandy loam.

In general, ground water in the outcrop area of the Yegua occurs under water-table conditions, whereas artesian conditions exist downdip. Because of the lenticular nature of the water-bearing sands interbedded with shales, local artesian conditions also occur in the outcrop area. Water that has percolated to the zone of saturation generally moves in the direction of the structural dip of the formation in response to the hydraulic gradient. Natural discharge takes place in the Yegua outcrop in the form of springs, seeps, and transpiration. Artificial discharge takes place at the numerous wells which screen the aquifer in and near the outcrop. Some of the major points of discharge occur at the cities of Diboll, Pineland, Huntington, Keltys, and the community of Herty, where water wells screening the Yegua sands supply industrial and municipal needs.

The depths to water levels in wells screening the aquifer in and near the Yegua Formation outcrop range from 0 to 260 feet below the land surface. Long-term records are not available to determine the effects of pumpage on the aquifer's water levels. The quantity of water pumped is relatively small and it is not believed that water levels are being adversely affected by pumping. Water levels indicate, however, that cones of depression have developed in the areas of intensive pumpage.

Pumping-test data on a well located at the city of Huntington indicate that the permeability of the Yegua sands is very low. The tested well screened seven separate sand bodies totaling 100 feet in thickness. The pumping test indicated that the coefficient of transmissibility of the screened sands was 1,600 gpd/ft. and the coefficient of permeability was 16 gpd/ft^2. The tested well is located in the Yegua outcrop and screens only a part of the formation's total thickness. Downdip from the outcrop area, the full thickness of the Yegua Formation ranges from about 950 to 1,100 feet. If the coefficient of permeability of the sand in the city of Huntington well is indicative of the formation as a whole, the coefficient of transmissibility of the full thickness of the Yegua Formation would be on the order of 8,000 gpd/ft. It must be emphasized, however, that a single test is highly inadequate to determine the production potential of the Yegua Formation. Tests in other localities may prove the aquifer to be either more, or less favorable for the development of ground-water supplies.

The chemical quality of water obtained from the Yegua Formation varies from place to place and with depth. As a general rule, the deeper sands will contain water that is more mineralized than shallower sands at a given location. Little is known about the quality of water downdip from the outcrop, but it presumably becomes increasingly more mineralized away from the outcrop. Chemical analyses indicate that the mineral content of water in the Yegua Formation in and near the outcrop ranges from 300 to 1,500 ppm dissolved solids. Generally the water is high in bicarbonate, has a pH greater than 7, and locally is high in iron and chloride. In local areas, the water has a low pH and tends to be corrosive. Water that is suitable for municipal and most industrial purposes may be found in and near the Yegua outcrop. Locally, however, water is not suitable for either purpose, even in the outcrop, and there appears to be no way of predicting the quality of water that will be encountered in a given locality prior to drilling and testing.

In the Neches River Basin, the Yegua Formation furnishes water for several small municipalities and industries, all of which are located in or very near the outcrop area. The municipal and industrial wells range in size from 14 to 6-5/8 inches in diameter. The total amount of screen in each well ranges from 20 to 115 feet. The sand layers of the Yegua Formation are relatively thin and commonly the screen is set in several separate sections so as to screen several sands.

As a general rule the specific capacities of the wells are low, ranging from 0.3 to 10.5 gpm per foot of drawdown, with the majority of the wells having a specific capacity of 0.3 to 6 gpm per foot of drawdown. In 1960, 788 acre-feet of water was reported pumped from the Yegua Formation to supply municipal and industrial needs. The greater part of this pumpage was used to supply the cities of Pineland, Diboll, and Keltys, and the large lumbering industries associated with these communities. The city of Huntington, the community of Herty, and a number of small industries accounted for the remainder of the pumpage from the Yegua Formation.

At the present time, data on the water-bearing characteristics of the Yegua Formation is insufficient to allow a proper evaluation of the aquifer's development potential. Several factors indicate that the amount of water available for development is limited. The formation has a considerable sand thickness, but it is made up of a large number of relatively thin beds. Consequently, many of the municipal and industrial wells completed in the Yegua are required to screen several sands. The yields of the individual sand beds are apparently small. Wells screening the formation have been reported to produce as much as 800 gpm, but most major wells presently produce less than 300 gpm. In addition to low yields which may be expected from the Yegua Formation, the chemical quality of the water may be a limiting factor to the development of the formation.

Future development will probably be limited to or near the outcrop since the water becomes increasingly more mineralized downdip. The expense of screening a large number of thin sands will be considerable where large quantities of water are desired or required. Before any large development takes place, extensive test drilling should be undertaken so as to determine the most favorable localities for development of the aquifer. The sands of the Yegua Formation are very important as a source of ground-water supply since they occur over an extensive area in which there is no other ground water available. Some of the more productive aquifers of the region occur at greater depths, but their waters are more mineralized than the water from the Yegua Formation in the area where the Yegua contains usable water.

Jackson Group

The Jackson Group is exposed in an outcrop 12 to 16 miles in width across southern Sabine, San Augustine, Angelina, and Trinity Counties, and northern Polk, Tyler, and Jasper Counties of Region I. The Jackson consists of shale, sandy shale, sand, and a few thin beds of limestone. The thickness of the Jackson Group ranges from zero at the Jackson-Yegua contact to more than 1,200 feet downdip.

The Jackson Group supplies water to numerous livestock and domestic wells in the outcrop area. The city of Corrigan, located in northern Polk County, in the southern part of Region I, derives its water supply from the Jackson Group. The 1960 pumpage for this municipality was about 60 acre-feet.

Chemical analyses indicate that the dissolved solids content of water taken from wells in the outcrop range from 450 to more than 3,000 ppm.

The Jackson Group is important as a source of water in and near its outcrop because it is located in a part of the region in which no other suitable ground water is available. Although the Jackson Group is capable of supplying small quantities of water, its development potential is believed to be 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. None of the aquifers in Region II are classified as secondary. An aquifer which may yield small to moderate quantities of water locally is the Jackson Group which crops out in the extreme northern part of Region II and the southern part of Region I.

The statements and data on the following pages are a general summary of conditions occurring in Region II. 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 dip toward the Gulf Coast at about 50 to 60 feet per mile. The Catahoula Sandstone, consisting of sand, clay, silt, tuff, volcanic ash, and in places fuller's earth, is the basal formation of this unit. Extensive cementing of the sand reduces the potential ground-water storage, movement, and production of the Catahoula. The Oakville Sandstone which overlies the Catahoula is a massive, light-colored sand or sandstone interbedded with gray or yellow clay and silt. The Lagarto Clay is predominantly a massive clay and sandy clay interbedded with sand and sandstone.

The Goliad Sand, Willis Sand, and Lissie Formation 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 1,200 feet and extend downdip to a depth of more than 2,800 feet below sea level in parts of Jasper and Tyler Counties. The water in the deeper sand beds of the Gulf Coast aquifer becomes progressively more mineralized downdip resulting in a sharp decrease in the total thickness of the fresh water-bearing sand in the southern part of Region II. These features are illustrated on Plates 3, 10, and 11. The contours shown on Plates 10 and 11 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 in the Gulf Coast aquifer was determined from a study of electric logs of oil tests in Region II.

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

Occurrence and Movement of Ground Water

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

Where water-table conditions 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 upwards 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 Neches 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 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 111 to 4,510 ppm. All of the public supplies of the region obtain ground water containing less than 900 ppm dissolved solids.

The quality of water in some parts of Region II, expecially 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 38,927 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 Neches River Basin. About 5,200 acre-feet per year of this is being pumped for irrigation purposes. Pumpage for public supplies and industry total 2,643 and 31,084 acre-feet per year respectively.

The greatest development of underground water in Region II occurs in the southern part of the region in major drainage subdivisions 18 and 19 where all of the industrial and irrigation 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

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

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

Analysis No. [1]	Location of well	Screened interval (ft.)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na + K)	Bicarbonate (HCO_3) [2]	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
5	Beaumont, Jefferson, County	[3] 494-612	21	0.46	64	30	1,660	286	2	2,590	0.2	--	4,510	283	43	--	--
14	In Jasper County 8 mi. E. Silsbee	[3] 716-1,328	18	.09	13	2.6	64 1.7	203	5.4	7.5	.3	0.0	213	43	4.2	342	7.8
16	Jasper, Jasper County	[3] 382-703	59	1.2	5.3	.6	8.1 4.3	25	12	3.5	.2	.3	111	16	.9	90	6.2
17	10 mi. S. Silsbee, Hardin County	?-804	14	.02	2.6	.4	133 .5	319	.8	25	.8	.0	336	8	20	562	7.9
18	20 mi. SW Silsbee, Hardin County	171-221	22	.37	--	--	196	238	4.0	190	.5	.2	529	42	13	985	7.8
19	20 mi. SW Silsbee, Hardin County	770-809	16	.57	--	--	396	511	5	330	3.6	.2	1,180	37	28	1,790	7.8
20	22 mi. SW Silsbee, Hardin County	166-186	--	--	11	1.9	144	232	4	108	.6	0	384	36	10	--	--
21	Silsbee, Hardin County	303-384	54	1.2	19	2.2	18 2.6	79	5.6	21	.0	.0	162	56	1.0	202	6.5
22	15 mi. W Silsbee, Hardin County	1,747-1,953	19	--	--	--	188	371	1	76	1.4	.2	458	8	29	810	8.6
23	22 mi. NW Silsbee, Hardin County	[3] 227-866	--	--	39	1.0	40	201	3	14	.1	0	196	101	1.7	--	--
24	5 mi. W Woodville, Tyler County	?-629	48	17	30	1.7	21	114	2	23	.1	.2	182	82	1.0	260	6.8
25	Woodville, Tyler, County	346-392	48	[4] .09	38	3.5	21	134	7.4	26	.0	.2	216	109	.9	292	7.9
26	10 mi. S Woodville, County	?-478	38	[4] .01	59	4.5	15 4.6	219	4.0	16	.0	.0	249	166	.5	384	7.4

[1] All analyses are from Wood, Gabrysch, and Marvin (1963).
[2] Includes equivalent of any carbonate (CO_3) present.
[3] Not screened throughout interval.
[4] Iron in solution at time of analysis.

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, Neches River Basin 1/

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

Subdivision	15	16	18	19	Total
Municipal	851	448	188	1,156	2,643
Industrial	--	--	1,143	29,941	31,084
Irrigation	--	--	5,200	--	5,200
Total	851	448	6,531	31,097	38,927

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

Approximately 39,000 acre-feet of water is presently being pumped from the Gulf Coast aquifer in the Neches River Basin. It is estimated that under maximum gradients about 123,000 acre-feet of water per year could be withdrawn from the aquifer, or 84,000 acre-feet could be produced perennially in addition to that presently being pumped providing sufficient recharge is available. 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.

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 Neches River Basin occupies approximately 52 percent of the area for which storage was calculated. Thus, it appears that approximately 15,700,000 acre-feet of ground water could be produced from storage in the Neches 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.

Other Aquifers

Jackson Group

The Jackson Group, consisting of a sequence of shale, sandy shale, sand, and a few thin beds of limestone, crops out over a small area in the extreme northern part of Region II (Plate 2).

The sands of the Jackson Group presently supply water to a number of small domestic and livestock wells in and near the outcrop in Region II. The quality of the water in and near the outcrop is highly variable and ranges from 500 to 3,000 ppm dissolved solids.

The Jackson Group is believed to be limited in its development potential, but may be capable of supplying water to small industries and communities where no better supply is available.

Summary of Ground-Water Pumpage and Availability

More than 73,000 acre-feet of ground water is presently being pumped annually from the aquifers of the Neches River Basin for municipal, industrial, and irrigation purposes. About 74 percent of this is pumped for industrial purposes, 19 percent for municipal purposes, and 7 percent for irrigation purposes. Pumpage from the two primary aquifers of the basin, the Carrizo-Wilcox of Region I and the Gulf Coast of Region II, accounted for 97 percent of the total pumpage in the basin in 1960. Pumpage for municipal, industrial, and irrigation purposes from the Carrizo-Wilcox and the Gulf Coast aquifers totals about 32,000 and 39,000 acre-feet respectively. Table 6 shows the distribution of pumpage in the basin by region, by use, and by aquifer.

On the order of 400,000 acre-feet of ground water is estimated to be available annually from the primary and secondary aquifers of the Neches River Basin. This figure 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.

In addition to the perennial yields, large quantities of water can be withdrawn from storage in the primary and secondary aquifers during development and the establishment of the assumed conditions of pumpage. Most of this water available from storage occurs in the Gulf Coast aquifer of Region II. However, water in storage is not available on a perennial basis and can be produced only once during development of the aquifers.

Additional quantities of water are available for development from "other" aquifers in the basin, but the amount is small in comparison to the primary and secondary aquifers. Also, additional quantities of water may be developed in the outcrop area of the various aquifers where more water is available as recharge than the aquifer is capable of transmitting to the areas of pumpage.

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

(Pumpage expressed in acre-feet 1/)

Aquifer 2/	Municipal	Industrial	Irrigation	Total
REGION I				
Carrizo-Wilcox (P)	11,222	20,691	24	31,937
Gulf Coast (P)	--	133	--	133
Queen City (S)	3	1,126	84	1,213
Sparta (S)	57	18	--	75
Others 3/	97	751	--	848
Subtotal	11,379	22,719	108	34,206
REGION II 4/				
Gulf Coast (P) 5/	2,643	31,084	5,200	38,927
Subtotal	2,643	31,084	5,200	38,927
TOTAL	14,022	53,803	5,308	73,133

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 Yegua Formation and Jackson Group.
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 Neches 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 two secondary aquifers 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 Neches River Basin, but should include the entire aquifers throughout their statewide extent.

In addition to the primary and secondary aquifers, investigations should be made in the basin on the Yegua Formation and Jackson Group to determine their development potential and to point out areas of possible development. Although the Yegua Formation and Jackson Group are believed to possess only a limited potential, they are present over an extensive area of the basin where no other source of ground water is available. A number of small industries and municipalities are dependent upon these aquifers, and this source of ground water should not be neglected.

Special, intensive ground-water studies should be made in the vicinity of municipalities and communities which derive their water supplies from ground-water sources.

The present water-level observation program in the basin is very inadequate and should be expanded as soon as possible. Additional 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 large 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 Neches River Basin which have been published by the Texas Water Commission (formerly Texas Board of Water Engineers) or the United States Geological Survey.

Area or District Reports

Geology and ground water resources in the Lufkin area, Texas, W. N. White, A. N. Sayre, and J. F. Heuser: Texas Board Water Engineers duplicated rept., 1938; U. S. Geol. Survey Water-Supply Paper 849-a, 1941.

County Reports

Cherokee

Records of wells, drillers' logs, and water analyses, and map showing location of wells in Cherokee County, Texas, G. H. Cromack, 1936: Texas Board Water Engineers duplicated rept.

Hardin

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

Henderson

Records of wells, drillers' logs, and water analyses, and map showing location of wells in Henderson County, Texas, W. M. Lyle, 1936: 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.

Jefferson

Water-well data, Jefferson County, Texas, Penn Livingston and G. H. Cromack, 1942: Texas Board Water Engineers duplicated rept.

Liberty

Ground water resources of Liberty County, Texas, W. H. Alexander, Jr., and S. D. Breeding, 1945: Texas Board Water Engineers duplicated rept.

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Nacogdoches

Records of wells, drillers' logs, and water analyses, and map showing location of wells in Nacogdoches County, Texas, G. H. Cromack, 1937: Texas Board Water Engineers duplicated rept.

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

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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 test of municipal wells at Tyler, Texas, W. L. Broadhurst, 1944: 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. Woods, 1956.

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Anderson

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Hardin

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