RECONNAISSANCE INVESTIGATIONS OF THE GROUND-WATER RESOURCES OF THE RIO GRANDE BASIN, TEXAS

TEXAS WATER COMMISSION

BULLETIN 6502

JULY 1965

TEXAS WATER COMMISSION

Joe D. Carter, Chairman
William E. Berger, Commissioner
O. F. Dent, Commissioner

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July 1965

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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 contains three reports, presenting the results of ground-water reconnaissance investigations in the upper, middle, and lower parts of the Rio Grande Basin in Texas. These reports have been published in a single volume in order to save time and cost in printing, thus facilitating the distribution of information contained herein to water-development planners and the general public, as well as affording a more composite view of ground-water resources in the entire basin in Texas. For convenience to the reader, the page, illustration, and table numbers of the upper basin report are coded with a prefix letter "U," those for the middle basin report are prefixed with "M," and those for the lower basin with "L." The reports for the upper and lower parts of the basin were prepared by personnel of the U. S. Geological Survey; the middle Rio Grande Basin report was prepared by personnel of the Texas Water Commission.

The reports in this bulletin provide a generalized evaluation of the ground-water conditions in the basin and point out areas where detailed studies and continuing observations are necessary. The additional studies will be required to provide estimates of the quantity of ground water available for development in smaller areas, to provide more information on changes in chemical quality that may affect the quantity of fresh water available for development, and to better determine the effects of present and future pumpage.

TEXAS WATER COMMISSION

Joe D. Carter

Joe D. Carter, Chairman

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE UPPER RIO GRANDE BASIN, TEXAS

By

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United States Geological Survey

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

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLES

ILLUSTRATIONS

Figures

TABLE OF CONTENTS (Cont'd.)

Plates
[All plates in pocket]

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE UPPER RIO GRANDE BASIN, TEXAS

ABSTRACT

The reconnaissance of the upper Rio Grande Basin was undertaken as part of a statewide program to provide estimates of the general order of magnitude of ground-water supplies potentially available from the principal water-bearing formations of Texas. The upper Rio Grande Basin, as defined for the study, occupies about 22,000 square miles wholly within Texas, extending along the Rio Grande from Anthony on the Texas-New Mexico state line to the Pecos River and from the western drainage divide of the Pecos River to the Rio Grande.

The upper Rio Grande Basin is part of the Trans-Pecos area of Texas and is characterized by complex geologic structures and mountainous terrain. The drainage generally is toward the Rio Grande except in the Salt Basin, which has no exterior drainage.

The upper Rio Grande Basin is in the arid climatic zone except for the mountainous areas in the eastern part, which are semiarid. Rainfall is insufficient for growing most crops without supplemental supplies of water, and irrigation is practiced extensively in the valley of the Rio Grande between Anthony and Redford, in La Mesa and Hueco bolsons, and in the Salt Basin.

The rocks cropping out in the basin range in age from Precambrian to Recent, almost all of the geologic systems being represented. However, only the alluvial and bolson deposits of Cenozoic age are primary aquifers; secondary aquifers in the basin include the Bone Spring and Victorio Peak Limestones, undifferentiated, the Marathon Limestone, the Trinity, Fredericksburg, and Washita Groups and equivalents, and igneous rocks.

The quality of ground water used in the basin ranges from fresh to moderately saline.

The largest supplies of fresh ground water, including a small proportion of slightly saline water, are in the bolson deposits near El Paso, which contain at least 9 million acre-feet of theoretically recoverable water in storage. An additional large volume is available in the bolson deposits in the southern part of the Salt Basin. Data were insufficient to determine the quantity of fresh water in the rest of the upper Rio Grande Basin, but it probably is relatively small. The alluvial deposits along the Rio Grande contain large volumes of slightly to moderately saline water. The volume of the water in storage is not known, but the recharge from infiltration of surface water applied to the land surface for irrigation is large.

In 1960, about 250,000 acre-feet of ground water, or about 220 million gallons per day, was pumped in the upper Rio Grande Basin. About 70 percent was for irrigation, 20 percent was for public supply, and 5 percent each for industry and for domestic and livestock purposes.

The most serious problem common to the areas where ground-water development is greatest is the declining water table. In these areas water is being "mined," denoting a serious problem of a decreasing supply of ground water in an area whose economy depends upon ground water. Associated with the decrease in ground water in storage is the possibility of contamination of the fresh-water supplies by saline water that overlies, underlies, or adjoins the fresh-water beds in the bolson deposits. On the other hand, the saline water represents a potential additional supply of water to be used either by mixing with the fresh water or by demineralization.

The lack of sufficient data hampers determination of the water budget for a large part of the upper Rio Grande Basin. It seems doubtful, however, that supplies approaching the magnitude of the fresh water known to be in storage are available in the other parts of the upper Rio Grande Basin.

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

INTRODUCTION

Purpose and Scope

The Texas Legislature, by the Texas Water Planning Act of 1957, created a Water Resources Planning Division within the Texas Board of Water Engineers (changed to Texas Water Commission, January 1962). The act directed the Board "To prepare and submit to the Legislature a Statewide report of the water resources of the State... and to make recommendations to the Legislature for the maximum development of the water resources of the State...." As a result, a report entitled, "Texas Water Resources Planning at the End of the Year 1958, A Progress Report to the Fifty-sixth Legislature," was prepared and states (Texas Board Water Engineers, 1958, p. 78), "...Initial planning for development of the State's water resources will require that reconnaissance groundwater studies be made in much of the State because time is not available to complete the recommended detailed investigations. Studies of this type will be made chiefly to determine the order of magnitude of the ground-water supplies potentially available from the principal water-bearing formations."

To implement the directive of the Legislature, the Texas Board of Water Engineers and the U. S. Geological Survey in September 1959 began a cooperative project entitled, "Reconnaissance ground-water investigations in Texas."

The Planning Division of the Texas Board of Water Engineers based its approach to water-resources development planning upon the needs and availability of water (both surface and ground) of each river basin and subdivision of a basin; therefore, the cooperative program between the Ground Water Branch of the U. S. Geological Survey and the Texas Board of Water Engineers was planned by major river basins also.

The reconnaissance studies of the river basins were designed to have their principal emphasis on the following items (Texas Board Water Engineers, 1958, p. 78):

1. Inventory of large wells and springs.

2. Compilation of readily available logs of wells and preparation of generalized cross sections and maps showing subsurface geology.

3. Inventory of major pumpage.

4. Pumping tests of principal water-bearing formations.

5. Measurements of water levels in selected wells.

6. Determination of areas of recharge and discharge.

7. Compilation of existing chemical analyses of water and sampling of selected wells and springs for additional analyses.

8. Correlation and generalized analysis of all data to determine the order of magnitude of supplies available from each major formation in the area and the general effects of future pumping.

9. Preparation of generalized reports on principal ground-water resources of each river basin.

Fieldwork in the upper Rio Grande Basin (Figure U1) was started in September 1959 and was completed in August 1961. The inventory of wells included locating all the public supply, industrial, and irrigation wells. The locations of the wells and selected domestic and livestock wells are shown on Plates U1 and U2. Complete data on individual irrigation wells were obtained on approximately 10 percent of the wells in areas of concentrated development. Electric logs of water, oil, and gas wells, along with water samples from 34 wells and springs that were collected and analyzed during the study, and several hundred other analyses that had been made before the study began were used in determining the extent of the fresh-water-bearing deposits. Pumping tests in about 20 wells were made to determine the water-bearing characteristics of the formations.

Location and Extent of the Area

The upper Rio Grande Basin, as defined in this report, lies wholly within Texas and extends southward along the Rio Grande from Anthony on the Texas-New Mexico state line nearly to the Pecos River and from the Rio Grande eastward to the western margin of the Pecos River drainage area; it also includes the Salt Basin. The area contains all or parts of 9 counties and encompasses about 22,000 square miles. Most of the area lies between latitude 29° and 32°N and longitude 102° and 107°W.

Economic Development

The upper Rio Grande Basin occupies about 8 percent of the area of Texas, but has only slightly more than 3 percent of the population of the State, about 331,000. More than 314,000 people or 95 percent of the total are in El Paso County; 276,617 resided in the city of El Paso in 1960.

The economy of the basin is diversified. In areas where the rugged terrain precludes farming, the principal industry is the raising of beef cattle, goats, and sheep. Farming is practiced primarily in several widely scattered areas where water for irrigation is available.

According to the U. S. Census of Agriculture (U. S. Bureau of the Census, 1959, p. 174-193), about 98,000 acres was irrigated in the basin in 1959, of

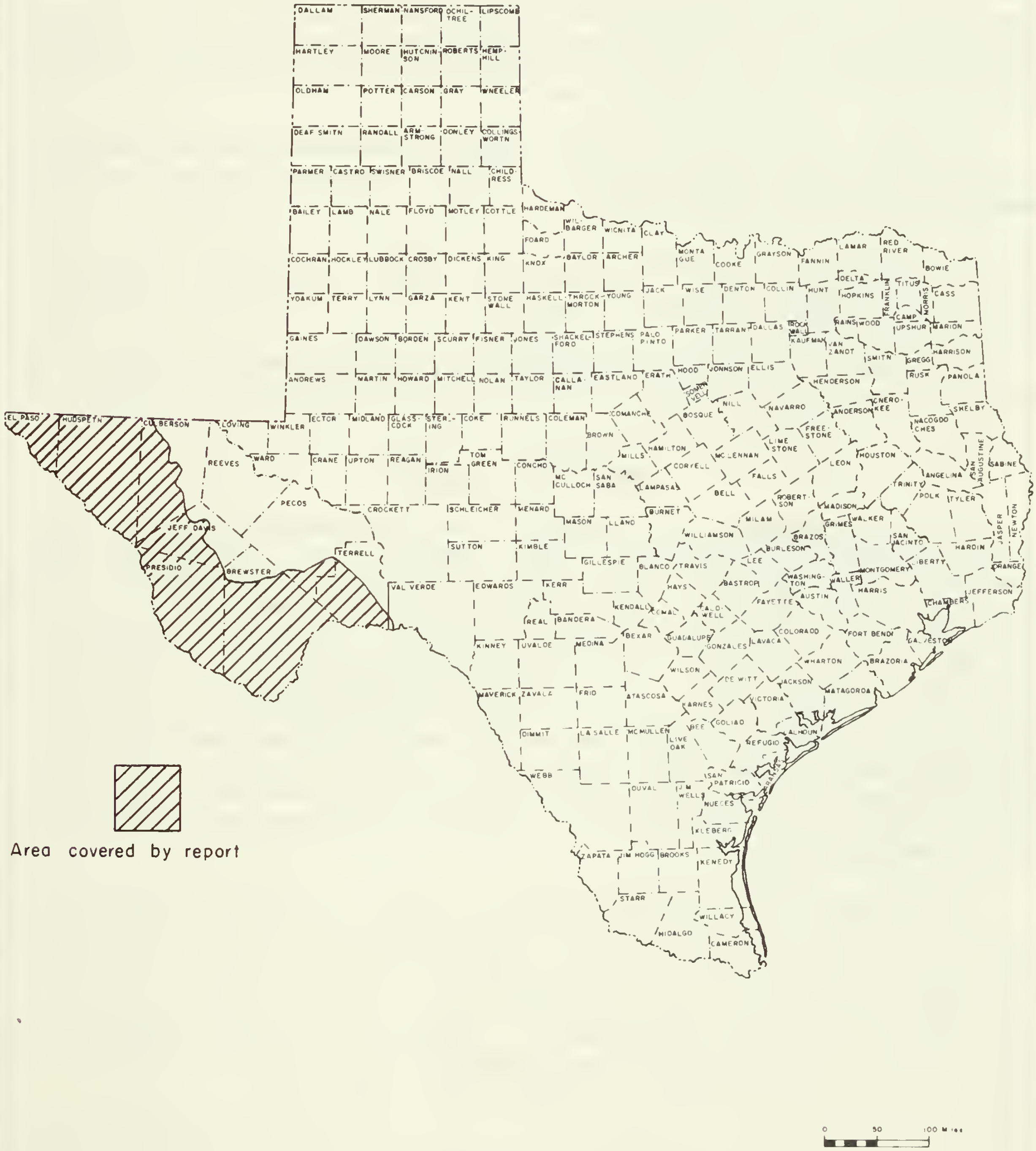


Figure UI

Map of Texas Showing the Location of the Upper Rio Grande Basin

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

which nearly 60,000 acres was in the long narrow valley of the Rio Grande between Anthony and Fort Quitman (Plate U1). In the area, which includes the El Paso Valley and a part of the lower Mesilla Valley, irrigation water is obtained primarily from the Rio Grande except where surface water rights are not available. In the Hudspeth County part of the valley, irrigation water is obtained from wells, but excess surface water from El Paso County is used when it is available in the river. Another intensively irrigated area is in the Salt Basin, which extends from near Dell City in northeastern Hudspeth County southward to a divide near Valentine in Jeff Davis County. In this area in 1960, approximately 30,000 acres of cotton, alfalfa, and truck crops was irrigated by wells. In the valley of the Rio Grande between Candelaria and Redford, about 5,300 acres was irrigated in 1960.

Industry in the upper Rio Grande Basin is concentrated in El Paso and includes primary smelting and refining of ores, petroleum refining, and building materials and apparel manufacture.

The defense establishments, such as Fort Bliss and Biggs Air Force Base at El Paso and the White Sands Proving Grounds nearby in New Mexico, contribute much to the economy of the El Paso area.

The upper Rio Grande Basin is served by air, rail, and bus lines and hundreds of miles of paved Federal and State highways and secondary roads.

Previous Investigations

Previous investigations of the ground-water resources in the upper Rio Grande Basin have been confined to small specific areas. Harrington (1890) discussed briefly the ground water in the El Paso Valley and on the mesa northeast of El Paso. Richardson (1904) discussed in more detail the occurrence of ground water in the upper Rio Grande Basin north of the Texas and Pacific Railway, which is that part of the basin lying roughly north of a line through Sierra Blanca and Van Horn. Slichter (1905) reported on the ground-water conditions in the vicinity of El Paso. Further investigations were not made until 1935, when a cooperative program was started among the Texas Board of Water Engineers, the U. S. Geological Survey, and the city of El Paso. Since then detailed reports concerned primarily with ground water have been published at intervals (Sayre and Livingston, 1945; Knowles and Kennedy, 1958; and Leggat, Lowry, and Hood, 1962).

Other reports discuss the development of ground water for irrigation in the Dell City area in Hudspeth County (Scalapino, 1950); the Lobo Flats area in Culberson and Jeff Davis Counties (Hood and Scalapino, 1951); the geology and ground-water resources in the vicinity of Alpine (Littleton and Audsley, 1957), Marathon (DeCook, 1961), and Marfa (Davis, 1961). Numerous other short reports (see Selected References) in addition to progress reports have been published and many reports covering small areas are in the open files of the U. S. Geological Survey and the Texas Water Commission.

Acknowledgments

The writers acknowledge the cooperation of the many well owners, well drillers, government officials, and consulting firms who so generously supplied information upon which this report is based.

Well-Numbering System

The numbers assigned to wells and springs in the report conform to the statewide system used by the Texas Water Commission. The system is based on the division of Texas into 1-degree quadrangles bounded by lines of latitude and longitude. Each 1-degree quadrangle is divided into 64 smaller quadrangles, $7\frac{1}{2}$ minutes on a side, each of which is further divided into 9 quadrangles, $2\frac{1}{2}$ minutes on a side. Each of the 89 1-degree quadrangles in the State has been assigned a 2-digit number for identification (Figure U2). The $7\frac{1}{2}$-minute quadrangles are given 2-digit numbers consecutively from left to right beginning in the upper left-hand corner of the 1-degree quadrangle, and the $2\frac{1}{2}$-minute quadrangles within each $7\frac{1}{2}$-minute quadrangle are similarly numbered with 1-digit numbers. Each well inventoried in each $2\frac{1}{2}$-minute quadrangle is assigned a 2-digit number. The well number is determined as follows: From left to right, the first 2 numbers identify the 1-degree quadrangle, the next 2 numbers identify the $7\frac{1}{2}$-minute quadrangle, the fifth number identifies the $2\frac{1}{2}$-minute quadrangle, and the last 2 numbers designate the well within the $2\frac{1}{2}$-minute quadrangle.

In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for the nine counties that are all or partly in the upper Rio Grande Basin are as follows:

County	Prefix	County	Prefix
Brewster	BK	Pecos	US
Culberson	HL	Presidio	UW
El Paso	JL	Terrell	XX
Hudspeth	PD	Val Verde	YR
Jeff Davis	PS		

In the report only the degrees of latitude and longitude are shown on the maps; the $7\frac{1}{2}$-minute and $2\frac{1}{2}$-minute lines are not shown as they would obscure other details. However, a well whose number is known can be located by identifying the 1-degree quadrangle from Figure U2 and using the degree lines on the individual well maps. Similarly, a well located on a map can be identified approximately by dividing a 1-degree quadrangle into $7\frac{1}{2}$-minute and $2\frac{1}{2}$-minute quadrangles.

GEOGRAPHY

Physiography

The upper Rio Grande Basin lies within the Mexican Highland and Sacramento sections of the Basin and Range physiographic province and on the Edwards Plateau section of the Great Plains province as designated by Fenneman (1931, pl. 1); the basin is a part of the generally applied regional term Trans-Pecos Texas. Characteristically, the basin is a region of mountains and canyons and stretches of plateau plain and bolson between two relatively broad valleys--the

Rio Grande on the west and the Pecos River on the east. In general, the mountain ranges trend south and southeast and are separated by parallel belts of lowlands or bolsons. The mountains are irregular in shape, "Some...are really plateaus, deeply dissected by erosion in some of their marginal areas; others are asymmetrical ranges, or cuestas, with a steep scarp on one side and gentle slope on the other, others are more or less isolated peaks or ridges, some places grouped together more or less irregularly..." (Baker, 1934, p. 137).

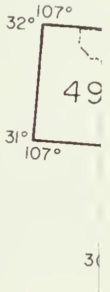
In general, the northern part of the basin, which is entirely within the Basin and Range province, can be divided into three relatively mountainous areas separated by elongated lowlands; from west to east these features are the Mesilla Valley or La Mesa bolson, the Franklin Mountains, the Hueco bolson, the Diablo Plateau including the Hueco and Finlay Mountains, the Salt Basin, and the Guadalupe-Delaware-Apache Mountain chain, which roughly forms the east edge of the basin (Plate U1). The mountains and basins are formed by faulting, the basins being partly filled with material eroded from the highlands. The highest of the mountains is Guadalupe Peak in the Guadalupe Mountains (8,751 feet), which rises nearly 5,000 feet above the floor of the adjoining Salt Basin.

The Hueco bolson, the largest of the intermontane lowlands, separates the Franklin and Hueco Mountains and extends from a low transverse divide a few miles north of the state line in New Mexico southward into Mexico southwest of the Quitman Mountains. The Salt Basin, which is a depressed fault block, is one of the most extensive intermontane basins in the region, extending from within a short distance of the Rio Grande north of the Chinati Mountains northward into New Mexico (Plate U1).

In the southern part of the upper Rio Grande Basin, the mountains are "...closely allied with the northeastern Mexico province of overfolds and overthrusts towards the east-northeast" (Baker, 1934, p. 211). In general, the mountains in this part of the basin are lower and are characterized by an abundance of intrusive igneous and volcanic rocks. These rocks, which form the mountains, typically have been tilted, flexed, and strongly folded in places. The Davis Mountains are the most extensive of the volcanic mountains. South of the Davis Mountains are several groups of mountains made up chiefly of volcanic rocks. Of these, the Chisos Mountains in Big Bend National Park consists of a group of sharp peaks, rising to an altitude of 7,835 feet, or nearly 6,500 feet above the Rio Grande.

Along the east side of Big Bend National Park and extending northwestward are the Sierra del Carmen, Santiago, and Del Norte Mountains, which represent the easternmost range of conspicuous summits in the upper Rio Grande Basin. The Sierra del Carmen continues southward into Mexico, although it is cut by the Rio Grande in a series of deep canyons below Boquillas. East of this range of mountains in the southeastern part of the basin, the main topographic feature is the Stockton Plateau (Fenneman, 1931, p. 47), which is a part of the Great Plains province. The plateau, which is cut by deep canyons, is a westward extension of the Edwards Plateau, it being separated from the Edwards Plateau by the Pecos River.

Extending southward from the Diablo Plateau and roughly paralleling the Salt Basin on the west are several mountains of unlike origin, consisting of solitary peaks, low mountains, areas of elevated plateaus, buttes, cuestas, and volcanic necks and dikes. They include the Carrizo, Van Horn, and Tierra Vieja Mountains.


32°
107°
49
31°
107°

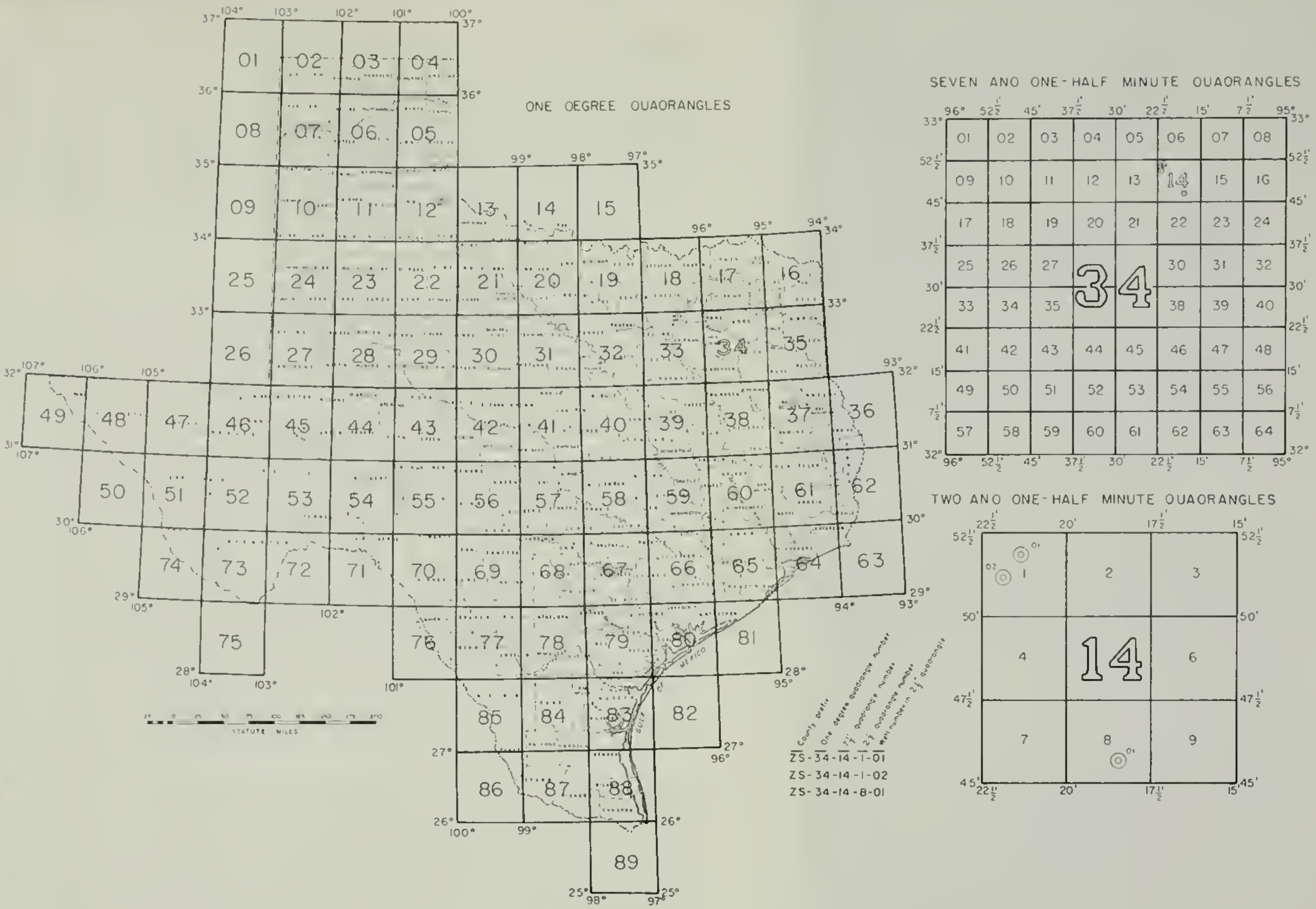


Figure U2

Map of Texas Showing the Well-Numbering System Used by the Texas Water Commission

U S Geological Survey in cooperation with the Texas Water Commission

Extending northwest of the Tierra Vieja Mountains are the Eagle, Quitman, and Malone Mountains, which are a part of the Mexican overthrust province (Baker, 1934, p. 156), and the Finlay Mountains.

The Rio Grande, the only through flowing stream in the report area, forms a continuous border on the west and south. All other streams in the area are ephemeral.

In general, vegetation in the upper Rio Grande Basin is scanty, consisting chiefly of desert grasses and shrubs. On the higher elevations, the greater rainfall maintains a moderate grass cover and a sparse growth of trees, which includes both eastern and Rocky Mountain varieties of oak and pine. In the Rio Grande Valley, cottonwood, willow, salt cedar, and mesquite are abundant.

Climate

The climate of the upper Rio Grande Basin is typical of the arid and semi-arid parts of the southwestern United States. The days generally are warm and the nights are cool. In the late winter and spring, high winds and blowing sand and dust are common, although the sandstorms are less frequent in the southeastern part of the basin.

According to Thornthwaite (1952, p. 32), the basin is predominantly in the arid zone except for the mountainous areas in the eastern part, which are classified as semiarid. In both of the zones moisture is deficient; the moisture deficiency index, which is based on a comparison of potential evapotranspiration and precipitation, ranges between 40 and 60 in the arid zone and between 20 and 40 in the semiarid zone.

Precipitation in the basin is low, generally averaging less than 12 inches a year except in the mountainous areas where it is greater (Figure U3). Most of the precipitation falls in thundershowers during the summer months, about 60 percent of the average annual precipitation occurring during the months of June through September. The average monthly precipitation at El Paso, Van Horn, Presidio, and Alpine, which is 23 miles east of Marfa, is shown in Figure U4. The average annual precipitation at these stations ranged from 8.39 inches at Presidio to 15.50 inches at Alpine. Although most of the precipitation is during the summer, it generally is insufficient for growing most crops without supplemental supplies of water.

The low relative humidity and, consequently, high rate of evaporation are characteristic of the basin. Relatively long-term records of evaporation rates are available only for the Ysleta station near El Paso. Although the station is in the most arid part of the basin, evaporation rates measured there are probably of the correct order of magnitude for the upper Rio Grande Basin. Evaporation from a U. S. Weather Bureau Class A pan at Ysleta for the period 1953-60 averaged 99 inches (Figure U5), or about 10 times the average annual precipitation. Figure U5 shows that evaporation is greatest in June but is less in July when the precipitation is greater.

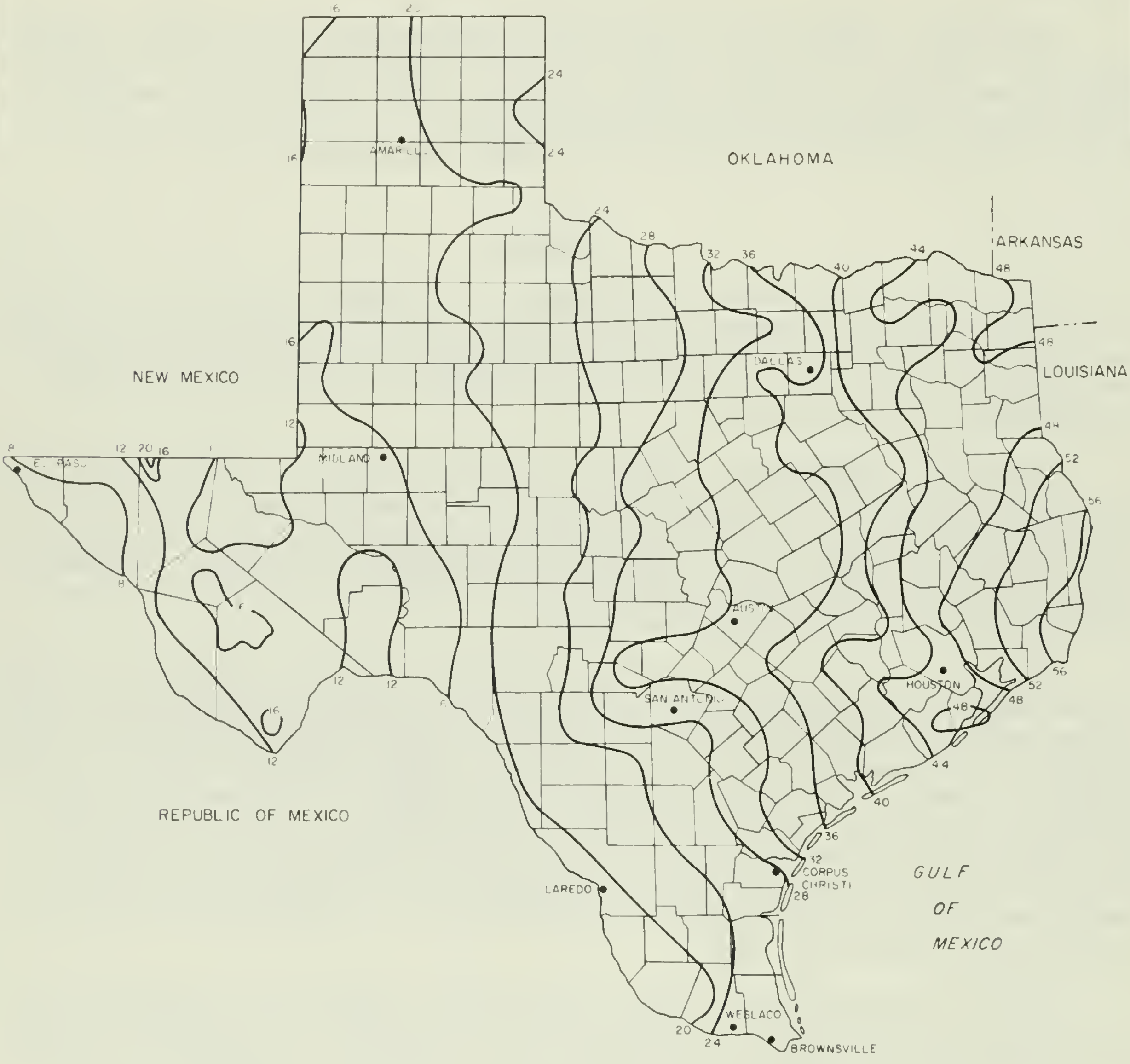


Figure U3
Map of Texas Showing Mean Annual Precipitation, in Inches, Based on the Period 1931-55
(After map prepared by U. S. Weather Bureau)

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

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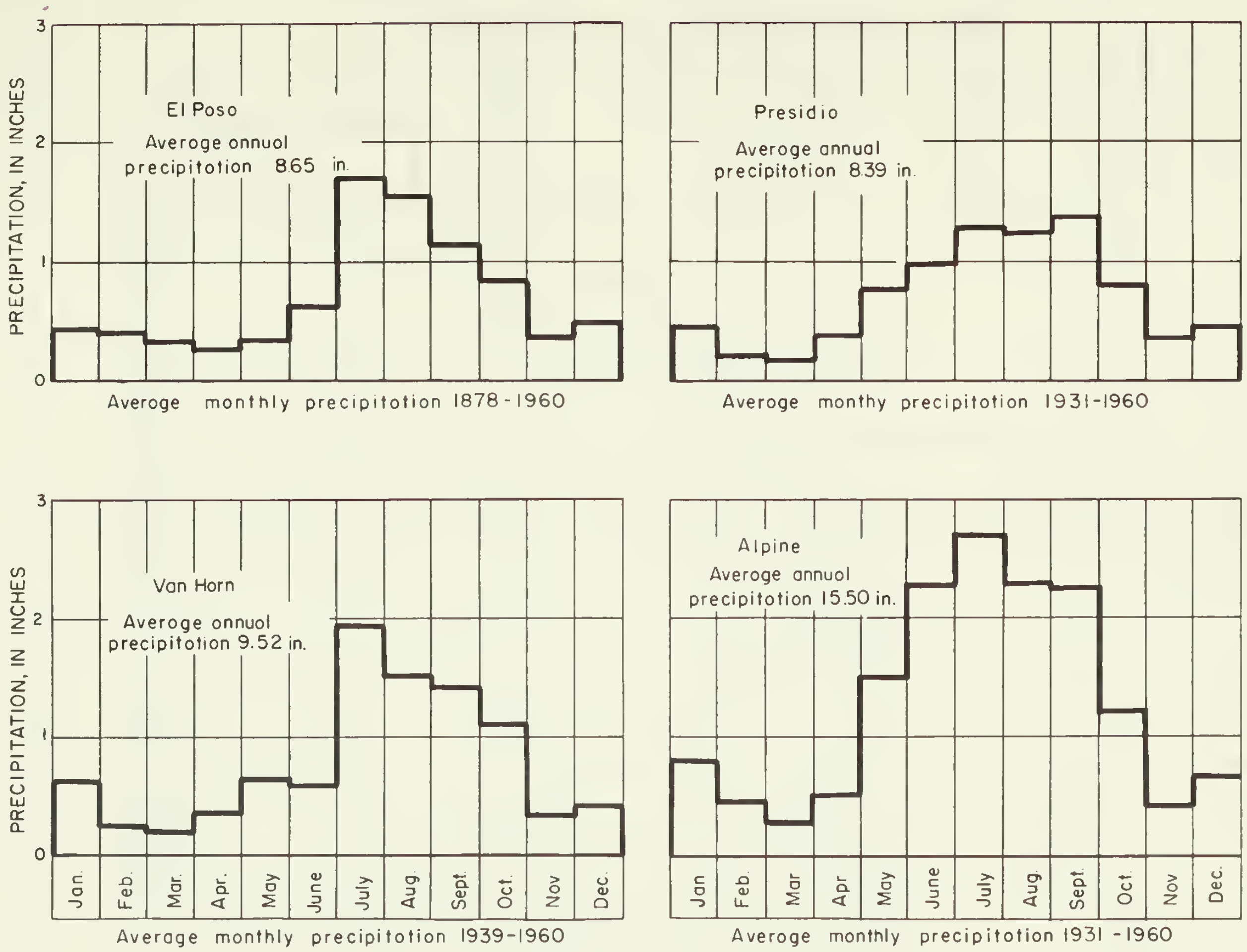

Figure U4

Average Monthly Precipitation at El Paso, Presidio, Van Horn, and Alpine

(From records of the U.S. Weather Bureau)

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

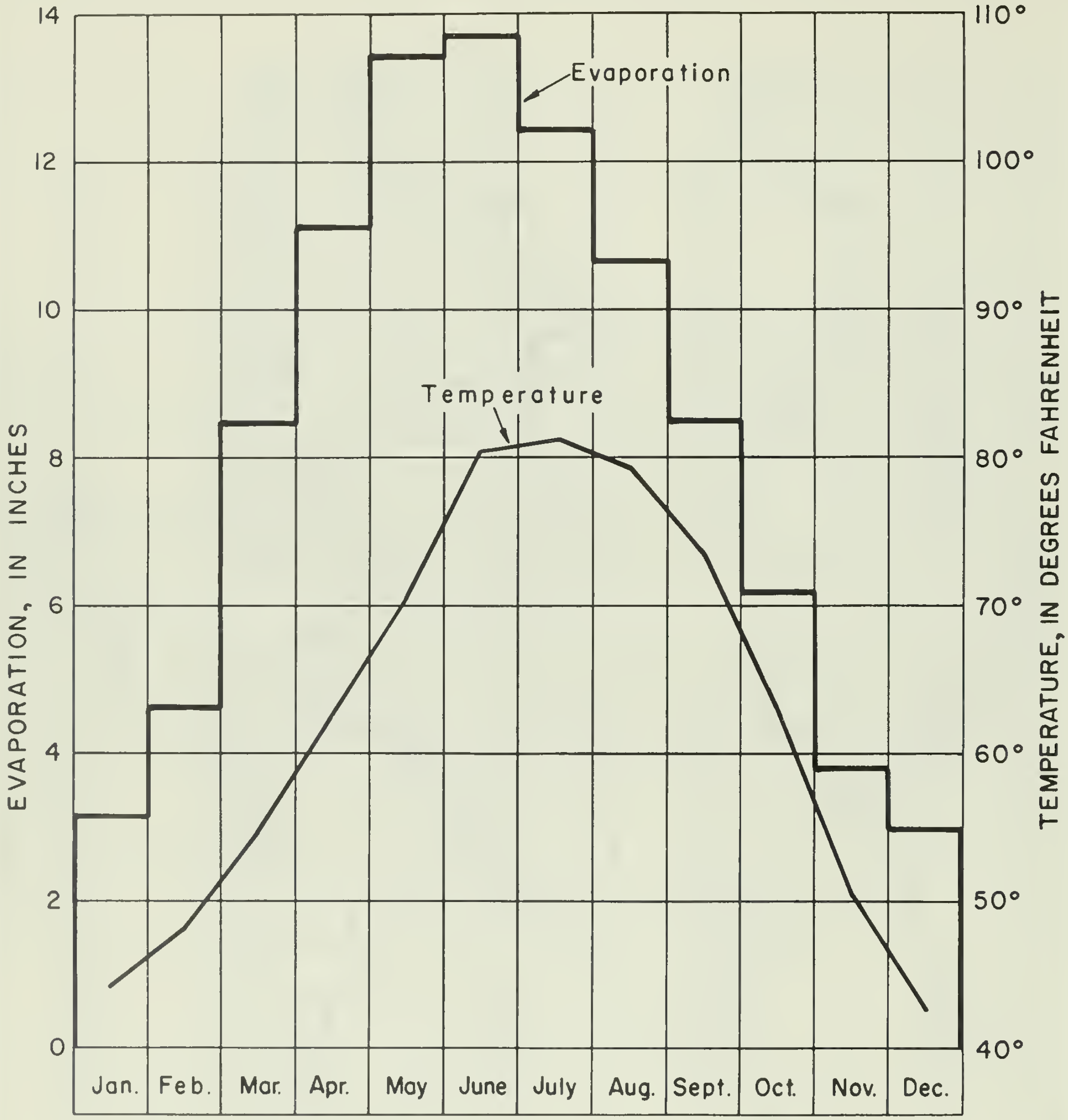

Figure U5

Average Monthly Evaporation and Temperature at Ysleta, 1953-60

(From records of the U.S. Weather Bureau)

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

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Drainage

The upper Rio Grande Basin is drained by the through-flowing Rio Grande, except for the Salt Basin which is without exterior drainage. The course of the Rio Grande from Anthony to Presidio follows structural basins. North of El Paso, the river flows from the Mesilla Valley through a narrow gorge into the broad lowland of the El Paso Valley (Plate U1). The El Paso Valley narrows southward and is terminated where the river cuts through a narrow gorge at the southeast end of the Quitman Mountains. Downstream from the canyon through the Quitman Mountains, the river flows through another valley, which terminates near Glenn Creek. Southeastward from Glenn Creek to Candelaria, the river flows through a narrow valley emerging in a broad valley that continues from Candelaria to Redford. Below Redford, the Rio Grande again becomes a mountain and canyon river flowing through three successive canyons in Big Bend National Park--Santa Elena, Mariscal, and Boquillas (Plate U2). Downstream from Boquillas Canyon, the river flows northeastward and eastward between precipitous limestone cliffs.

A large number of tributaries, most of which are short arroyos that have been formed by storm runoff from sudden heavy showers, enter the Rio Grande in the basin. A few of the tributaries, particularly those that rise in the mountains, drain large areas and may have small perennial flows in their upper reaches, but the flows generally do not reach the Rio Grande. The southeastern part of the basin, which includes parts of Terrell and Val Verde Counties, is drained by streams flowing in long deep canyons (Plate U2). These include Big Canyon, Meyers Canyon, Lozier Creek, and Sanderson Canyon, all ephemeral streams.

Prior to the construction of Elephant Butte Dam in New Mexico, the Rio Grande from New Mexico to the Rio Conchos, which enters the Rio Grande from Mexico near Presidio, was a desert stream receiving only little inflow from tributaries. The flow of the Rio Grande was highly variable, and often the summer water supply for irrigation and drinking purposes was erratic and unreliable. Follet (in National Resources Committee, 1938, v. 1, p. 73) reported that before 1888 the river went dry at intervals of about 10 years and "Since 1888 it has been dry every year but two." Slichter (1905, p. 21) also reported no water in the Rio Grande below El Paso for 9 months prior to August 25, 1904. Since construction of Elephant Butte Dam, however, the flow of the Rio Grande in summer is maintained principally by releases from the dam and in the winter by return drainage flow from irrigation. The flow of the river decreases between Anthony and a short distance above Presidio, at which point the Rio Conchos which heads in Mexico flows relatively large volumes of water into the Rio Grande. Between the Rio Conchos and Pecos River, the Rio Grande receives flow from its tributaries only during periods of rainfall.

The Salt Basin, which is a closed basin, has three relatively large drainageways that flow toward the Salt Lakes between Van Horn and Dell City. The Sacramento River, which drains a large area north of Dell City in New Mexico, flows only after heavy rains; however, the flows seldom reach the salt flats in Texas. In the southern part of the Salt Basin, Chispa Creek, which heads in Presidio County, flows northward joining Wildhorse Creek near Chispa. Wildhorse Creek heads in Jeff Davis County and flows northward to disappear in the flats near the Baylor Mountains north of Van Horn. The western part of Eagle Flat, which is west of the main Salt Basin, drains interiorly to a depression about 10 miles east of Sierra Blanca; the eastern part drains southeastward to the Salt Basin. Evapotranspiration removes water from the Salt Basin at a greater rate than water drains into the basin so that the Salt Lakes are dry for long periods.

The upper Rio Grande Basin has been delineated into major subdivisions by the Planning Division of the Texas Water Commission (Plates U1 and U2). The subdivisions range in size from 90 to 4,295 square miles and are numbered starting at the north end of the basin and proceeding downstream to the Pecos River drainage area, which marks the southern limit of the upper Rio Grande Basin.

For the purposes of this report and to permit the use of adequate scale maps, the upper Rio Grande Basin has been divided into two regions. Region I, including the Salt Basin, contains subdivisions 1 through 7, 10, and 24 (Plate U1); Region II includes subdivisions 8, 9, and 11 through 23 (Plate U2). Subdivisions 3, 13, and 20 have not been delineated by the Planning Division.

GEOLOGY

Geologic History

The geology of the upper Rio Grande Basin is extremely complex and the many processes such as faulting, folding, and igneous intrusions have been important in the formation of many of the large ground-water reservoirs in the basin. The rocks that are exposed in the basin range in age from Precambrian to Recent, almost all of the geologic systems being represented. Although the rocks are principally of sedimentary origin, igneous rocks occupy a large part of Jeff Davis, Presidio, and Brewster Counties.

During a part of Precambrian time, sediments were deposited in the basin and later in the same era were intruded by sills and dikes of igneous rocks. These rocks are exposed near El Paso and Van Horn. In some places, as near Van Horn, the Precambrian rocks were altered and subjected to structural deformation.

A long period of erosion followed and probably continued into early Paleozoic time. During most of Paleozoic time, the basin was a part of the large Llanoria geosyncline and the broad depression that adjoined the geosyncline on the north and northwest. At times the seas of the Paleozoic Era were withdrawn probably entirely from at least parts of the broad depression and the geosyncline, and at other times the area was flooded extensively (Sellards, 1932, p. 23). Beginning in Cambrian time and continuing through a part of Pennsylvanian time, the Paleozoic deposits accumulating in the geosyncline prevailingly were clastic, while sediments accumulated over the foreland part of the region were partly clastic and partly organic or chemical (Sellards, 1932, p. 18). Prior to the deposition of the Permian sediments, the basin was subjected to uplifting, folding, and overthrusting. Following the Late Pennsylvanian deformation, the former area of subsidence of the Llanoria geosyncline stood as a land area, probably of mountainous character. North and northwest of this land, thick sections of Permian sediments were deposited in the new areas of subsidence (King, 1935, p. 233).

In early Mesozoic time (Triassic and early Jurassic), the Paleozoic rocks were subjected to erosion and a large part of the basin was peneplained. In Late Jurassic time, an invading sea extended northward through Mexico into the upper Rio Grande Basin, depositing clastic sediments presently exposed in the

Quitman and Malone Mountains. The seas progressively inundated the area of the basin during Cretaceous time until the close of the Cretaceous Period when the area again became emergent.

The Cenozoic Era was one of extensive erosion, volcanism, uplifting, and faulting. The northwest-trending belts of mountains and the associated basins were formed by faulting during the Tertiary Period and the filling of these depressed blocks or basins continued into the Quaternary Period. The largest basins are the Hueco bolson, Salt Basin, and that part of the Rio Grande Valley west of Shafter between Candelaria and Redford. At the close of the mountain-building period, the region was drained into a series of inclosed basins. Near the close of the Tertiary Period, the basins, except the Salt Basin, were drained and the Rio Grande formed its present course. During the Recent Period, erosion continued in the highland areas, whereas sediments continued to be deposited in the Salt Basin, which is still undrained.

Figure U6 is a generalized geologic map of the upper Rio Grande Basin showing the outcrop areas of rocks representing the geologic eras.

Table U1 shows the thickness of many of the rock units in the basin and gives a brief description of their lithologic and water-bearing properties, although it was not feasible to describe all the formations that crop out in the basin or that are penetrated in wells. In the following discussion, only those rock units that are important to the ground-water resources of the basin are discussed. In some cases, it was beyond the scope of the reconnaissance to differentiate the known water-bearing formations within a particular series or group of rocks.

Descriptions of the Water-Bearing Units

Practically all the geologic formations in the upper Rio Grande Basin yield some water, but only the primary and secondary aquifers are discussed. A primary aquifer is defined as one that yields a large quantity of water throughout a large area; a secondary aquifer is one that yields small quantities of water in a large area or a large quantity of water in a small area. On this basis, the Cenozoic bolson and alluvial deposits comprise the only primary aquifer in the basin, whereas the Marathon Limestone, the Bone Spring Limestone and Victorio Peak Limestone, undifferentiated, the rocks of Trinity, Fredericksburg, and Washita Groups and equivalents, and the Tertiary igneous rocks are secondary aquifers. Many other water-bearing formations yield small quantities of water in the basin, but because of their local extent they are considered as insignificant and are not discussed in the text but are included in Table U1.

Paleozoic Era

Ordovician System

Marathon Limestone

The Marathon Limestone, which crops out in the town of Marathon, has a thickness ranging from 800 or 900 feet at Marathon to about 350 feet 6 to 14 miles south of Marathon. It consists principally of dark-gray flaggy limestone and gray or green clayey shale. Sandstone and conglomerate are interbedded with the limestone and shale. Near the middle of the formation is a massive mottled dolomitic limestone which has a maximum thickness of 90 feet.

The Marathon Limestone is a secondary aquifer, but is the most productive aquifer in the Marathon area. According to DeCook (1961, p. 10), "It yields water to 92 wells, most of which are in the town of Marathon. The yields of the wells vary widely, ranging from a few gallons per minute to probably more than 300 gpm.... Most of the water probably is obtained from the limestone beds that have been extensively fractured as a result of folding. Small quantities of water may be obtained from the beds of sandstone and conglomerate and perhaps from the well-indurated, brittle and fractured shale."

Permian System

Bone Spring and Victorio Peak Limestones, Undifferentiated

The Bone Spring and Victorio Peak Limestones crop out in a narrow sinuous belt along the west-facing escarpment of the Guadalupe Mountains. They pass beneath the surface of the Salt Basin, but crop out again in the eastern part of the Diablo Plateau. In the Dell City irrigated area of the Salt Basin, the Bone Spring and Victorio Peak Limestones are overlain by 5 to 150 feet of alluvial deposits of Cenozoic age; south of Dell City they occur at increasingly greater depths. About 10 miles south of U. S. Highway 62, the top of the limestone was reported at a depth of at least 1,620 feet (Baker, 1934, p. 171). Although these formations are readily recognized in the outcrop, they are difficult to differentiate in drillers' logs of wells, and for the purpose of this report, they are undifferentiated.

In the outcrop area, the Bone Spring Limestone, which is the oldest formation exposed in the Guadalupe Mountains, typically consists of black, cherty, dense, fine-textured, thin-bedded limestone. Some of the limestone beds are separated by partings of shaly black limestone. The thickness of the Bone Spring, which here is restricted to the black limestone sequence, is at least 500 feet.

Overlying the Bone Spring is the Victorio Peak Limestone, which is a succession of thick-bedded layers of gray limestone having a total thickness of about 800 feet. The lower part of the Victorio Peak consists of gray-brown, fine-grained, dolomitic limestone in beds several feet thick, the limestone containing widely spaced chert nodules; the upper part of the formation is more calcitic, light gray and noncherty. A sequence of thin-bedded, light-gray or white limestone, containing buff, fine-grained calcareous sandstone, separates the lower and upper parts of the formation.

The occurrence of ground water in the Bone Spring and Victorio Peak Limestones is related in a large part to the geologic structure. Fault zones east and south of the Dell City irrigated area, as well as at the west foot of the Guadalupe and Delaware Mountains, are related to the recharge, movement, discharge, and quality of the ground water. In the area west of the main body of Salt Lakes, the nearly level water table in the limestone may result, in part, from a damming action caused by a difference in permeability at the fault zone.

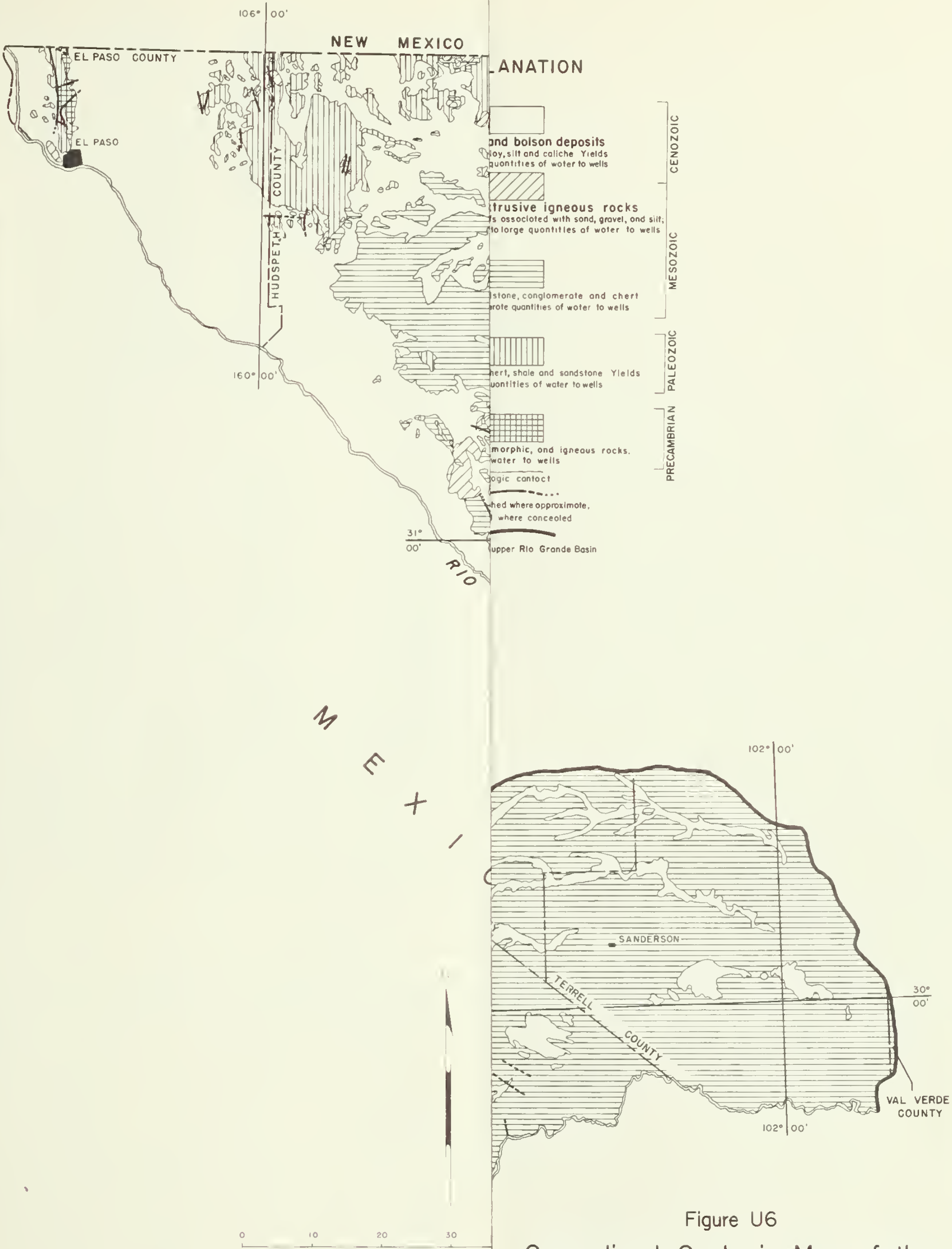


Figure U6

Generalized Geologic Map of the Upper Rio Grande Basin

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

After geologic map of Texas, U.S. Geological Survey, 1937

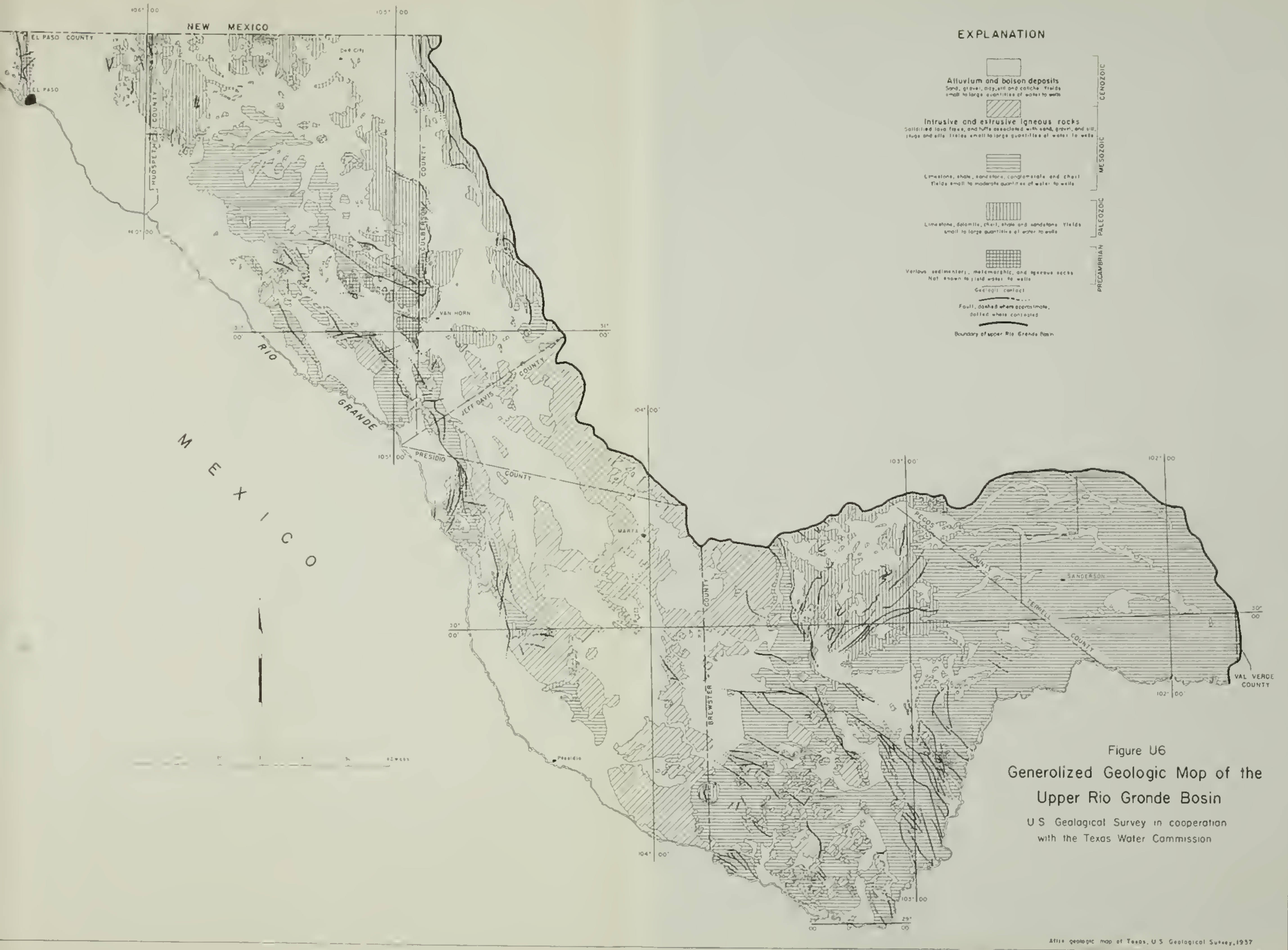


Figure U6
Generalized Geologic Map of the Upper Rio Grande Basin
U.S. Geological Survey in cooperation with the Texas Water Commission

Table U1.--Rock units and their water-bearing properties, upper Rio Grande Basin

Era	System	Series	Unit	Maximum thickness (feet)	Lithologic properties	Water-bearing properties
Cenozoic	Quaternary		Alluvium	390	Sand, gravel, clay, silt, and caliche.	Supplies large quantities of fresh to moderately saline water for public supply, domestic, irrigation, and industrial purposes in the Rio Grande Valley. Small quantities of fresh to moderately saline water obtained from tributaries of Rio Grande.
	Tertiary		Bolson deposits	4,920+	Sand, gravel, clay, and caliche.	Principal aquifer in the upper Rio Grande Basin. Supplies large quantities of fresh to slightly saline water in La Mesa and Hueco bolsons and in the Salt Basin. Contains large volume of moderately saline to very saline water in Hueco and La Mesa bolsons.
			Igneous rocks	4,000+	Lava flows and associated tuffs and unconsolidated sand, gravel, and silt. Rhyolite, trachyte, syenite, and basalt.	Small to large supplies of fresh water obtained from Tascotal Formation of Goldich and Seward (1948) in Marfa area. Small to moderate quantities of water obtained from Rawls Basalt of Goldich and Seward (1948) and Duff Formation of Goldich and Elms (1949) in Marfa area. Small supplies obtained from igneous rocks in Jeff Davis, Presidio, Brewster, and Hudspeth Counties.
Mesozoic	Cretaceous		Rocks of Fredericksburg and Washita Groups (undifferentiated) and equivalents	600	Hard, massive light-gray crystalline limestone, with layers of soft chalky limestone; contains layers and nodules of flint and some small nodules of hematite.	Small quantities of fresh water obtained from Devils River Limestone in Terrell and Val Verde Counties, and small supplies of fresh water are obtained from limestone in eastern Brewster County. Equivalents of the Georgetown and Edwards Limestone and Walnut Clay are important water-bearing units.
			Rocks of Trinity Group and equivalents	12,000	Massive soft brownish sandstone and interbedded gray limestone, conglomerate, and shale.	Small quantities of slightly to moderately saline water obtained from Cox Sandstone in vicinity of Finlay and Quitman Mountains. Small quantities of fresh to slightly saline water obtained from the Maxon Sandstone in Terrell and southern Pecos Counties.
	Jurassic	Upper Jurassic	Malone Formation	200	Conglomerate, brown sandstone, limestone, and some shale.	Not known to yield water to wells.

Table U1.--Rock units and their water-bearing properties, upper Rio Grande-Basin--Continued

Era	System	Series	Unit	Maximum thickness (feet)	Lithologic properties	Water-bearing properties
Paleozoic	Permian	Ochoa		1,000+	Limestone, dolomite, anhydrite, sandstone, and salt.	Not known to yield water to wells.
		Guadalupe		3,475	Massive beds of buff friable sandstone, conglomerate, gray limestone, and anhydrite.	Not known to yield water to wells, although a sandstone in western part of Guadalupe Mountains may yield fresh water to springs.
		Leonard		2,000+	Gray and black cherty limestone, shale, silicious shale, clay, calcareous sand, and conglomerate.	Contains the Bone Spring Limestone and Victorio Peak Limestone, undifferentiated, which yields large quantities of slightly saline to saline water for irrigation in the Dell City area. Rocks of the Leonard Series are not known to yield water to wells in other areas.
		Wolfcamp		1,710	Gray thick-bedded limestone, conglomerate, and red beds.	Contains Hueco Limestone which yields small quantities of slightly to moderately saline water to wells for livestock use in Diablo Plateau.
	Pennsylvanian			12,000	Shale, sandstone, limestone, and conglomerate.	Yields small quantities of water to wells in the Marathon area.
	Mississippian and Devonian (undifferentiated)			1,250+	Thin-bedded dark limestone, green shale. Locally chert occurs in concretions, layers and masses, novaculite, bedded chert, limestone, black sandstone, and fissile shale.	Not known to yield water to wells, but springs issue from joints or fissures in weathered parts of Caballos Novaculte in Marathon area.
	Silurian			960	Light-gray dolomite.	Not known to yield water to wells.
	Ordovician	Upper Ordovician		650	Bedded chert, locally thick-bedded, limestone, sandstone, and conglomerate.	Not known to yield water to wells, but springs occur along contact of Maravillas Chert and underlying Woods Hollow Shale in Marathon area.
		Middle Ordovician		700	Light gray-green to tan shale interbedded with sandy limestone, calcareous sandstone, shale, siltstone, and conglomerate.	Generally not known to yield water to wells except for small quantities from the Fort Peña Formation in the Marathon area.
		Lower Ordovician		2,400+	Dark gray flaggy limestone, dense blue limestone, gray or green clayey shale, conglomerate, and sandstone.	Contains Marathon Limestone, the principal aquifer in Marathon area, yielding from a few to more than 300 gpm to wells.
	Cambrian			500	Sandstone, shale, and dark-gray to black nodular limestone.	Not known to yield water to wells.
Precambrian					Various sedimentary, metamorphic, and igneous rocks.	Do.

In the area the less permeable alluvial deposits abut the limestone, in which the openings and consequently the permeability are large. An east-trending fault or fault zone probably is related to the availability of water in sufficient quantities for irrigation. South of the zone, wells generally yield insufficient quantities of water for irrigation, whereas north of this line some wells yield more than 2,000 gpm (gallons per minute). In the Dell City area east of the Salt Lakes, water of good quality occurs in limestone east of a line of north-trending faults; west of this line, the water increases rapidly in mineralization.

The Bone Spring and Victorio Peak Limestones, undifferentiated, yield large quantities of slightly to moderately saline water to wells in the Dell City irrigation area. In a small area near U. S. Highway 62 and along the Culberson-Hudspeth county line, fresh water is obtained from at least one well which taps limestone probably of Bone Spring or Victorio Peak age. Generally, the water from the limestone is unsatisfactory for municipal supply, but it is used successfully for irrigation because of the highly permeable soil which provides for adequate leaching.

Mesozoic Era

Cretaceous System

Trinity Group and Equivalents

Rocks of Trinity age crop out in scattered disconnected areas forming a belt roughly paralleling the Rio Grande between the southern end of the Hueco Mountains and Presidio. Rocks of Trinity Group and equivalents are exposed also in the Van Horn Mountains and south and southeast of Marathon. Rocks of the Trinity Group and equivalents probably underlie a large part of the upper Rio Grande Basin, but only in the Stockton Plateau and in Hudspeth County are they considered as a source of ground water.

In this report the rocks of Trinity Group and equivalents refer to the basal sands, the exact correlation of which is doubtful, the Maxon Sandstone, the Cox Sandstone, and to limestone, which may be equivalent to the Glen Rose Limestone. Other formations have been assigned to Trinity age by various authors, but they are of only local importance as sources of ground water.

Rocks of Trinity Group and equivalents everywhere contain a basal sand or conglomerate where it is present in the basin, but because of the transgressive nature of the deposits, they are of different ages in different places. Locally, the rocks of Trinity Group and equivalents are composed principally of massive soft brownish sandstone of the marginal facies, but in places they contain also gray limestone and shale of the offshore neritic facies.

The thickness of the rocks of Trinity age differs from place to place because the sediments were deposited on an eroded surface of moderate relief. Baker (1927, p. 13) reported a maximum thickness of the rocks of Trinity age in the vicinity of the Quitman Mountains of probably more than 3,500 feet, but this included 1,500 feet of Finlay Limestone of Fredericksburg age. However, Scott (1939, p. 978) reported that the thickness of the section of Trinity age in the Quitman area is more than 12,000 feet and that no repetition of beds was found. In the Marathon area, King (1937, p. 112) reported a thickness of 650 feet, of which 500 feet consisted of beds of massive limestone and soft marl of Glen Rose age. The thickness of the rocks of Trinity age in much of the remaining part of the basin is not known because few wells have penetrated completely the Cretaceous rocks.

The Cox Sandstone crops out along the southwestern flank of the southern Quitman Mountains in Hudspeth County; it forms the hogback of Devil Ridge; it occupies most of the area of the southern Eagle Mountains; and crops out extensively in the Van Horn Mountains (Baker, 1927, p. 19). The Cox consists largely of massive soft brownish sandstone, which is, in places, crossbedded gray limestone and dark maroon sandy clay. In the eastern Van Horn Mountains west of Lobo, Baker (1927, p. 19-20) reported 1,500 feet of Cox Sandstone and in Quitman Gap, which is about 9 miles east of Fort Quitman, about 2,000 feet was referred to the Cox.

The Maxon Sandstone, which roughly is equivalent to the Cox Sandstone, crops out along the east side of the Marathon area and in the southern part of Pecos County where it forms massive ledges between the Glen Rose Limestone and the overlying limestones and marls of the Fredericksburg Group. The subsurface extent of the Maxon is not known, but drillers' logs of wells at Sanderson indicate that it underlies at least a part of the Stockton Plateau in Terrell County. The Maxon consists of brown, well indurated, coarse to medium-grained sandstone with prominent crossbedding, thin shaly layers, sandy marl, and conglomerate. It has a thickness of 102 feet in the Marathon area (King, 1937, p. 114), but Livingston and Bennett (1940, p. 7) reported a thickness of about 305 feet in a well drilled for the city of Sanderson.

The rocks of Trinity Group and equivalents are classed as a secondary aquifer. They yield small quantities of fresh to slightly saline water in a rather large area. In the southern part of Pecos County, the sandstone of the Trinity Group, probably the Maxon Sandstone, furnishes small quantities of water to domestic and livestock wells. Some wells in the area, however, may be screened in both the Maxon Sandstone and the Cenozoic alluvium, which constitute the Pecos aquifer of Armstrong and McMillion (1961, p. 43).

Fredericksburg and Washita Groups, Undifferentiated, and Equivalents

Rocks of the Fredericksburg and Washita Groups, undifferentiated, form the surface of the Stockton Plateau in Brewster, Terrell, and Pecos Counties. Rocks of Fredericksburg and Washita Groups, and equivalents are exposed also in a relatively large area in the southern half of the Diablo Plateau in Hudspeth County as well as in several small widely scattered areas in Presidio and southern Brewster Counties.

For the purpose of this report, the rocks of the Fredericksburg and Washita Groups are undifferentiated; where they are important as a source of ground water, they include the equivalents of the Georgetown Limestone of the Washita Group and the Edwards Limestone and Walnut Clay of the Fredericksburg Group. In the southeastern part of the area, particularly in Terrell and Val Verde Counties, the rocks have been referred to as the Devils River Limestone (Christner and Wheeler, 1918, p. 12).

The Devils River Limestone consists principally of limestone which ranges from hard massive limestone to soft chalky material. The limestone is light gray and crystalline and contains layers and nodules of flint and small nodules of hematite. The thickest exposures of the Devils River Limestone in Terrell County are along the Rio Grande where the limestone cliffs are slightly more than 600 feet high (Christner and Wheeler, 1918, p. 13).

The rocks of the Fredericksburg and Washita Groups, undifferentiated, and equivalents form a secondary aquifer in the upper Rio Grande Basin. In the Stockton Plateau in Terrell and Val Verde Counties, the Devils River Limestone yields small quantities of fresh water to wells, and in the eastern part of Brewster County, limestone of the Fredericksburg and Washita Groups furnish small supplies of fresh water for domestic and livestock uses.

Cenozoic Era

Tertiary System

Igneous Rocks

Igneous rocks of Tertiary (or Late Cretaceous) age occupy an extensive area in the southern part of the upper Rio Grande Basin (Figure U6). The rocks are both extrusive and intrusive. Despite their widespread occurrence, they generally are insignificant as sources of ground water although locally they yield moderate quantities of fresh water and are classed as a secondary aquifer.

The extrusive or volcanic rocks consist of a succession of solidified lava flows with associated tuffs and unconsolidated sand, gravel, and silt. The lavas are predominantly rhyolitic but also syenitic, trachytic, andesitic, and basaltic. The maximum thickness of the extrusive rocks is not known, but Baker (1927, p. 35) reported a thickness of 4,000 feet or more in the Tierra Vieja Mountains, and Davis (1961, p. 40, table 4) reported a thickness of 3,000 feet near Marfa.

In general, the extrusive rocks are not considered as important sources of ground water except in the Marfa area where the Tascotal Formation of Goldich and Seward (1948) yields small to large quantities of water to public supply, domestic, and livestock wells. The Tascotal Formation crops out in a belt of irregular width and pattern in the western and southwestern parts of the Marfa area and underlies an area of possibly 80 square miles south of Marfa extending along the valley of Alamito Creek to the vicinity of Casa Piedra; north of Marfa the formation is absent. The Tascotal, which has a thickness of at least 707 feet (Davis, 1961, p. 14), consists predominantly of sandy tuff, tuffaceous sand, and thick beds of sandstone and conglomerate.

Small to moderate quantities of water are obtained locally near Marfa from the Rawls Basalt of Goldich and Seward (1948) and the Duff Formation of Goldich and Elms (1949).

Intrusive igneous rocks, chiefly in the form of plugs and sills, crop out in widely scattered small areas in the southern part of the upper Rio Grande Basin. Because of their small areal extent, they are mapped with the volcanic rocks on Figure U6. The intrusive rocks are nearly impermeable; consequently, they yield only small quantities of water. Only the wells that tap fractures or joints produce sufficient water for livestock use. Small supplies are obtained from these rocks in parts of Jeff Davis, Presidio, Brewster, and Hudspeth Counties.

Bolson Deposits

The sediments that occupy the extensive intermontane basins of the upper Rio Grande Basin are herein referred to as bolson deposits. The deposits principally are Tertiary in age although an unknown but probably relatively small part may be of Quaternary age.

The bolson sediments occupy La Mesa and Hueco bolsons; the Salt Basin, which includes its western extension, Eagle Flat; Quitman Arroyo; Glenn Creek; and the Rio Grande Valley between Candelaria and Redford.

In general, the sediments consist of unconsolidated sand, gravel, clay, and caliche derived primarily from the weathering and erosion of local rock. They also contain interbedded lava flows. The character of the deposits varies considerably from basin to basin. In the Hueco bolson and Salt Basin, the sediments are poorly sorted, and individual layers range in thickness from zero to about 100 feet. Individual beds and lenses of sand, gravel, and clay generally are not continuous over wide areas but instead pinch out or grade laterally or vertically into finer or coarser materials. However, in the part of La Mesa bolson in Texas, the sand in the lower part is well sorted, thickly bedded, and moderately uniform. Whether this body of uniform sand extends over a large part of the bolson is not known definitely. Overlying the sand, which locally is referred to as the "deep aquifer," are alternating layers of sand and clay of the "medium aquifer" which are similar in character to the deposits in the other basins.

The maximum thickness of the bolson deposits is not known. On La Mesa bolson, a well near Canutillo, which is 6 miles south of Anthony, was in unconsolidated deposits at a depth of 1,705 feet (Leggat and others, 1962, p. 14). On the Hueco bolson, King (1935, p. 253) reported 4,920 feet of unconsolidated sediments penetrated in an oil test about 2 miles south of the New Mexico-Texas state line near U. S. Highway 54. In the Salt Basin, a well drilled about 10 miles south of U. S. Highway 62 was still in bolson deposits at 1,620 feet (Baker, 1927, p. 40). About 2 miles south of Van Horn, the base of the bolson deposits was penetrated at a reported depth of about 1,200 feet. About 1 mile north of Chispa, the thickness of the bolson deposits is known to be 1,180 feet (Sellards, 1934, p. 377). In Eagle Flat at Hot Wells, a railroad siding 11 miles west of Van Horn, a well was in bolson deposits at 1,000 feet. In the Rio Grande Valley, a Santa Fe railroad boring at Presidio was in boldon deposits at 1,320 feet.

The bolson deposits of La Mesa and Hueco bolsons and the Salt Basin near Van Horn and Lobo Flats furnish large quantities of fresh to slightly saline water for municipal, domestic, irrigation, and industrial purposes. In addition, moderate to large quantities of slightly saline to moderately saline water are obtained from the bolson sediments in the vicinity of Dell City.

Alluvium

Alluvial deposits of Quaternary age occupy a large part of the Rio Grande Valley between Anthony and Presidio and smaller tributary streams; they mantle the Hueco and La Mesa bolsons and also occur in places in the upland areas.

The alluvium of the Rio Grande Valley consists for the most part of poorly sorted sand, gravel, clay, and silt. The thickness of these sediments is not known definitely, but in the Lower Mesilla Valley, Leggat and others (1962, p. 15) estimated the thickness as probably not exceeding 150 feet. It may be assumed, therefore, that the alluvium that overlies the bolson deposits in the Rio Grande flood plain below El Paso probably is not greater than 150 feet. On La Mesa and Hueco bolsons the alluvium is thin, generally consisting of a veneer of sand and gravel overlying a layer of caliche which forms a caprock for the bolson deposits. The alluvium in the bolsons probably is less than 20 feet thick except near the slopes of the mountains.

In the upland areas, the alluvium, generally in the form of a surficial mantle or as alluvial areas along the mountain fronts, is composed of debris derived from the disintegration of local rocks. Generally, the alluvium in the upland areas is relatively thin, probably about 30 feet thick, although Davis (1961, p. 16) reported a thickness of about 390 feet in the Marfa area. In the Marathon area at the base of the escarpment of the Glass Mountains, a thickness of as much as 125 feet of alluvium was reported by DeCook (1961, p. 15).

Large supplies of fresh to moderately saline water are obtained from the alluvium in the valley of the Rio Grande principally for irrigation. However, where the water is fresh or only slightly saline, relatively large supplies also are pumped for municipal and industrial supplies. In the upland areas, the alluvial deposits yield small to moderate quantities of water principally for domestic and livestock purposes but in a few places also for irrigation.

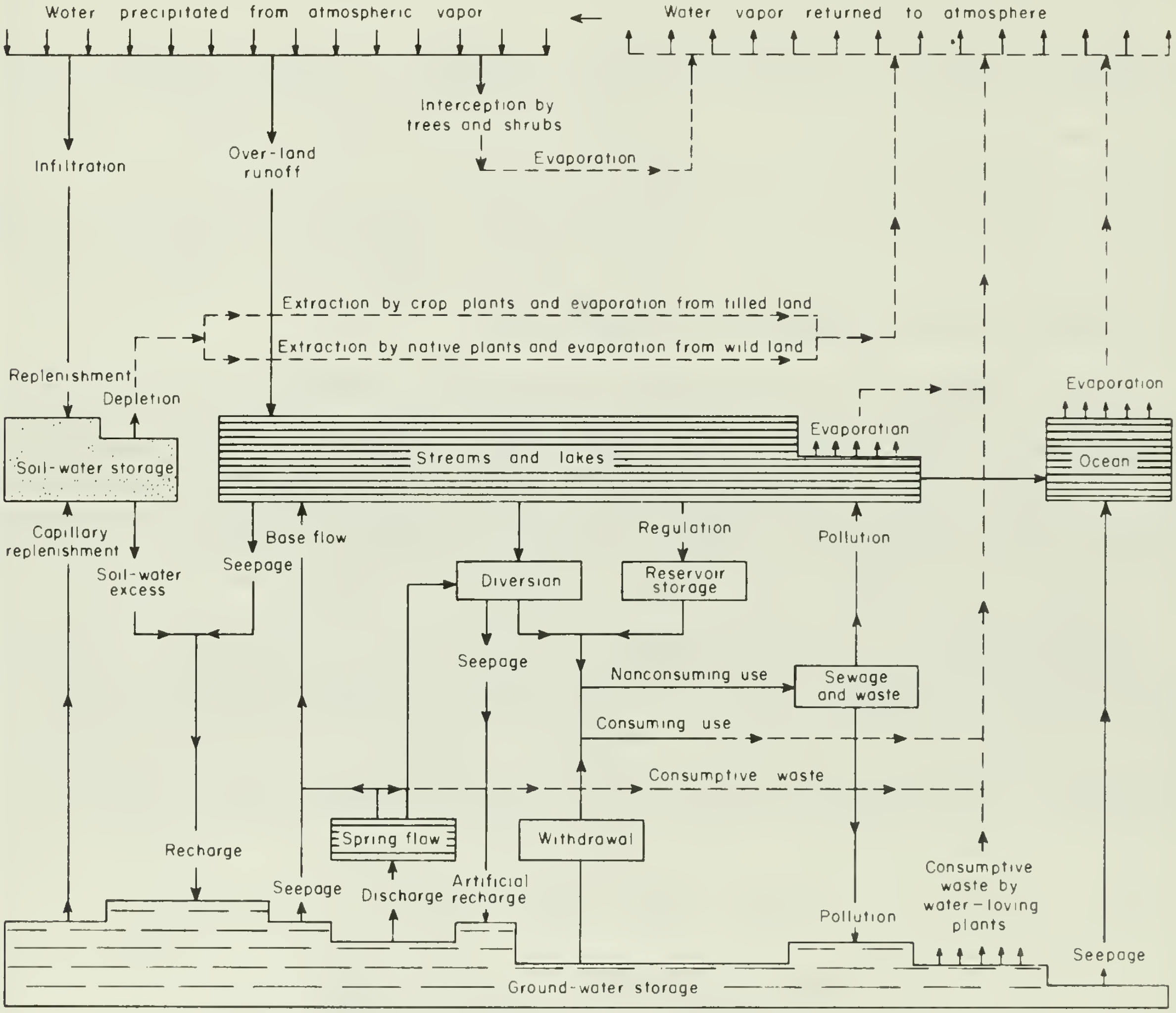
GENERAL GROUND-WATER HYDROLOGY

Source, Occurrence, and Movement

The fundamental principles of the source, occurrence, and movement of ground water entail an understanding of the hydrologic cycle. Figure U7 is a diagrammatic representation of the cycle, but only that part of the cycle pertaining to ground water will be discussed in the report.

Ground water contained in the rocks in the upper Rio Grande Basin is derived chiefly from precipitation. A part of the precipitation runs off the land surface and enters streams, a part is evaporated or used by plants, and a part passes through pores and openings in the rocks and as recharge enters a zone in which the rocks are saturated, thus becoming ground water.

The volume of water that can be stored by a rock depends on its porosity--that is, the number and size of the openings in the rock. In sedimentary rocks the porosity is a function of the size, shape, sorting, and degree of cementation of the component particles. In soluble rocks, such as limestone, the



(Modified from Piper, 1953, p. 9)

Figure U7

The Hydrologic Cycle

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

100

porosity is chiefly a function of the size and distribution of cavities or channels. In dense rocks, such as igneous or metamorphic rocks, the porosity is largely a function of the size and distribution of fractures or crevices.

The porosity of rocks generally decreases with depth as the interstices or pores decrease in size, partly because of increased pressures, and partly because of cementation by mineralized waters. The porosity may be defined as the ratio of the volume of voids in the rocks to the total volume of the rock. It determines only the amount of water the rock can hold and not the amount it may yield to wells.

The permeability of a rock relates to its capacity to transmit water under a hydraulic gradient. Well cemented sandstone and conglomerate, dense limestone, and fine-grained materials, such as clay, silt, and shale, generally have low permeabilities. They may act as barriers impeding the movement of water into or out of more permeable rocks. On the other hand, cavernous limestone, gravel, and well-sorted sand generally are highly permeable. Beds of sand and gravel and permeable zones of limestone serve not only as conduits through which ground water moves, but also as reservoirs in which water is stored.

Ground water moves slowly but steadily under the influence of gravity from areas of intake to areas of discharge. The rate of movement is proportional to the permeability of the rocks, and the slope of the water table or artesian pressure surface is called the hydraulic gradient. The movement of ground water ranges from tenths of a foot per day to many feet per year in most sand and gravel; whereas, the movement may be comparable to that of surface streams in some cavernous gypsum or limestone aquifers.

A water-bearing formation that yields water in usable quantities is termed an aquifer. On the basis of water occurrence, aquifers may be classified as water-table or artesian. In a water-table aquifer, the water is unconfined. The static water level in a well finished in a water-table aquifer stands at the level at which water first entered the hole when the formation was penetrated. The water surface in unconfined aquifers is termed the water table. In an artesian aquifer, ground water is confined under pressure by an overlying formation of relatively low permeability. The water level in a well that is finished in an artesian aquifer and is tightly cased through the confining beds stands above the level where water was first encountered. The surface formed by water levels in wells tapping an artesian aquifer is termed the piezometric surface. Although the terms, water table and piezometric surface, are synonymous in the outcrop area, the term piezometric surface alone and as used in this report is applicable only in artesian areas.

Recharge and Discharge

The ground-water reservoirs in the upper Rio Grande Basin are recharged by infiltration of precipitation and stream runoff, by seepage from canals and irrigation water applied to the land, and by underground inflow from outside the basin.

The amount of precipitation that reaches the water table is determined by the duration, intensity, and type of precipitation, the thickness of the cover, porosity and permeability of the soil and underlying rocks, and the areal extent of the recharge area. A large part of the precipitation occurs during the summer when the evaporation rate is high, thus only a small fraction of the precipitation escapes evaporation and becomes recharge. However, most of the recharge occurs from the torrential rains that fall during the summer. Runoff from the downpours emerges from the steep slopes of the mountainous areas, spreads out over the alluvial fans, and percolates into the porous material forming the fans. Some recharge occurs from runoff ponded in the many depressions in the bolson areas. The ponded water seeps rapidly from some of the depressions, whereas in others, it stands for long periods, being slowly consumed by evaporation.

Ground water is discharged by springs, seepage to streams, lakes, and marshes that intersect the water table, transpiration, and evaporation through the soil where the water table is close to the land surface. It is discharged also by seepage upward through the confining beds in the artesian aquifers into the overlying alluvial deposits, whence the water is discharged by evapotranspiration or by flow into the river. In some areas of the basin, large amounts of ground water are discharged by pumping.

Fluctuations of Water Levels

Water levels in wells in the upper Rio Grande Basin fluctuate almost continuously in response to natural and artificial processes. Fluctuations of water levels in wells indicate changes in the amount of water in storage in the aquifer, the magnitude of the change in storage depending on the degree of confinement of the water, and the causes of the fluctuations. The major fluctuations of water levels are the effects of pumping; minor fluctuations are caused by such factors as changes in atmospheric pressure, loading and unloading of the aquifer, and earthquakes.

Water levels in artesian wells are many times more sensitive to changes in storage than are water levels in water-table wells, owing to the great difference in storage coefficients. A fluctuation of several feet in artesian wells may be equivalent to a change of a fraction of a foot in a water-table well. In either case, the magnitude of the change in water level depends on the proximity of the well to the center of pumping.

Water levels have been observed in a large network of wells in the upper Rio Grande Basin. Because of variations in seasonal pumpage, measurements made in December or January of each year are the most reliable for showing annual changes of water levels.

Hydraulic Characteristics

The capacity of an aquifer to yield water to wells depends largely upon its hydraulic properties. The coefficients of permeability, transmissibility, and storage are terms used to describe these properties.

The coefficient of permeability is the rate of flow of water in gallons per day through a cross section of one square foot under a unit hydraulic gradient at a temperature of 60°F. In practice, however, because of the nearly constant temperature of the ground water in a given region, the coefficient of permeability generally is determined at the prevailing field temperature of ground water in each aquifer tested.

The development of certain formulas and field methods for appraising the hydraulic properties of water-bearing formations has resulted in wide adoption of the term coefficient of transmissibility in place of coefficient of permeability. The coefficient of transmissibility, which was introduced by Theis (1935, p. 520), is the number of gallons of water that will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity. It is the field coefficient of permeability times the thickness of the aquifer in feet.

The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit of surface area of the aquifer per unit change in the component head normal to that surface. For an unconfined aquifer, the coefficient of storage is virtually the same as the specific yield, which is defined as the unit volume of water that will drain by gravity from a unit volume of saturated material. Although in an artesian aquifer, water generally is not available from storage by drainage from the saturated materials, some water is released from storage when the hydrostatic pressure declines owing to the compressibility and elasticity of the aquifer and adjacent confining beds and to the slight expansion of water itself.

The hydraulic properties of the rocks can be determined by laboratory or field methods, the preferred method being pumping tests of wells. This method is preferred because a large area of the aquifer can be tested, whereas samples tested in the laboratory may be representative of only small areas. Moreover in most instances, samples collected during the drilling of a well are not representative of the undisturbed material of the aquifer.

When a well is pumped or allowed to flow, the water level in the well drops and an hydraulic gradient is developed toward the well from all directions. As the hydraulic gradient increases, the water flows faster toward the well. Within limits, the rate at which water will enter the well varies directly with the amount the water level is lowered. The ratio of the yield of a well to the drawdown is called the specific capacity and may be expressed as yield in gallons per minute per foot of drawdown. The term might imply that the ratio of yield to drawdown is constant, but the specific capacity of a well is only an approximation because of the effects imposed by the rate of withdrawal and the element of time. Moreover, a comparison of the specific capacities as an indication of aquifer productivity is subject to considerable error unless the methods of well construction and the degree of development are taken into account.

Chemical Quality

The chemical quality of water depends on the dissolved minerals present and often determines its suitability for use. A general classification of water, according to dissolved-solids content, is shown on the following page (Winslow and Kister, 1956, p. 5).

Most of the ground water used for municipal supplies in the upper Rio Grande Basin is classified as fresh, although in some areas slightly saline water may be used.

Description	Dissolved solids content (ppm)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Criteria of general application in evaluating the chemical aspects of ground water in relation to domestic and public-supply use, industrial use, and agriculture or irrigation use serve as useful guides. The water required for domestic and public-supply use, in general, must not contain radiological, biological, chemical, or physical substances in concentrations which may be health hazards; should be free of turbidity, taste, and odor to the extent that it is not objectionable to the user; and should not be excessively corrosive to the water-supply system (U. S. Public Health Service, 1962, p. 2152-2155).

The United States Public Health Service (1962, p. 2152-2155) has established standards of drinking water to be used on common carriers engaged in interstate commerce. The standards were designed to help protect travelers from digestive upset, but generally are used in evaluating the suitability of public water supplies in the United States. According to the standards, chemical constituents should not be present in a water supply in excess of the listed concentrations where other more suitable supplies are available or can be made available. The concentrations of the chemical constituents commonly are expressed in ppm (parts per million). The standards of the Public Health Service for some of the more common constituents are given in the following table:

Substance	Concentration (ppm)
Chloride (Cl)	250
Fluoride (F)	*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

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

Annual average of maximum daily air temperatures (°F)	Recommended control limits of fluoride concentrations (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

Water having concentrations of chemical constituents in excess of the recommended limits may be objectionable for various reasons. Concentrations of nitrate in excess of 45 ppm have been related to the incidence of infant cyanosis (methemoglobinemia or "blue baby" disease), a reduction of the oxygen content in the blood constituting a form of asphyxia (Maxcy, 1950, p. 271). High concentrations of nitrate may be an indication of pollution from organic matter, commonly sewage. Excessive concentrations of iron and manganese in water cause reddish-brown or dark-gray precipitates that stain clothes and plumbing fixtures. Water having a chloride content exceeding 250 ppm may have a salty taste, and sulfate in water in excess of 250 ppm may produce a laxative effect. Excessive concentrations of fluoride in water may cause teeth to become mottled. When fluoride is naturally present in the water, the concentration should not average more than the appropriate upper limit shown in the preceeding table. Thus, in the arid and semiarid upper Rio Grande Basin, fluoride in excess of 1.0 ppm may cause mottling of the teeth. However, fluoride in concentrations of about 1 ppm may reduce the incidence of tooth decay (Dean, Arnold, and Elvove, 1942, p. 1155-1179).

Calcium and magnesium are the principal constituents in water that cause hardness. Although hardness as such is not a criterion for the suitability of drinking water, it is important in general domestic use. Excessive hardness causes increased consumption of soap and induces the formation of scale in hot water heaters and water pipes. The commonly accepted standards and classification of water hardness are shown in the following table:

Hardness range (ppm)	Classification
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 181	Very hard

Water quality in industry is used without reference to the concept of potability. A water of suitable quality for industrial use may or may not be acceptable for human consumption. Ground water used in industry may be classified into three principal use categories: cooling water, process water, and boiler water.

Cooling water usually is selected for its temperature and the source of supply, although its chemical quality is significant also. Any characteristic that may affect adversely the heat exchange surfaces is undesirable. Calcium, magnesium, aluminum, iron, and silica may cause scale. Corrosiveness is another objectionable feature. Calcium and magnesium chloride, sodium chloride in the presence of magnesium, acids, oxygen, and carbon dioxide are among substances that make water corrosive.

The quality of boiler water for the production of steam must meet rigid requirements. Here the problems of corrosion and encrustation are greatly intensified. Silica in boiler water is undesirable because it forms a hard scale, the scale-forming tendency increasing with pressure in the boiler.

Process water is subject to a wide range of quality requirements. Usually rigidly controlled, these requirements commonly involve physical, chemical, and biological factors. Unlike cooling water and boiler water, much of the process water usually is consumed or undergoes a change in quality in the manufacturing process and generally is not available for reuse.

The suitability of water for irrigation depends not only on the chemical quality of the water but also upon such factors as soil texture and composition, infiltration rate, drainage, climate, salt tolerance of the crop, and irrigation practices. Many classifications of irrigation water express suitability of water in terms of one or more of these variables and offer criteria for evaluating the relative overall suitability of irrigation water rather than placing rigid limits on the concentrations of certain chemical constituents. The most important chemical characteristics that are pertinent to the evaluation of water for irrigation are (1) relative proportion of sodium to other cations, an index to the sodium hazard; (2) total concentration of soluble salts, an index to the salinity hazard; and (3) concentration of boron. The total concentration of soluble salts is related to the electrical conductivity expressed in micromhos per centimeter.

Sodium can be a significant factor in evaluating quality of irrigation water because of its potential effect on soil structure. A high percent sodium in water tends to break down soil structure by deflocculating the colloidal soil particles. Consequently, soils can become plastic, movement of water through the soil can be restricted, drainage problems can develop, and cultivation can become difficult. A system of classification commonly used for judging the quality of water for irrigation was proposed in 1954 by the U. S. Salinity Laboratory Staff (1954, p. 69-82). The classification is based primarily on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the sodium-adsorption ratio (SAR). This classification of irrigation water is diagrammed in Figure U8.

The significance and interpretation of the classification of water with respect to sodium content have been described by the U. S. Salinity Laboratory Staff (1954, p. 69-82).

An excessive concentration of boron will render a water unsuitable for irrigation. Scofield (1936, p. 286) has indicated that boron concentrations

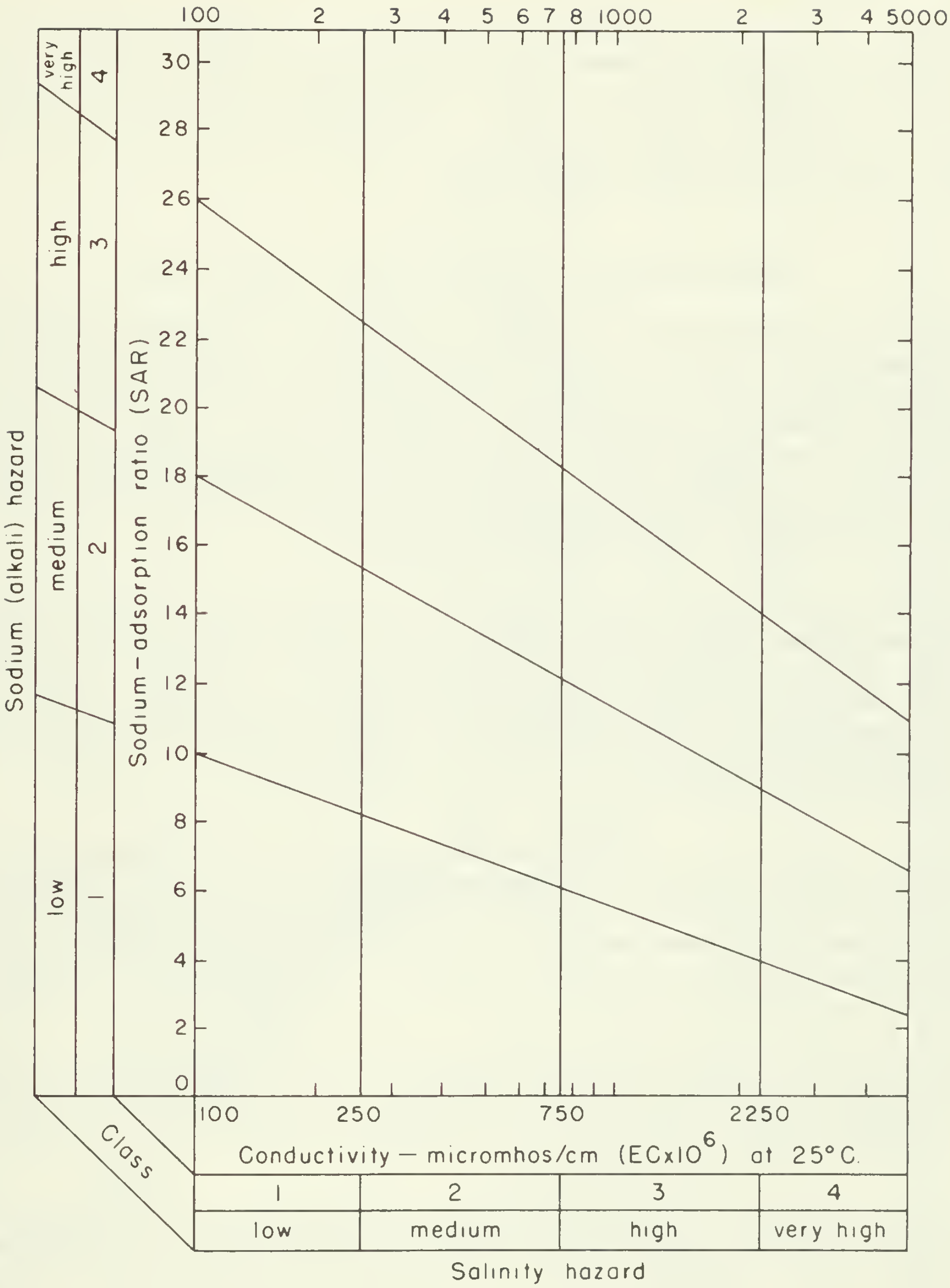


Figure U8.

Diagram for the Classification of Irrigation Waters

(After United States Salinity Laboratory Staff, 1954, p 80)

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as much as 1 ppm are permissible for irrigating the more average boron-sensitive crops, and concentrations as much as 3 ppm are permissible for the more average boron-tolerant crops.

Quality limits for livestock are variable. The limit of tolerance depends principally on the kind of animal and, according to Heller (1933, p. 22), the total amount of soluble salts in the drinking water, more so than the kind of salt, is the important factor. Heller also suggests that as a safe rule 15,000 ppm dissolved-solids content should be considered the upper limit of subsistence for most of the more common stock animals.

GROUND WATER IN THE UPPER RIO GRANDE BASIN

The use of surface-water supplies in the upper Rio Grande Basin had its beginning with the early Spanish settlers, the development of these supplies being concentrated in the Rio Grande Valley. The use of ground-water supplies other than for domestic and livestock purposes began at least by 1892 when 30 shallow wells were drilled in the bed of the Rio Grande for the municipal supply of El Paso. Drilling gradually spread to the uplands where a large supply of good quality water was developed first in the City Artesian subarea of the Hueco bolson then in the Mesa subarea (Plate U1).

The earliest use of ground water for irrigation in the upper Rio Grande Basin is not known, but Slichter (1905, p. 31) gave data on five irrigation wells near El Paso in the valley of the Rio Grande. However, large-scale development of the ground water in the valley probably began about 1950, owing to an annually decreasing supply of surface water for irrigation. By 1960, about 811 wells were available in the vicinity of El Paso for municipal and industrial purposes and for irrigation.

In the other parts of the upper Rio Grande Basin, excluding the Rio Grande Valley, only small amounts of ground water were used for irrigation prior to 1947. In the few years following 1947, the use of ground water for irrigation in the Salt Basin expanded rapidly, the development being concentrated in or near Dell City, Van Horn, and Lobo. By 1960, 336 wells were available for irrigation in these areas.

In 1960, the withdrawals of ground water in the upper Rio Grande Basin from all sources was about 250,000 acre-feet, or 220 mgd (million gallons per day). Of this total, 170,000 acre-feet was for irrigation and 53,000 acre-feet was for public supply.

For the purposes of this report, the development, occurrence, availability, and quality of ground water in the upper Rio Grande Basin are discussed by areas (Figure U9). The areas have been delineated principally on the basis of the ground-water development and also on the occurrence of the primary and secondary aquifers. Some areas in which the development of the ground-water resources has been relatively insignificant have been delineated on the basis of physiographic features.

The areas which are discussed in their order of importance include the El Paso area, Salt Basin, Marfa-Presidio area, Marathon area, and the Stockton Plateau. Areas in which development of available ground-water supplies is small or insignificant include the Quitman Arroyo-Glenn Creek area, Big Bend area, and Diablo Plateau.

Figure U9

Map of the Upper Rio Grande Basin Showing Major Drainage Subdivisions and Principal Areas of Ground-Water Development

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General

The El Paso area includes major subdivisions 1, 2, and 4 of the Rio Grande Basin (Figure U9). It encompasses all of El Paso County and the western part of Hudspeth County.

The El Paso area has been subdivided into four parts on the basis of ground-water development (Plate U1):

1. The Mesa subarea, which is a part of the Hueco bolson, is bounded on the east by the Quitman, Malone, Hueco, and Finlay Mountains; on the north by the New Mexico state line; on the west by the Franklin Mountains; and on the south and southwest by the rimrock or scarp at the edge of the El Paso Valley of the Rio Grande.

2. The City Artesian subarea, which also is a part of the Hueco bolson, includes part of the city of El Paso and extends to Ysleta between the rimrock and the Rio Grande.

3. The Lower Mesilla Valley subarea, a part of La Mesa bolson, extends from Anthony on the Texas-New Mexico state line to the gorge northwest of El Paso.

4. The Lower Valley subarea extends from Ysleta southward to Fort Quitman. The occurrence of ground water in the Lower Valley subarea is similar to that in the City Artesian subarea; however, the Lower Valley is primarily an irrigated farming area and is separated from the City Artesian subarea on that basis only.

Occurrence and Movement

Ground water in the El Paso area occurs in the unconsolidated bolson deposits of the Hueco and La Mesa bolsons, in the river alluvium of the Mesilla and Lower Valleys, and in consolidated rocks principally of Cretaceous age.

In the Mesa subarea of the Hueco bolson, ground water occurs under water-table conditions and the sediments are filled with water to an altitude of about 3,735 feet at the Texas-New Mexico state line and to about 3,660 feet at the southern edge of the Mesa subarea near the rimrock. Except in the vicinity of areas of heavy pumping and along the foot of the Franklin Mountains, the gradient of the water table in the Mesa is approximately 4 feet per mile toward the south-southeast. The depth to water below the Mesa varies according to the slope of the land surface. The surface of the Mesa is troughlike, sloping steeply upward toward the Franklin Mountains and more gently upward toward the east. The depth to water ranges from about 206 feet near well 8 of section A-A' (Figure U10) to more than 400 feet on the slopes of the Franklin Mountains.

In the Mesa subarea, saline water occurs beneath and east of the fresh water-bearing beds in the bolson deposits. The depth to the salt water varies considerably within short distances largely due to the presence of clay beds and other relatively impervious material. In general, however, the fresh-water

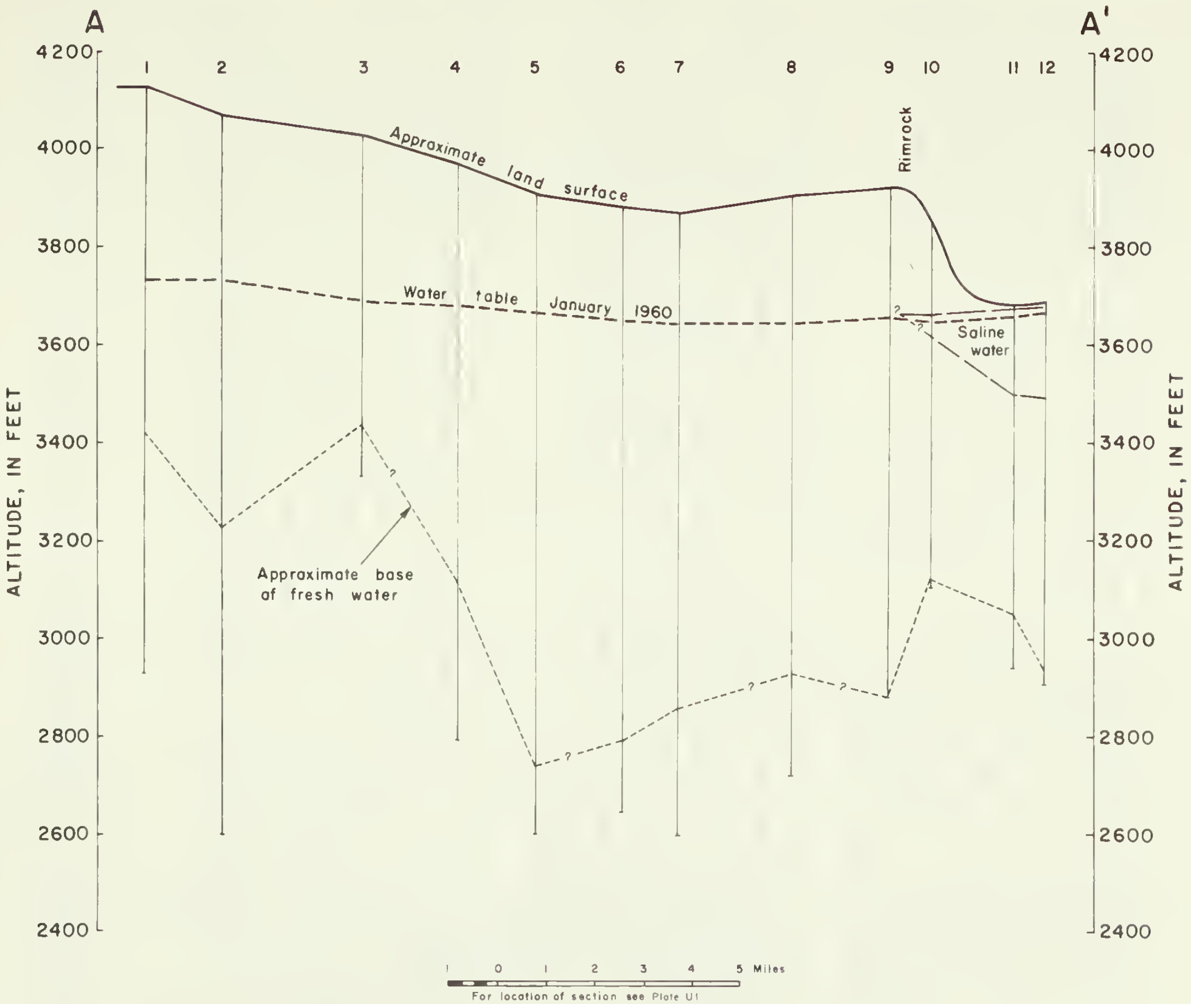

Figure U10

Section A-A', Hueco Bolson

(Leggat, 1962, fig 1, p. 8)

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body occurs as a trough roughly paralleling the Franklin Mountains. The contact between the fresh and salt water slopes steeply upward near the Franklin Mountains and more gently upward toward the east on the east side of the trough.

Fresh water occurs only in small quantities east and southeast of El Paso, and in some places it may be absent entirely. Results of chemical analyses of water from several wells drilled southeast of El Paso for construction purposes indicated a progressive increase in mineral content of the ground water in that direction.

Ground water moves from the Mesa subarea into the City Artesian subarea passing beneath relatively impermeable sediments and there becomes confined under pressure exerted by the higher elevation of the water surface underlying the Mesa. Figure U10 shows the abrupt thinning of the fresh-water sands south of the rimrock, which is the south edge of the Mesa subarea. It also shows that saline water overlies and underlies the fresh-water body in the City Artesian subarea. A part of the saline water may be attributed to the accumulation of salts resulting from evaporation of irrigation water. A larger part, however, probably is due to concentration by evaporation of ground water that formerly was discharged upward into the alluvium.

Figure U11 shows that saline water adjoins the fresh-water body on the south and that the fresh-water body thins to extinction approximately 15 miles downstream from the outcrop of the bedrock in the gorge near El Paso. Figure U11 shows a small lenticular body of relatively fresh water in the bolson deposits in the vicinity of Fabens (well 11 on Figure U11). The source of the water is probably in Mexico, being derived from precipitation and runoff from the east slopes of the Sierra del Presidio, southwest of the Rio Grande in Mexico. Test wells indicate that this zone of relatively fresh water extends only a short distance northeast of the Rio Grande.

In the Lower Mesilla Valley subarea, ground water occurs in the unconsolidated bolson deposits and in the overlying alluvium under both confined and unconfined conditions. In the valley, water in the bolson deposits is under artesian pressure, which is maintained by the altitude of the water table underlying the La Mesa bolson surface. Before pumping started in the bolson sediments, the hydrostatic pressure was sufficient to cause the water level in tightly cased wells in the valley to rise above the land surface. Pumping tests and fluctuation of water levels in observation wells reveal that the bolson deposits and the overlying river alluvium are hydraulically connected to some degree and pumping from the bolson deposits affects the water levels in the river alluvium.

In the Lower Valley subarea, ground water occurs in the alluvium under water-table conditions. In the underlying bolson deposits, however, ground water is under artesian pressure.

In the Mesa subarea near the southern end of the Hueco bolson in major subdivision 4, ground water occurs in sandstone probably of Trinity age. Few data are available to indicate the source of the water, but it probably is derived from precipitation on the outcrop of the sandstone, which lies northeast at the southern edge of the Diablo Plateau. The extent of the rocks of Trinity age is not known, but because of the post-Cretaceous block faulting the rocks of Trinity age probably underlie the Rio Grande Valley at depths greater than 3,000 feet. The ground water in these rocks probably is discharged into the overlying bolson deposits.

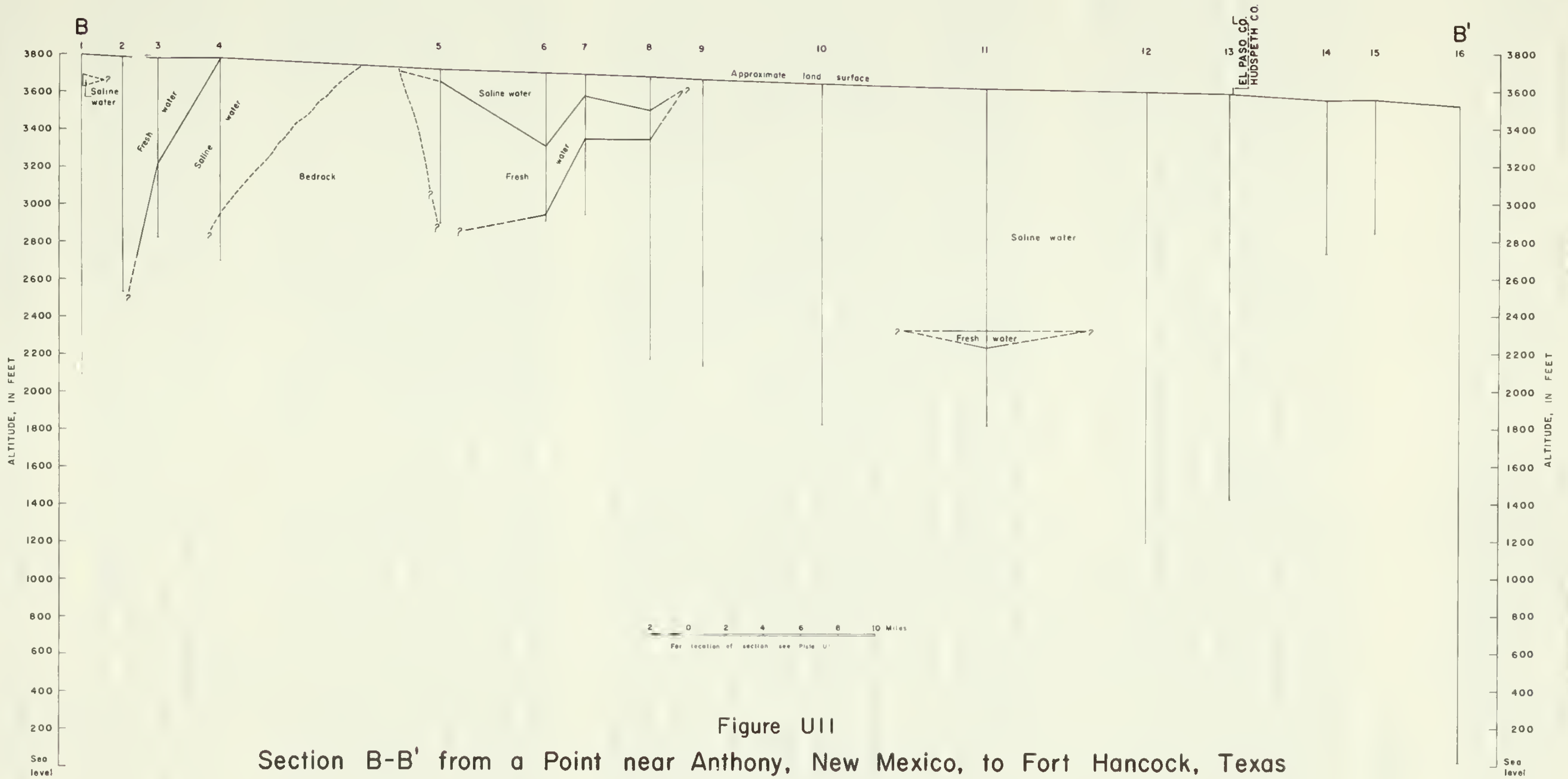

Figure U11

Section B-B' from a Point near Anthony, New Mexico, to Fort Hancock, Texas

(After Leggat, 1962, fig. 2, p. 9)

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The general movement of ground-water flow in the uplands is toward the Rio Grande except where large or concentrated withdrawals of ground water have formed cones of depression. The cone of depression is produced in the water surface by pumping and is shaped, roughly, like an inverted cone.

Recharge and Discharge

Recharge to the Hueco bolson is by infiltration of runoff from the mountains and of precipitation on the surface of the bolson. The principal area of recharge is relatively narrow, extending along the foot of the Franklin Mountains and mountains in New Mexico, although some recharge occurs from runoff ponded in several depressions in the bolson surface. The ponded water seeps rapidly from some of the depressions, whereas in others the water stands for long periods, slowly being consumed by evaporation. Sayre and Livingston (1945, p. 72) estimated that the average annual recharge to the Hueco bolson northeast of the Rio Grande was about 13 mgd. The amount of recharge from the Mexico side of the Rio Grande is not known.

Prior to the start of pumping in the Hueco bolson, the natural recharge was balanced approximately by the natural discharge. The ground water moved southward and southeastward to the Rio Grande, where the principal method of natural discharge was by seepage upward through the confining beds of the artesian part of the aquifer into the alluvial deposits where the water was discharged by evapotranspiration or by flow into the Rio Grande. However, as a result of heavy pumping, the hydrostatic pressure in the artesian part of the aquifer has been lowered below the level of the water table in the overlying alluvium and natural discharge upward has ceased in some places, and, instead, the saline water in the overlying deposits probably is moving downward into the fresh-water body. Although pumpage of ground water from the Hueco bolson far exceeds the average rate of natural recharge, all of the natural discharge of ground water by seepage into the valley alluvium has not been intercepted. In the southern part of the bolson in the El Paso Valley, the natural discharge from the bolson sediments upward probably is continuing.

Recharge to the bolson deposits in the Lower Mesilla Valley subarea is derived from precipitation on the bordering uplands and by underflow from the valley in New Mexico north of Anthony. It is estimated that recharge to the bolson sediments amounts to at least 13 mgd (Leggat and others, 1962, p. 18). Recharge to the shallow alluvium is principally by infiltration of surface water applied to the land surface for irrigation, but also to a lesser extent by seepage from canals and precipitation on the valley floor. It has been estimated (Leggat and others, 1962, p. 51) that the potential annual accretion to the alluvium in the valley is at least 36,000 acre-feet or about 33 mgd when surface-water supplies for irrigation are adequate and storage space is available in the alluvium.

Ground water in the bolson deposits in the Lower Mesilla Valley subarea is discharged naturally by upward movement in the shallow alluvium where it is lost by evapotranspiration, drain flow, and seepage to the Rio Grande. In localized areas pumping from the bolson deposits has retarded the movement of water into the alluvium from the bolson deposits. Moreover, if pumpage is great enough, the flow may be reversed.

Recharge and discharge of ground water in the shallow alluvium of the Lower Valley subarea is influenced by conditions similar to those in the Lower Mesilla

Valley. Recharge is principally by infiltration of surface water applied to the land surface for irrigation and limited amounts of seepage from canals and precipitation on the valley floor. The alluvium may be recharged also by upward seepage of water from the underlying bolson deposits. Discharge is by evapotranspiration, drain flow, and seepage to the Rio Grande.

Utilization

The development and utilization of ground-water supplies are concentrated more in the El Paso area than in any other part of the upper Rio Grande Basin. The general location and density of major water wells and other selected wells in the area are shown in Plate U1. However, in a part of the area, the density of wells was too great to permit locating individual wells, but the number of wells for a specific use in a concentrated area is shown. The amount of water pumped by the major wells for various uses in the El Paso area is shown in Table U2 (major subdivisions 1, 2, and 4).

In 1960, the withdrawal of ground water from all sources in the El Paso area was approximately 92,000 acre-feet, or about 82 mgd. Of this total, 46.1 mgd, or 56 percent, was pumped for public supply. Pumpage from small domestic and livestock wells was about 3,300 acre-feet or nearly 3 mgd, which represents less than 5 percent of the total pumpage in 1960.

The city of El Paso is the principal user of ground water in the area. In 1960, the city pumped an average of 40 mgd, 65 percent of which was obtained from 42 wells in the Hueco bolson deposits. The remaining 35 percent was pumped from 13 wells in the recently developed well field northwest of Canutillo in the Lower Mesilla Valley subarea. Some of the wells in the Canutillo well field are in the La Mesa bolson deposits and some are in the alluvium.

The industrial use of ground water in 1960 was about 7 mgd (Table U2), of which nearly 90 percent was obtained from 25 wells in the Hueco bolson; less than 1 mgd was pumped from the alluvial deposits in the Lower Mesilla Valley for industrial use.

Irrigation in the El Paso area is limited principally to the Lower Mesilla and Lower Valleys, although a few acres are irrigated in the Mesa subarea. Inasmuch as the ground-water supplies in the alluvial deposits of the Lower Mesilla and Lower Valleys supplement the surface-water supply from Elephant Butte Reservoir in New Mexico, the quantity of water pumped for irrigation is related inversely to the availability of surface water. In 1960 when 3.25 acre-feet per acre of surface water was allotted, 14,000 acre-feet was pumped from the alluvial deposits in El Paso County. Approximately 600 wells were available to irrigate about 58,500 acres of cotton, alfalfa, and truck crops. Because of the large surface-water allotment, however, many of the wells were not used. In that part of the Lower Valley in Hudspeth County, which is not included in the Rio Grande Reclamation Project, irrigators must rely on waste water from the project or ground water. In 1960, the amount of waste water available to the Hudspeth County Reclamation and Conservation District No. 1 was 2.58 acre-feet per acre; consequently, only 9,100 acre-feet of ground water was pumped from the alluvial deposits to irrigate about 9,500 acres.

Most of the 28,000 acre-feet of ground water pumped for irrigation in the El Paso area was slightly saline except in Hudspeth County, where the ground water ranges from slightly to moderately saline. In the Mesa subarea, however,

Table U2.--Withdrawals of ground water for public supply, industrial, and irrigation use, 1960, upper Rio Grande Basin

Major sub-division	Water-bearing unit	Number of wells			Public supply		Industrial		Irrigation		Totals*		Domestic and stock†
		Public supply	Industrial	Irrigation	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(acre-ft/yr)
RG- 1	Alluvium	18	--	97	2.75	b/ 3,081	--	--	1.9	b/ 2,100	4.6	5,200	210
	Bolson deposits	5	2	--	11.98	13,414	0.13	151	--	--	12	14,000	
2	Alluvium	--	--	522	--	--	--	--	11	b/ 12,000	11	12,000	3,000
	Bolson deposits	56	25	2	31.32	35,083	7.19	8,049	4.0	4,500	43	48,000	
4	Alluvium	1	--	83	.03	37	--	--	8.1	b/ 9,100	8.0	9,100	87
	Bolson deposits	--	--	--	--	--	--	--	--	--	--	--	
5	Alluvium	--	--	6	--	--	--	--	1.1	b/ 1,200	1.1	1,200	66
6	Alluvium	--	--	5	--	--	--	--	1.1	b/ 1,200	1.1	1,200	76
	Bolson deposits	--	--	2	--	--	--	--	.5	600	.5	600	
7	Alluvium	--	--	24	--	--	--	--	4.8	b/ 5,400	4.8	5,400	90
8	Igneous rocks	3	--	2	.72	805	--	--	.7	750	1.4	1,600	115
9	Alluvium	--	--	1	--	--	--	--	.1	150	.10	150	100
	Igneous rocks	--	--	2	--	--	--	--	.5	600	.50	600	
10	Alluvium	1	--	a/ 25	.02	24	--	--	0	0	.02	24	170
11	Alluvium	--	--	a/ 5	--	--	--	--	0	0	--	--	80
12	--	--	--	--	--	--	--	--	--	--	--	--	125
14	--	--	--	--	--	--	--	--	--	--	--	--	35
15	Alluvium	5	--	--	.02	17	--	--	--	--	.02	17	35
16	Marathon Limestone	2	--	--	.01	6	--	--	--	--	.01	6	300
17	--	--	--	--	--	--	--	--	--	--	--	--	100
18	--	--	--	--	--	--	--	--	--	--	--	--	50
19	--	--	--	--	--	--	--	--	--	--	--	--	160
21	--	--	--	--	--	---	--	--	--	--	--	--	140
22	Rocks of Fredericksburg and Washita Group, undifferentiated	1	--	--	--	2	--	--	--	--	--	2	140

See footnotes at end of table.

Table U2.--Withdrawals of ground water for public supply, industrial, and irrigation use, 1960, upper Rio Grande Basin--Continued

Major sub-division	Water-bearing unit	Number of wells			Public supply		Industrial		Irrigation		Totals*		Domestic and stock†
		Public supply	Industrial	Irrigation	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(mgd)	(acre-ft/yr)	(acre-ft/yr)
RG-23	Rocks of Trinity Group	12	--	--	0.22	250	--	--	--	--	0.22	250	135
	Bolson deposits	3	--	119	.32	357	--	--	32.0	36,000	32	36,000	
24	Bone Spring and Victorio Peak Limestones	2	1	210	.05	61	0.25	b/ 284	89	b/ 100,000	89	100,000	1,000
	Rocks of Trinity Group	1	--	--	.04	b/ 41	--	--	--	--	.04	41	
Subtotal major wells.....		110	28	1,105	47	53,000	7.6	8,500	150	170,000	210	240,000	
Domestic, stock, and miscellaneous wells.....											6	6,200	6,214
Total.....											220	250,000	

* Figures are approximate because some of the pumpage is estimated. Irrigation figures are shown to no more than two significant figures. Public supply, industrial, or other pumpage figures are shown to the nearest 0.01 mgd and to the nearest acre-foot. Totals are rounded to two significant figures.

† Water-bearing unit does not apply to domestic and stock withdrawals.

a/ Wells not used in 1960.

b/ Includes slightly saline to moderately saline water.

sands containing fresh and slightly saline water are screened in the same wells and somewhat more than 4 mgd was pumped for irrigation in 1960.

Fluctuations of Water Levels

Changes in water levels in wells in the El Paso area have been observed for many years. Prior to 1950, most of the changes were in the Hueco bolson where the withdrawals have been concentrated.

The withdrawals of ground water in the Hueco bolson have caused a decline in water levels over substantial parts of the Mesa, City Artesian, and Lower Valley subareas. Because the water occurs under both artesian and water-table conditions in the bolson, the decline represents an actual dewatering of the aquifer only in the Mesa subarea, whereas it represents a decline in pressure in the bolson sediments that underlie the City Artesian and Lower Valley subareas.

Water levels in observation wells in the Mesa subarea have declined steadily since at least 1936, the declines being greatest in wells closest to the areas of concentrated withdrawals (Figure U12). As the demands for additional water supplies increased, well fields were developed at progressively greater distances from the old well fields. Since 1937, water levels in the Mesa subarea have declined as much as 33.9 feet (Figure U13). The area of decline extends to the north beyond the Texas-New Mexico state line and to the east probably more than 10 miles from the main areas of pumping.

During the period 1959-60, the water levels in 45 wells in the Mesa subarea declined an average of 2.0 feet, the largest declines occurring in the north-central part of the city in the vicinity of the city of El Paso old Mesa well field and Biggs Field.

Water levels in wells in the City Artesian subarea respond rapidly to changes in pumping rates in the area. Furthermore, the effect of pumping from the Mesa subarea has caused an additional decline in the water levels. The hydrographs of two observation wells (Figure U12) show a fluctuation over a rather wide range, which is typical of the fluctuations in an artesian aquifer. They show that during the period of record, the water levels were highest in 1951. Since then they have declined steadily until 1956 when they began to level off or to rise slightly. In 1959, pumpage from the City Artesian subarea by the city of El Paso and industry decreased, resulting in a general rise of water levels; in 21 wells the rise averaged 3.0 feet. The largest rises in water levels were centered in the downtown section of El Paso and the refinery area of the industrial section in east El Paso.

Since 1937, the water levels declined a measured maximum of 29.5 feet in the industrial section (Figure U13) and declines as great as 26.6 feet were measured in downtown El Paso. Data are not available to determine the extent of the area of decline, but because of the barrier formed by the Franklin Mountains, which halts the spread of the cone of depression to the northwest, it is probable that the effect of pumping from the City Artesian subarea extends a considerable distance into the Lower Valley subarea.

In the Lower Mesilla Valley subarea, water levels in the alluvium fluctuate chiefly in response to changes in the availability of surface water for

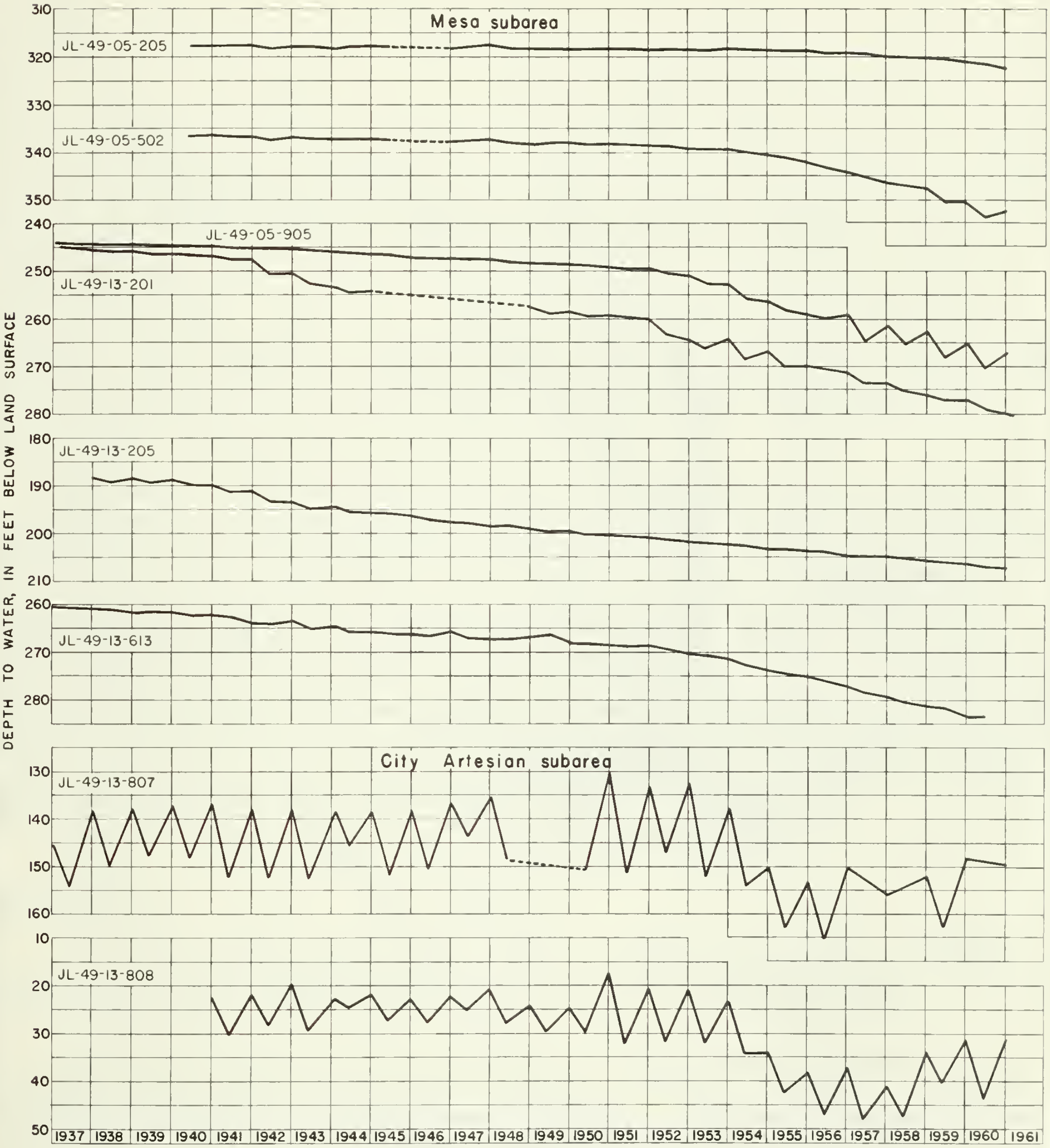

Figure U12

Hydrographs of Selected Wells in the Hueco Bolson

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

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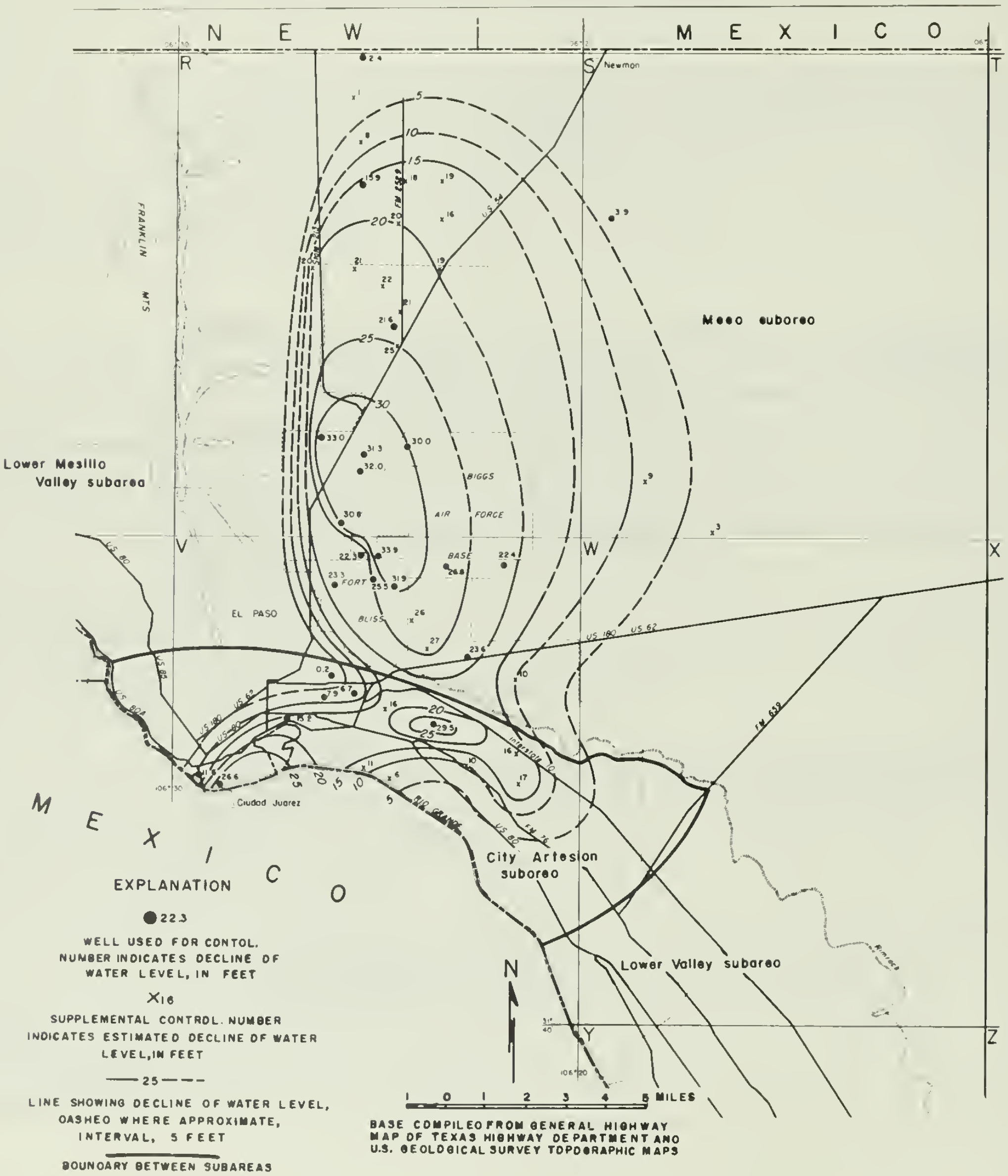

Figure U13

Approximate Decline of Water Levels in Wells Tapping the Bolson Deposits in the Vicinity of El Paso, 1937-60

(After Leggat, 1962, pl 5)

U S Geological Survey in cooperation with the Texas Water Commission

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irrigation. In most wells, the water levels generally were relatively stable through 1950, except for seasonal variations (Figure U14). The uniformity in the water levels indicates that the supply of surface water for irrigation was adequate. In general, water levels were highest during the growing season because of the infiltration of surface water applied to the land, and lowest during the winter in response to the discharge of ground water to the drains and river. During the period from about 1950 to 1957, the water levels in the alluvium declined throughout the Lower Mesilla Valley subarea, the rate and magnitude of the decline depending on the amount of ground water pumped to supplement the steadily decreasing supply of surface water. Most water levels rose during the period 1957-59 in response to the increase in surface-water allotments for irrigation and the substantial decrease in the pumpage of ground water, except in those parts of the valley where the irrigation supply is entirely from ground water. In January 1960, the water levels in some wells in the subarea (well JL-49-04-701, Figure U14) were higher than the lowest water levels in 1946, probably because silting had raised the beds of the drains and the river. In any well in the alluvium the minimum level is controlled largely by the altitude of the bottom of a nearby drain or the river, and it occurs just before irrigation begins in the spring.

The Lower Valley subarea is an irrigated farming area and the availability of water and fluctuations of water levels in wells tapping the alluvium are similar to those in the Lower Mesilla Valley subarea. The hydrographs of six wells tapping the alluvium in the Lower Valley subarea are shown in Figure U15. In general, the water levels in wells in the Lower Valley subarea showed a steady downward trend from 1953 to 1957. Since then, the water levels have risen steadily until in January 1960 they were higher than in January 1953 except in the part of the valley northwest of Ysleta where in recent years irrigation has been greatly reduced. As a consequence, less surface water has been applied for irrigation, which resulted in less recharge to the alluvial deposits. The decline in water levels in three wells in the latter part of 1959 indicates that the reservoir was full and the excess water was being discharged to the drains and the river.

Aquifer Tests

Ground-water development from aquifers in the El Paso area is dependent largely upon the hydraulic properties of the aquifers, principally the ability of the aquifers to transmit and store water.

Measured transmissibility values ranged from as high as 200,000 gpd (gallons per day) per foot in the Mesa subarea of the Hueco bolson to as low as 22,000 gpd per foot in the City Artesian subarea. An average transmissibility in the fresh-water zone of the Mesa subarea is probably about 150,000 gpd per foot, but in the artesian part of the bolson, where the thickness of the fresh-water sands is much reduced, the average transmissibility probably is on the order of 100,000 gpd per foot.

The specific yield of the bolson deposits is difficult to determine from pumping tests of short duration. Sayre and Livingston (1945, p. 29) estimated the average specific yield of all the bolson deposits in the Mesa subarea to be about 17.5 percent. Southward in the artesian part, the coefficient of storage is considerably smaller than that of the sediments in the Mesa subarea; pumping tests of five wells showed that the coefficient of storage was relatively uniform, ranging from 0.0027 to 0.00063, and averaging 0.0015 (Leggat, 1962, p. 25).

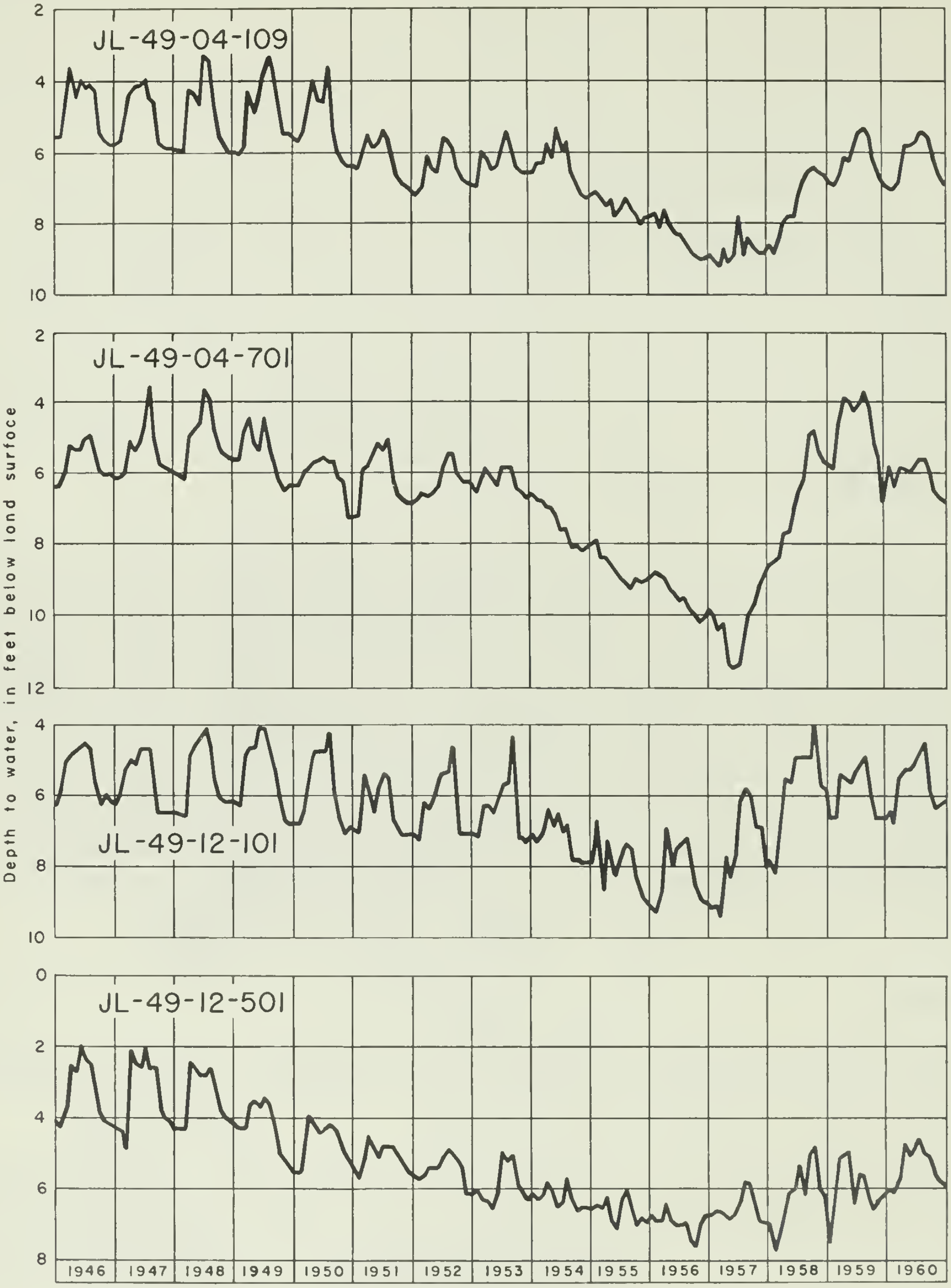

Figure U14

Hydrographs of Selected Wells in the Alluvium of the Lower Mesilla Valley Subarea

(From records of the U.S. Bureau of Reclamation)

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

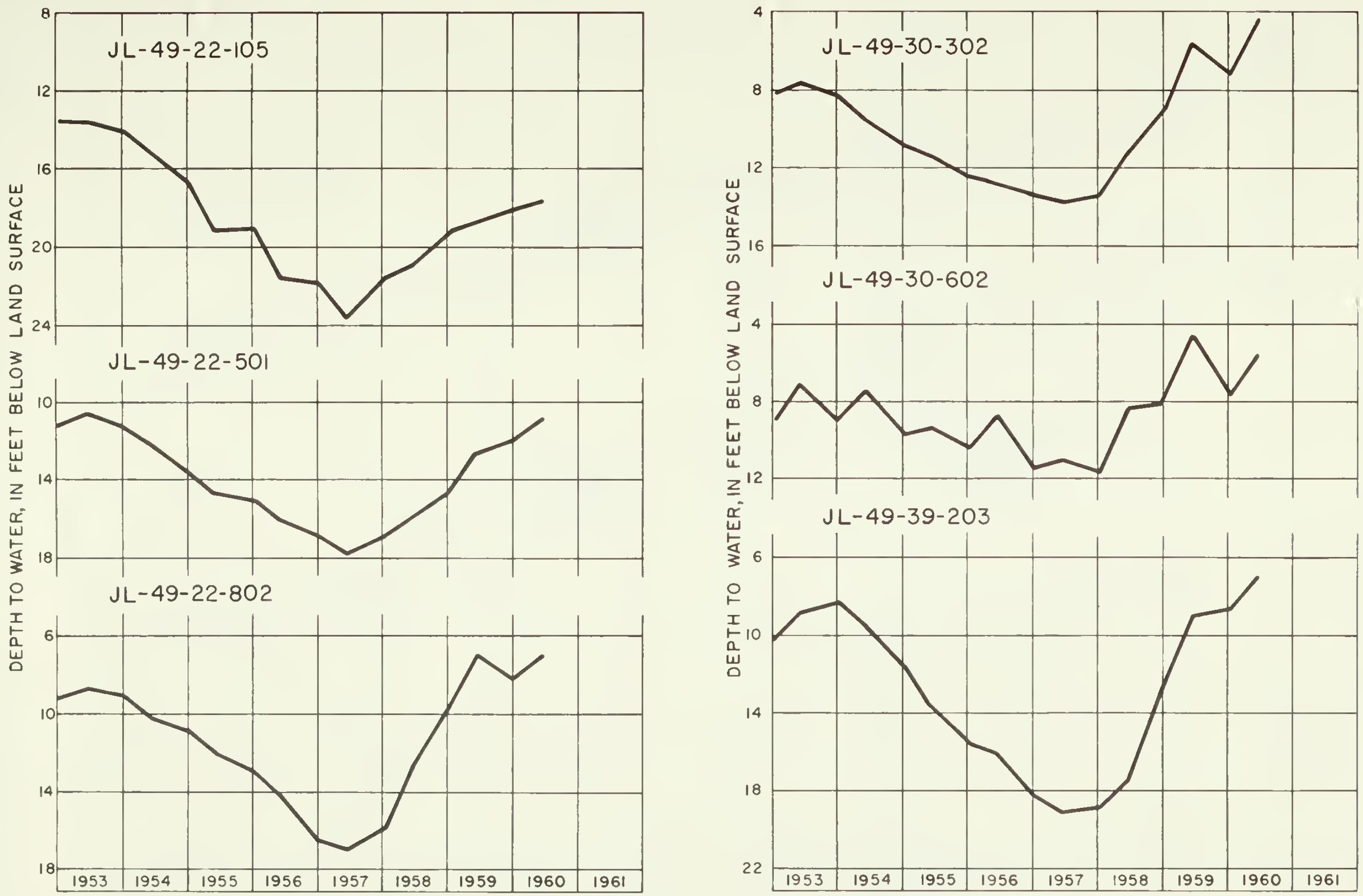

Figure U15

Hydrographs of Selected Wells in the Alluvium of the Lower Valley Subarea

(From records of the U.S. Bureau of Reclamation)

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

The yields of wells in the Hueco bolson range over wide limits. Yields as great as 3,000 gpm have been obtained on test; however, the average yield of most of the wells in the Mesa subarea probably is about 1,500 gpm; in the City Artesian subarea, the yields are smaller, probably averaging less than 1,000 gpm. Specific capacities as high as 58.0 gpm per foot of drawdown were measured in the Mesa subarea, but the average is probably about 25 gpm per foot. In the City Artesian subarea, the specific capacities in 11 wells ranged from 10.6 to 23.0 gpm per foot, and averaged 16.0 gpm per foot, nearly 35 percent less than the average specific capacity of wells in the Mesa subarea (Leggat, 1962, p. 25).

In the Lower Mesilla Valley subarea, aquifer tests indicate that the average transmissibility of the bolson and alluvial deposits, which are interconnected, is about 250,000 gpd per foot, of which 100,000 gpd per foot probably is representative of the bolson sediments; the remaining 150,000 gpd per foot probably is the average transmissibility for the shallow alluvial deposits. Aquifer tests in the bolson deposits revealed an average coefficient of storage of 0.0007; however, after 24 hours of pumping from the deep aquifer, which is the homogeneous sand body in the lower part of the bolson deposits, the drawdown in the wells was less than the predicted drawdown, indicating leakage from the overlying aquifers (medium aquifer and the alluvium). Actually, the coefficient of storage from the bolson deposits ultimately may equal the 0.1 specific yield estimated for the alluvium (Leggat and others, 1962, p. 34).

Yields as great as about 3,000 gpm have been measured in wells that tap the alluvial or bolson deposits in the Lower Mesilla Valley subarea. Most of the wells used for irrigation or public supply had yields greater than 1,000 gpm. In the uplands, however, yields were considerably less owing to a marked decrease in the saturated thickness of the bolson deposits toward the Franklin Mountains. Because of the wide variation in well construction and the heterogeneity of the alluvial deposits and the upper part of the bolson deposits, specific capacities ranged from 3.0 to 61 gpm per foot of drawdown. Specific capacities of six wells that tap the deep aquifer of the bolson deposits ranged from 19.7 to 30.7 gpm per foot; in a well screened in the medium aquifer, the specific capacity was 14.0 gpm per foot (Leggat and others, 1962, p. 31).

The hydrologic properties and performances of wells tapping the alluvium in the Lower Valley subarea are similar to those of wells in the Lower Mesilla Valley subarea. The bolson sediments, however, may be considerably different than those in the Lower Mesilla Valley. Several wells obtain water from the bolson deposits underlying the alluvium in the Lower Valley subarea and the data from one of the wells indicated that the coefficients of transmissibility and storage are low, probably on the order of 25,000 gpd per foot and 0.00003, respectively (Leggat, 1962, p. 27). If these low coefficients are representative of the bolson deposits in the Lower Valley subarea, large drawdowns and considerable mutual interference would characterize wells screened in the bolson deposits. Yields of the wells tapping the bolson are relatively small, ranging from 150 gpm in wells supplying the city of Fabens to 530 gpm in a well tapping a sand at a depth of 1,454 to 1,647 feet 3 miles southwest of Fabens.

If the geologic and hydrologic conditions are favorable, the coefficients of transmissibility and storage may be used to predict the general order of magnitude of drawdown in water levels caused by withdrawal of water or an increase in pumping in an area. The theoretical drawdown curves in Figure U16 were computed from representative coefficients for the bolson sediments in the Mesa and City Artesian subareas.

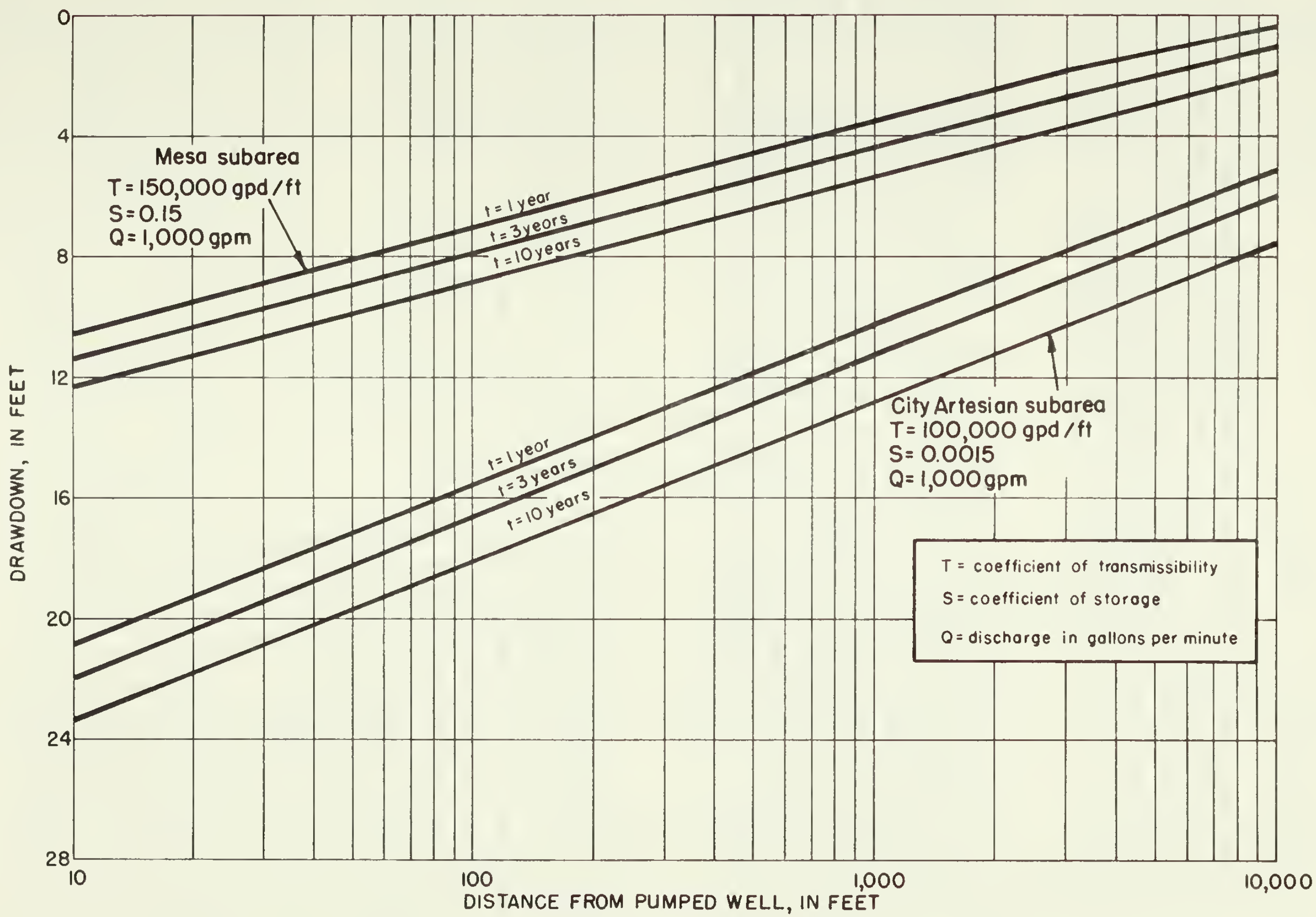

Figure U16

Theoretical Drawdown Due to Pumping in the Hueco Bolson in the Vicinity of El Paso

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

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Quality of Water

Ground water in the El Paso area ranges from fresh to very saline. Fresh ground water actually constitutes a small fraction of the total quantity of water in storage. Where fresh ground water is available, it is underlain, overlain, or adjoined by slightly saline water, the water becoming increasingly mineralized with depth as well as laterally.

Table U3 shows the chemical analyses of water from selected wells in the El Paso area (major subdivisions 1, 2, and 4). The analyses shown are only a small fraction of the analyses on record, but they may be considered representative of the water that occurs in the area. The locations of the wells sampled are shown in Plate U1. The dissolved-solids, chloride, and sulfate content of water from additional wells, some of which are not included in Table U3, are shown in Plate U3.

In the Hueco bolson, or major subdivision 2, the water pumped for public supply from the Mesa subarea generally is moderately low in dissolved-solids, chloride, and sulfate content, and is moderately hard. Southward in the City Artesian subarea, water pumped from the bolson for public supply and industry is somewhat more mineralized, and in many wells the chloride content exceeds the limits proposed by the U. S. Public Health Service. However, when the water is mixed with fresh water in suitable proportions, it is usable for public supply. The high chloride content in some wells tapping the bolson in the City Artesian subarea is due, in part, to contamination from overlying or underlying highly mineralized water which enters the wells through leaks and by interformational leakage.

In the Lower Mesilla Valley subarea, the quality of the water varies areally and also with depth. North and northwest of Canutillo, the bolson deposits yield fresh water which is low in dissolved-solids content and is soft. In 1960, the city of El Paso obtained 30 percent of its ground-water supply from the bolson deposits. According to Leggat and others (1962, p. 41) the fresh water in the bolson deposits probably could be used for irrigation, "Although the percent sodium generally exceeds 80, the residual sodium carbonate and the boron content...are lower than the recommended limits." West and southwest of Canutillo, however, the water in the bolson deposits increases in mineral content until it becomes unfit for most uses.

The quality of the water in the alluvium in the Lower Mesilla Valley subarea varies laterally and also with time. In general, the water is slightly to moderately saline, although in the city of El Paso well field northwest of Canutillo, water from the alluvium is relatively fresh but is higher in dissolved-solids content than the water in the underlying bolson deposits. However, during periods when the surface-water supply for irrigation is inadequate, ground water is pumped as a supplemental supply. As a consequence, the salinity of the water increases primarily because of concentration of the salts by evaporation. When surface-water supplies are adequate, the ground-water reservoir is replenished with water containing lower mineralization. Southward from the El Paso well field, the water in the alluvium increases in mineralization, but generally it is of better quality than the water in the underlying bolson deposits. Although the water is used for irrigation, excess water is applied to leach the soil of accumulated salt. Based on data from Longenecker and Lyerly (1959, table 2, p. 4), the water is classed as very high in salinity hazard. Generally, water of this type may be used under special circumstances,

Table U3.--Chemical analyses of water from selected wells and springs in the upper Rio Grande Basin

(Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio.)

Water-bearing unit: Qa, Alluvium; Tb, Bolson deposits; Kt, Trinity Group and equivalents; Ti, Igneous rocks; Om, Marathon Limestone; Qac, Alluvium and Cretaceous rocks, undifferentiated; Kfw, Fredericksburg and Washita groups, undifferentiated, and equivalents; ₽, Pennsylvanian rocks; Kdr, Devils River Limestone; Pvd, Bone Spring and Victorio Peak Limestones, undifferentiated; Tt, Tascotal Formation (of Goldich and Seward, 1948); K, Cretaceous rocks.

Major sub-division	Well number	Water-bearing unit	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
1	JL-49-03-901	Qa	125	Mar. 26, 1952	57	--	24	29	*337		466	240	192	--	0.0	0.66	1,110	179	80	11	1,760	8.0
	04-104	Tb	1,206	May 3, 1960	29	0.01	5.0	.1	86	1.0	[d] 81	74	43	0.7	.0	.09	279	13	92	10	438	8.8
	106	Tb	1,090	July 15, 1958	39	[a] .00	4.0	.3	80	.9	[c] 74	69	38	1.2	.0	.08	257	11	93	10	411	8.5
	107	Tb	550	Aug. 28, 1957	32	[a] .03	13	1.2	97	3.2	95	99	52	.3	.0	.12	345	38	84	6.9	538	8.0
	202	Tb	501	Oct. 13, 1960	33	.69	64	38	166	13	189	219	215	.4	1.0	.27	843	316	52	4.1	1,380	7.5
	404	Qa	156	June 19, 1956	39	--	86	18	319	3.9	311	399	232	--	.5	--	1,250	288	70	8.2	1,960	8.1
	407	Qa	200	May 29, 1956	39	--	78	18	*132		240	218	92	.7	.0	--	696	268	52	3.5	1,080	7.7
	12-101	Qa	128	Mar. 30, 1951	45	--	94	59	*933		808	939	610	.6	1.0	1.2	3,080	477	81	19	4,510	7.7
	103	Qa	130	Mar. 26, 1952	51	--	41	37	*1,120		458	955	940	--	.8	1.3	3,370	254	91	31	5,340	8.2
2	JL-48-33-702	Qa	180	July 23, 1956	33	--	137	38	598	13	235	518	780	--	.2	.51	2,230	498	72	12	3,600	7.8
	49-05-201	Tb	631	Feb. 24, 1959	35	[a] .02	32	7.9	101	9.1	100	71	86	.8	3.0	.18	435	112	64	4.1	704	8.1
	304	Tb	875	July 12, 1957	38	--	67	12	223	8.1	82	24	435	--	6.8	.07	854	216	68	6.6	1,610	7.6
	802	Tb	830	May 10, 1956	32	[a] .01	39	17	100	4.3	226	74	86	1.4	3.8	.06	469	168	56	3.4	772	7.6
	08-602	Tb	467	Mar. 25, 1960	39	--	64	9.1	*65		180	110	47	.5	10	--	434	197	42	2.0	656	7.5
	13-302	Tb	812	May 16, 1961	39	[a] .00	24	9.0	*119		191	87	71	1.3	6.6	--	454	97	73	5.2	733	7.5
	603	Tb	780	Oct. 20, 1960	28	.09	17	6.7	*83		162	55	38	.9	5.6	--	320	70	72	4.3	505	7.6
	907	Tb	694	June 12, 1959	30	--	42	12	*185		150	72	252	.9	.8	--	669	154	72	6.5	1,180	7.7
	14-301	Tb	420	Mar. 30, 1953	28	2.7	59	21	185	10	114	206	240	.4	4.2	.19	810	234	62	5.3	1,380	7.7
	701	Tb	722	May 15, 1959	24	.05	18	4.7	91	7.7	162	62	47	.8	4.2	.08	340	64	73	4.9	557	7.8
	15-401	Tb	600	Mar. 25, 1952	31	--	79	29	*489		120	685	410	.8	2.0	.22	1,780	316	77	12	2,790	8.2
	601	Tb	475-495	July 19, 1953	12	32	20	2.1	128	3.0	180	88	73	.9	1.5	.24	422	58	82	7.3	681	8.0
	16-801	Tb	526	Feb. 16, 1953	30	--	253	67	*2,170		270	688	3,320	--	--	--	6,660	906	84	31	11,300	7.5
	22-201	Tb	600	Nov. 9, 1950	28	1.8	40	9.8	*200		130	84	269	--	1.0	--	704	140	76	7.3	1,220	7.8
	301	Tb	312	Apr. 6, 1960	32	--	64	21	*346		106	303	422	--	1.0	--	1,240	246	75	9.6	2,080	7.5
	23-201	Tb	440	Dec. 8, 1952	25	--	60	15	*477		83	219	675	--	.2	--	1,510	211	83	14	2,670	7.8

See footnotes at end of table.

Table U3.--Chemical analyses of water from selected wells and springs in the upper Rio Grande Basin--Continued

Major sub-division	Well number	Water-bearing unit	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
2	JL-49-30-301	Qa	168	Sept. 24, 1948	23	--	30	10	*291		170	107	352	--	2.5	--	913	116	85	12	1,650	--
	31-201	Tb	400	May 16, 1958	--	a/ 0.003	364	--	--		39	799	2,670	0.4	--	--	5,140	1,140	--	--	--	8.2
	401	Qa	108	July 30, 1956	36	--	159	29	237	6.2	399	388	218	--	.5	0.22	1,270	515	50	4.5	1,930	7.7
	701	Qa	174	Mar. 11, 1957	33	--	196	35	444	7.0	343	624	498	.6	.5	.29	2,010	633	60	7.7	3,100	7.5
	32-501	Tb	521	Apr. 30, 1952	35	--	23	7.9	*426		204	322	365	--	.2	--	1,280	90	91	20	2,180	8.4
	701	Tb	400	Feb. 5, 1960	--	a/ .13	420	165	--	--	112	466	1,910	--	--	--	5,120	1,730	--	--	--	--
	39-301	Tb	328	July 19, 1956	32	--	38	8.4	132	3.8	230	103	91	.5	.0	--	522	129	68	5.1	851	8.0
	40-501	Qa	--	July 23, 1956	36	--	478	81	1,050	16	423	1,060	1,740	--	2.0	.42	4,670	1,530	60	12	6,940	7.4
	601	Tb	350	Apr. 6, 1960	42	--	47	16	*440		180	201	555	--	.8	--	1,390	184	84	14	2,400	7.5
4	PD-48-34-701	Tb	295	Dec. 10, 1959	30	--	68	25	*636		189	912	380	2.2	12	--	2,160	272	84	17	3,110	7.5
	801	Tb	906	Dec. 11, 1959	18	--	77	16	*837		154	1,440	310	4.4	4.2	--	2,780	258	88	23	3,730	7.0
	901	Kt	356	Dec. 10, 1959	19	a/ .01	46	17	362	5.5	290	514	142	5.3	1.0	.90	1,260	185	80	12	1,850	7.8
	902	Kt	406	do	21	--	46	18	*460		298	670	165	5.6	.0	--	1,530	189	84	15	2,220	7.7
	41-202	Qa	90	July 23, 1956	40	--	246	66	802	14	382	871	1,040	--	.5	.45	3,270	886	66	12	4,990	7.6
	42-701	Qa	50	do	34	--	181	48	612	8.6	262	614	810	--	1.0	.46	2,440	649	67	10	3,870	7.7
	702	Qa	213	Dec. 4, 1961	25	1.5	28	7.6	258	3.3	272	210	157	1.4	.2	--	825	102	84	11	1,340	7.5
	51-801	Qa	30	Apr. 19, 1961	52	--	74	28	*135		448	64	86	1.5	42	--	710	300	49	3.4	1,110	7.2
5	PD-48-61-201	Tb	--	Apr. 12, 1951	21	--	56	35	*130		328	233	39	--	.2	--	675	284	50	3.4	1,030	8.2
	62-701	Tb	525	do	25	--	46	26	*137		314	196	42	--	.2	--	626	222	57	4.0	967	8.3
	50-14-501	Ti	Spring	Dec. 14, 1961	42	.13	135	28	*2,370		892	1,150	2,600	--	--	--	6,760	452	92	49	10,400	6.5
	502	Ti	Spring	do	35	.03	63	19	*839		668	504	700	--	.0	--	2,490	235	89	24	3,990	7.2
6	UW-51-25-101	Qa	60	Apr. 19, 1961	32	--	140	34	300	8.8	300	378	350	1.0	.0	.46	1,390	490	57	5.9	2,210	7.0
7	UW-51-51-601	Ti	Spring	Mar. 30, 1961	29	--	19	.6	*183		350	117	27	--	.0	--	548	50	89	11	867	7.9
	801	Qa	50	Apr. 22, 1961	33	--	290	53	631	14	412	836	785	.9	.0	.55	2,850	942	59	9.0	4,250	7.3
	901	Qa	80	Mar. 30, 1961	85	a/ .01	26	2.4	107	2.6	292	36	12	2.0	9.2	.23	426	75	75	5.4	574	5.4
8	UW-51-48-602	Tt	881	July 19, 1948	72	a/ .05	26	2.2	59	13	192	26	17	2.8	4.2	.20	328	74	34	3.0	442	7.6
	52-41-901	Ti	840	Aug. 18, 1942	40	a/ .05	34	3.5	*78		199	48	30	3.2	6.7	--	341	100	63	3.4	--	7.7
	49-402	Tt	800	Aug. 25, 1958	75	.01	27	2.9	58	7.2	190	26	16	2.4	5.0	.28	314	79	59	2.8	427	7.7

See footnotes at end of table.

Table U3.--Chemical analyses of water from selected wells and springs in the upper Rio Grande Basin--Continued

Major sub-division	Well number	Water-bearing unit	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
9	UW-51-56-902	Qa	99	Aug. 3, 1958	65	0.01	57	6.6	14	8.3	219	10	6.2	1.4	8.4	0.18	295	169	14	0.5	410	7.2
	74-16-301	Ti	1,185	Aug. 1, 1958	26	.03	.8	.0	115	.4	b/ 243	25	13	2.8	7.5	.21	319	2	99	35	503	8.8
	24-201	Ti	694	do	21	.01	1.6	.2	119	.7	b/ 223	37	18	2.0	13	.29	336	5	98	23	520	8.5
10	UW-74-30-402	Qa	48	July 19, 1948	60	.05	78	9.8	63	8.4	260	114	28	1.2	9.6	--	524	235	--	1.8	--	--
	403	Qa	50	Mar. 29, 1961	52	--	210	22	289	6.1	346	624	194	--	43	.53	1,610	614	50	5.1	2,240	6.8
11	f/ UW-74-32-401	Ti	Spring	Nov. 23, 1949	59	--	44	6	24	2.0	151	20	16	1.1	12	.13	257	134	28	.9	359	7.8
	f/ 39-501	Qa	25	Nov. 2, 1949	67	--	125	21	439	5.1	252	566	383	4.0	32	.5	1,790	398	70	9.6	2,650	7.6
12	f/ BK-73-44-802	Qa	34	Sept. 22, 1949	29	--	143	17	142	7.0	196	552	11	1.3	11	.18	1,050	427	41	3.0	1,360	7.9
	46-801	Ti	Spring	July 13, 1960	24	--	37	1.8	*29		134	30	7.5	3.3	3.8	--	208	100	39	1.3	301	7.2
14	f/ BK-73-55-601	K	Spring	Sept. 22, 1949	38	--	76	6.8	67	2.0	330	43	18	2.9	--	.24	427	218	40	2.0	677	8.0
15	BK-73-47-501	Qa	217	July 13, 1960	30	--	45	3.5	*21		154	21	10	1.4	7.8	--	226	127	26	.8	327	7.1
	f/ 49-401	Qac	Spring	Sept. 22, 1949	26	--	134	38	101	5.9	273	372	71	2.1	.6	.32	934	541	31	1.9	1,290	7.5
	502	Qac	Spring	July 13, 1960	22	--	126	36	*100		266	344	69	1.9	1.5	--	900	462	32	2.0	1,210	7.0
16	BK-52-55-103	Om	200	Mar. 9, 1957	16	--	68	46	*82		322	123	98	1.8	3.0	--	596	358	33	1.9	1,020	7.5
	61-502	Kfw	Spring	Mar. 5, 1957	16	--	72	10	*13		258	27	5.8	.6	.5	--	276	220	12	.4	464	7.7
	63-101	₱	125	Mar. 12, 1957	26	--	108	22	*41		342	107	36	.8	5.0	--	533	360	20	.9	828	7.2
17	BK-73-23-801	--	122	Dec. 3, 1953	6.0	a/ .08	28	22	*1,590		435	2,920	159	2.2	1.0	--	4,940	160	96	15	6,350	8.2
18	f/ BK-72-10-201	Kt	1,690	Jan. 24, 1950	17	--	66	37	81	14	130	188	35	1.5	19	.30	610	316	35	2.0	951	7.6
	f/ 26-501	Kt	Spring	Jan. 9, 1950	28	--	71	18	58	3.9	227	123	47	1.1	2.5	.15	478	251	33	1.6	733	7.7
19	BK-52-56-201	Qa	75	Mar. 12, 1957	22	--	60	11	*108		332	98	37	.6	3.2	--	503	194	55	3.4	804	7.6
	72-11-701	Kdr	1,193	Apr. 20, 1961	9.3	--	38	41	*80		146	162	65	1.8	67	--	536	264	40	2.1	876	6.7
	f/ 12-801	Kdr	Spring	Jan. 24, 1950	27	--	72	21	68	5.1	242	134	50	1.1	6.8	.14	515	256	35	1.8	791	7.6
	13-201	Kdr	868	Apr. 20, 1961	16	--	44	12	5.5	1.0	162	12	9.2	.4	13	--	193	159	7	.2	337	6.9
21	US-52-33-801	₱	220	Apr. 4, 1958	24	--	117	79	*111		421	415	58	--	.0	--	1,010	617	28	1.9	1,470	8.2
	53-37-401	Tt	610	Oct. 28, 1958	18	--	66	14	*20		245	26	20	.6	9.8	--	294	222	16	.6	495	7.4
	XX-54-50-701	Kt	550	Nov. 8, 1960	8.6	--	39	40	*81		224	133	78	2.2	.0	--	492	262	40	2.2	832	7.9
	BK-52-48-201	₱	100	Mar. 11, 1957	19	--	60	60	*83		316	159	98	1.8	11	--	647	396	31	1.8	1,080	7.4
22	US-53-43-601	Kt	310	Oct. 9, 1958	12	--	54	11	*19		243	2.2	14	--	.0	--	231	180	19	.6	409	7.6

See footnotes at end of table.

Table U3.--Chemical analyses of water from selected wells and springs in the upper Rio Grande Basin--Continued

Major sub-division	Well number	Water-bearing unit	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
22	YR-71-03-401	Kdr	1,000	Apr. 18, 1939	--	--	82	20	*5		232	70	16	1.0	--	--	304	287	--	0.1	--	--
	f/ XX-53-64-601	Kdr	643	Jan. 23, 1950	20	--	63	23	15	3.1	234	47	23	.6	22	0.08	346	252	12	.4	540	7.7
23	US-53-50-601	Kt	--	Oct. 9, 1958	16	--	55	20	*22		228	30	27	--	13	--	304	219	18	.6	504	8.1
	XX-53-53-802	Kt	625	Aug. 17, 1940	--	a/ 0.05	18	17	*47		e/ 190	26	18	.5	7.5	--	391	115	47	1.9	--	--
	f/ 72-15-301	Kfw	--	May 7, 1951	21	--	52	21	14	1.6	117	25	13	.6	6.8	.09	272	216	12	.4	457	7.8
24	PD-47-09-802	Pvb	515	July 26, 1960	22	--	145	65	*91		278	438	98	--	5.4	--	1,000	630	24	1.6	1,460	7.1
	17-201	Tb	250	do	19	--	448	245	*601		252	1,370	1,270	--	11	--	4,090	2,130	38	5.7	5,760	7.0
	48-07-205	Pvb	325	July 2, 1960	18	--	465	209	251	4.3	217	1,370	590	1.8	102	.28	3,120	2,020	21	2.4	3,940	7.1
	501	Pvb	220	Mar. 22, 1960	16	--	458	185	438	9.7	223	1,450	820	--	63	.40	3,550	1,900	33	4.4	4,850	6.9
	601	Pvb	260	Mar. 25, 1960	15	--	228	77	197	7.1	278	592	345	--	4.8	.12	1,600	886	32	2.9	2,420	7.0
	12-101	--	2,308	Oct. 5, 1958	11	a/ .01	28	11	*2,210		928	224	2,820	3.6	--	--	5,760	115	98	9.0	9,730	7.9
	16-701	Pvb	125	July 26, 1960	20	--	270	126	*443		264	1,010	590	--	68	--	2,660	1,190	45	5.6	3,750	6.8
	54-401	Kt	1,100	Apr. 25, 1961	17	--	175	59	*1,000		416	562	1,360	3.4	.0	--	3,380	679	76	17	5,580	6.9
	402	Kt	975	Sept. 14, 1948	25	a/ .30	60	17	489	2.6	342	363	450	5.2	13	.99	1,620	220	81	14	2,660	7.7
	64-901	Tb	1,000	July --, 1943	--	--	10	8.2	*151		238	135	32	--	6.9	--	460	58	85	8.6	770	--
	51-01-501	Tb	501	Mar. 27, 1961	16	--	6.5	1.6	*139		b/ 315	46	14	--	.0	--	378	22	93	13	648	9.2
	HL-47-17-301	Pvb	385	Mar. 24, 1960	15	--	150	61	85	3.9	306	398	116	--	.2	.08	979	625	23	1.5	1,470	7.5
	602	Tb	200	July 26, 1960	25	--	270	71	*265		208	720	430	--	19	--	1,900	966	37	3.7	2,760	7.2
	43-301	Tb	280	Apr. 28, 1960	18	--	175	98	448	22	291	698	630	--	1.0	.48	2,230	840	53	6.7	3,470	7.0
	51-801	Tb	400	do	28	--	26	15	254	3.4	283	228	142	--	9.7	.64	846	126	81	9.8	1,370	7.5
	58-701	Tb	1,500	Mar. 28, 1960	38	--	17	7.1	117	7.6	250	83	22	2.3	6.3	.35	424	72	76	6.0	650	7.5
	59-101	Tb	625	Aug. 10, 1954	31	--	19	8.5	*194		290	157	70	1.6	6.3	.45	651	82	84	9.3	1,020	7.8
	201	Tb	550	May 12, 1960	20	--	98	61	285	12	262	390	362	--	2.8	.31	1,360	496	55	5.6	2,160	7.0
	60-502	--	600	July 29, 1960	14	--	156	78	*508		282	612	670	--	1.0	--	2,180	710	61	8.3	3,430	7.1
	51-10-303	Tb	403	May 13, 1960	58	--	13	4.2	86	5.0	201	48	18	--	5.3	.21	337	50	77	5.3	485	7.5
	606	Tb	355	do	60	--	12	5.0	82	5.6	200	44	16	--	3.5	.23	326	50	76	5.0	471	7.9
	PS-51-19-101	Tb	430	May 3, 1950	34	--	--	--	51	--	160	12	7.0	--	2.2	.06	209	44	72	3.3	311	8.0
	28-101	Tb	302	Mar. 29, 1961	29	--	38	4.6	19	2.2	153	13	10	.7	.2	.09	192	114	26	.8	302	7.4

See footnotes at end of table.

Table U3.--Chemical analyses of water from selected wells and springs in the upper Rio Grande Basin--Continued

Major sub-division	Well number	Water-bearing unit	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
24	UW-51-38-401	Tb	372	Mar. 30, 1961	72	--	16	2.8		*95	201	62	16	--	6.6	--	369	52	80	5.7	508	7.6
	46-402	Tb	600	do	67	--	30	12		*35	204	13	10	1.1	4.0	--	272	124	38	1.4	380	7.5

* Sodium and potassium calculated as sodium (Na).
a/ Iron in solution.
b/ Includes equivalent of any Carbonate (CO_3) present.
c/ Includes equivalent of 3 ppm Carbonate.
d/ Includes equivalent of 9 ppm Carbonate.
e/ Includes equivalent of 20 ppm Carbonate.
f/ Analyzed by U. S. Salinity Laboratory of U. S. Dept. Agriculture.

which include very permeable soil, excess water applied for leaching, and the raising of salt-tolerant crops.

In the Lower Valley subarea, the quality of the ground water varies in a similar manner to that of the water in the Lower Mesilla Valley subarea; however, it is generally slightly higher in dissolved-solids content. Analyses (Table U3 and Plate U3) show that the water in the alluvium ranges from fresh to moderately saline. According to Audsley (1959, table 3), the specific conductance of 77 samples of water from wells tapping the alluvial deposits in major subdivision 2 ranged from 1,130 to 11,000, or roughly 670 to 7,000 ppm (parts per million) dissolved-solids content and averaged an estimated 2,100 ppm. Although the ground water generally is unsatisfactory for public supply, it is used extensively for irrigation. Longenecker and Lyerly (1959, table 2) report that the salt (dissolved solids) content generally increased southward, except in the Fabens area where it decreased slightly. In the northern part of the valley, the salt content, in tons per acre-foot (a ton per acre-foot is equivalent to 735 ppm dissolved-solids content), in 65 wells in 1956 averaged 2.39, increasing to 3.95 in 40 wells within a few miles to the south. In the Fabens area, however, the salt content in 123 wells averaged 2.95 tons per acre-foot, the decrease being related possibly to recharge from a nearby arroyo during periods of stream runoff. The salt content increased sharply southward in Hudspeth County, averaging 5.34 tons per acre-foot in 56 wells. The marked increase in salt content in Hudspeth County is due principally to the general lack of surface water for irrigation. Consequently, ground water is the principal source of water for irrigation. In general, the water in the alluvium of the Lower Valley subarea is classed as being very high in salinity hazard and between medium and very high in sodium hazard.

The bolson deposits underlying the alluvial deposits in the Lower Valley subarea yield fresh to very saline water. The public supply of the city of Fabens is obtained from bolson deposits at a depth of about 300 feet. The water contained 522 ppm dissolved-solids content and had a hardness of 129 ppm. The city of El Paso drilled a test well (JL-49-39-202) 3 miles south of Fabens to a depth of 1,783 feet, which yielded water containing only 180 ppm of chloride; however, the sulfate and fluoride contents were 476 and 3.4 ppm, well in excess of the limits recommended by the U. S. Public Health Service for those constituents (Leggat, 1962, p. 11). The source of the water is probably to the southwest in Mexico. Additional drilling of test wells by the city and the Hudspeth County Reclamation and Conservation District No. 1 in Hudspeth County showed that throughout most of the valley the bolson deposits contained highly mineralized water. However, in several widely scattered areas near the large draws or arroyos that drain the bolson surface, fresh to slightly saline water is obtained at depths of less than 400 feet. The extent of these fresh-water bodies probably is limited to small areas adjacent to the draws.

In the southern part of the Hueco bolson north of Fort Hancock, two wells (PD-48-34-901 and PD-48-34-902, Table U3) obtain slightly saline water probably from the Cox Sandstone. The water is very hard and contains sulfate and fluoride in excess of 500 ppm and 5.0 ppm, respectively.

Availability

The amount of fresh ground water available in and the proportion that might be recovered from the aquifers underlying the El Paso area depends on many factors, among which is the movement of salt water that overlies, underlies, or adjoins the fresh-water body. It depends also on the distribution of pumpage, the rate of withdrawal, the amount of recharge to the aquifer, the amount of natural discharge that can be salvaged, and the amount of water that moves into the area from outside the district.

The natural recharge to the bolson sediments in the El Paso area is about 28 mgd (million gallons per day), a considerable part of which occurs in New Mexico. Prior to the start of pumping, the natural recharge was balanced by the natural discharge, but pumping has resulted in a change in this relationship. In the Hueco bolson, the head has been lowered below the head in the overlying alluvium in the Lower Valley (Smith, 1956, p. 11), which is the area of natural discharge of ground water. Thus, at least a part of the natural discharge has been salvaged. If it is assumed that all or a large part of the natural discharge can be salvaged, then the volume of recharge that falls in Texas or that can be induced to flow into Texas becomes an additional amount of ground water available for pumping. Actually, the volume of ground water that moves into the area from outside or that can be salvaged from natural discharge depends mainly on the distribution of pumpage and rates of pumpage to reduce incursion of the salt water to a minimum. In the following discussion, the natural recharge or the volume of natural discharge that can be salvaged is not considered; the volume of ground water available is based solely upon the water contained in the fresh water-bearing sediments in the Texas part of the Hueco and La Mesa bolsons.

The total amount of ground water in storage in the El Paso area is not known, but the volume of fresh ground water, including some slightly saline water, probably is a small fraction of the total, the major portion consisting of slightly saline to very saline water.

In the Hueco bolson, Knowles (1958, p. 37) estimated that the volume of saturated sand and gravel containing fresh water in that part of the bolson where the saturated section is more than 100 feet thick was at least 21.2 million acre-feet, of which 7.4 million acre-feet was theoretically recoverable. Actually, this estimated volume probably is conservative because it did not include that part of the bolson sediments in which the saturated thickness of sand and gravel was less than 100 feet, nor did it include the fresh water in the artesian part of the bolson. Data are not sufficient to determine accurately the volume of fresh water in transient storage in the artesian area; however, based on the thickness of the fresh-water body as determined from electric and drillers' logs and a specific yield of 15 percent, the volume of theoretically recoverable fresh water in the artesian part probably is about 1.0 million acre-feet.

All the fresh water in storage cannot be withdrawn by wells. Knowles and Kennedy (1958, p. 38) state that by proper well-field planning at least 50 percent of the water in storage in the bolson could be recovered before the water became so contaminated as to be unsuitable for public supply. However, in those parts of the bolson where the fresh-water sands are thin or where they are overlain and underlain by slightly to moderately saline water, possibly less than 50 percent of the fresh water can be recovered. Actually, the slightly saline water that adjoins the fresh-water body represents an additional supply of water that can be used either by mixing with the available fresh water or by demineralization. The volume of this more highly mineralized water is not known but it is probably many times the volume of fresh water in storage.

The fresh water available from storage in the alluvium and bolson deposits in the Texas part of the Lower Mesilla Valley was estimated to be at least 560,000 acre-feet, of which 150,000 acre-feet was in the alluvial deposits (Leggat and others, 1962, p. 38-39). This estimate probably is conservative because of the low specific yield (10 percent) used. Furthermore, only known thicknesses of fresh water-bearing materials were used, whereas in the northern part of the valley, water-bearing sediments may lie at great depths.

The estimate of the volume of fresh water theoretically available from the alluvial deposits may be liberal because of the variation in the quality of the water with time. During extended periods of drought, the ground water may increase in salinity and thus may be unsatisfactory for public supply unless mixed with fresh water.

Data are not available to permit a determination of the volume of water in storage that is suitable for irrigation or industry. A substantial part of the water that is unsuitable for public supply might be used for irrigation, particularly if large quantities of water can be applied for leaching of the salts from the soils. Some industries also may be able to use part of the water.

The volume of fresh water in the Lower Valley is negligible. In general, the water in the alluvial deposits is unsuitable for public supply and only relatively small amounts in widely scattered areas are available in the underlying bolson deposits.

In summary, the volume of theoretically recoverable fresh ground water in storage in the El Paso area is at least 9.0 million acre-feet. An additional large but undetermined amount of slightly saline water is available, some of which could be mixed with fresh water in suitable proportions to render it usable for public supply. The more highly mineralized water contained in the bolson and alluvial deposits represents a large potential supply when demineralization of the saline water becomes economical.

Problems

Except for a small amount of surface water from the Rio Grande, the El Paso subarea is dependent upon ground water for its municipal supply. In recent years, the city of El Paso has found it a continually pressing problem to meet the increasing demands being made upon its municipal water system. At the present time (1961), the city is developing the known fresh-water sources in the Texas part of the Hueco bolson and the Lower Mesilla Valley. The amount of water withdrawn each year exceeds the estimated annual recharge; thus, the fresh ground-water supply is being depleted or mined. Although the rate of depletion is slow, the supply of ground water is diminishing.

Associated with the problem of a decreasing supply of fresh water is the threat of salt-water contamination. Because of the slow rate of lateral movement of water at the low hydraulic gradients near the salt-water body, contamination in the Mesa subarea is more likely to occur from vertical movement from below. An exception, however, is in the vicinity of the rimrock, which is the northern limit of the City Artesian subarea where there apparently is no barrier to the lateral movement of saline water that overlies the fresh-water body in the artesian part into the fresh-water sands under the Mesa subarea. Where an increase in chloride content has been observed in wells in the Mesa subarea, the increase has not been serious.

In the City Artesian subarea, saline water occurs above and below the fresh water and, in places, as isolated lenses within the fresh water-bearing beds. In the area, salt-water contamination is likely to occur through leaky casings and by interformational leakage. According to Leggat (1962, p. 32), wells affected by saline water are not confined to any one part of the subarea but are widely scattered throughout the artesian part of the bolson. The most seriously contaminated wells have been abandoned; others have been repaired or placed in part-time service.

The problem of mining available water supplies and contamination are present also in the Lower Mesilla Valley subarea. Much additional data are needed, such as information concerning the rate at which ground water can be pumped to minimize the incursion of saline water, the rate of salt-water movement, and the amount of fresh water contained in the bolson deposits in the area in which well wells presently are not available.

The Salt Basin

General

The Salt Basin includes the eastern part of subdivision 24 (Figure U9) and occupies parts of Hudspeth, Culberson, Jeff Davis, and Presidio Counties. The basin in Texas extends from the Texas-New Mexico state line in the northeast corner of Hudspeth County, southeastward through Culberson and Jeff Davis Counties, to near the center of Presidio County. The basin is about 130 miles in length and from 5 to 15 miles in width. For purposes of discussion, it has been subdivided into two parts principally on the basis of ground-water development (Figure U9):

1. The Dell City subarea, which is in the northern part of the Salt Basin, is bounded on the north by the Texas-New Mexico state line, on the east by the Guadalupe and Delaware Mountains, and on the west by the Diablo Plateau; it extends southward about 33 miles to the north edge of Sierra Diablo.

2. The Wildhorse-Lobo Flats subarea, which adjoins the Dell City subarea on the south, extends southward through Van Horn and Lobo to Valentine. In this report, the irrigated area north of Van Horn is referred to as Wildhorse Flats. That part of the basin south of Valentine is known as Ryan Flat (Plate U1). Eagle Flat, west of Van Horn (Plate U1), is a westward extension of the Salt Basin.

The Bone Spring and Victorio Peak Limestones, undifferentiated, and the bolson deposits are the principal aquifers in the Salt Basin, although only the bolson deposits constitute a primary aquifer. Both aquifers yield large quantities of water for public supply, irrigation, domestic, and livestock purposes, although the Bone Spring and Victorio Peak Limestones, undifferentiated, is productive in only a relatively small area. Small quantities of water are obtained from sandstones and limestones of the Trinity Group in Eagle Flat.

Occurrence and Movement

Ground water in the Salt Basin occurs in joints, cracks, and solution cavities in limestones, in calcareous sand of the Bone Spring and Victorio Peak

Limestones, undifferentiated, in the sand and gravel of the bolson deposits, and in the sandstone and limestone of Trinity age.

In the Dell City subarea, the water is confined in the limestone part of the aquifer, but is under water-table conditions in the bolson sediments that overlie and adjoin the limestone. The distribution of openings in the limestone is erratic as indicated by the large number of wells drilled for irrigation that were abandoned because they failed to penetrate a zone capable of yielding quantities of water sufficient for irrigation. The water table, or piezometric surface, slopes gently southward from an altitude of about 3,600 feet at the Texas-New Mexico state line to about 3,560 feet at the south end of the Salt Lakes, the gradient being about 1 foot per mile (Figure U17).

In the Wildhorse-Lobo Flats subarea, the water in the bolson deposits generally is unconfined except locally where thick sections of clay have confined the water under artesian pressure. The slope of the water surface in the subarea ranges from nearly level in the north end of the area to more than 30 feet per mile in an area between Lobo and Chispa (Figure U18). The changes in the slope of the water surface in the Lobo Flats irrigated area, as shown in Figure U18, may be due to changes in the permeability of the water-bearing beds or to barriers resulting from faulting. Hood (1951, p. 5) suggested an underground barrier extending across Wildhorse Creek between the north end of the Van Horn Mountains and the south end of the Wylie Mountains. The barrier may be the cause of the nearly flat hydraulic gradient in the vicinity of Lobo and extending a short distance northward (Figure U18). Data are not available to show in detail the slope of the water table between the north end of the Lobo irrigated area and Van Horn.

The Salt Basin is without external surface drainage and the ground water moves generally northward from the southern part of the basin in Presidio County to the small salt lake about 8 miles north of the Baylor Mountains, except where large or concentrated withdrawals of ground water have formed cones of depression. In the northern part of the basin, the water moves southward from the Texas-New Mexico state line to the Salt Lakes and possibly beyond to the above-mentioned small salt lake. In Eagle Flat, the ground water moves southeastward and eastward between the Carrizo and Van Horn Mountains, entering the main part of the Salt Basin slightly north of Lobo.

Recharge and Discharge

The ground-water reservoirs in the Salt Basin are recharged by infiltration principally of stream runoff and to a lesser extent by precipitation on the land surface.

In the Dell City subarea, the Sacramento River in New Mexico probably is the chief source of recharge (Scalapino, 1950, p. 6). The Sacramento River, which generally loses all of its water before reaching the Dell City subarea, drains a large area in New Mexico entering the Salt Basin north of the Texas-New Mexico state line. Some direct penetration of rainfall and seepage along the smaller intermittent streams also probably contribute to the recharge.

In the Wildhorse-Lobo Flats subarea, most of the recharge is from seepage along the small intermittent streams that discharge into the basin from slopes of the surrounding mountains. According to Hood and Scalapino (1951, p. 5),

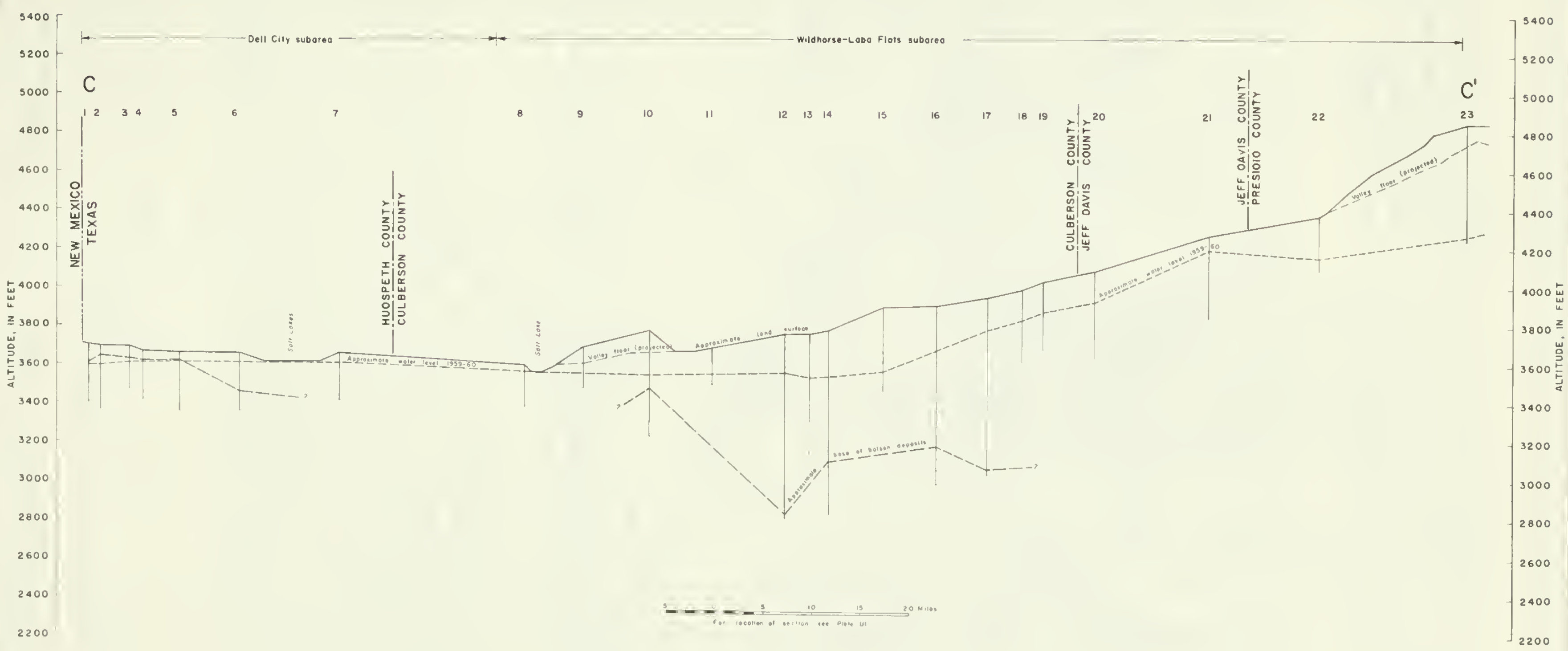

Figure U17

Section C–C', Salt Basin

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

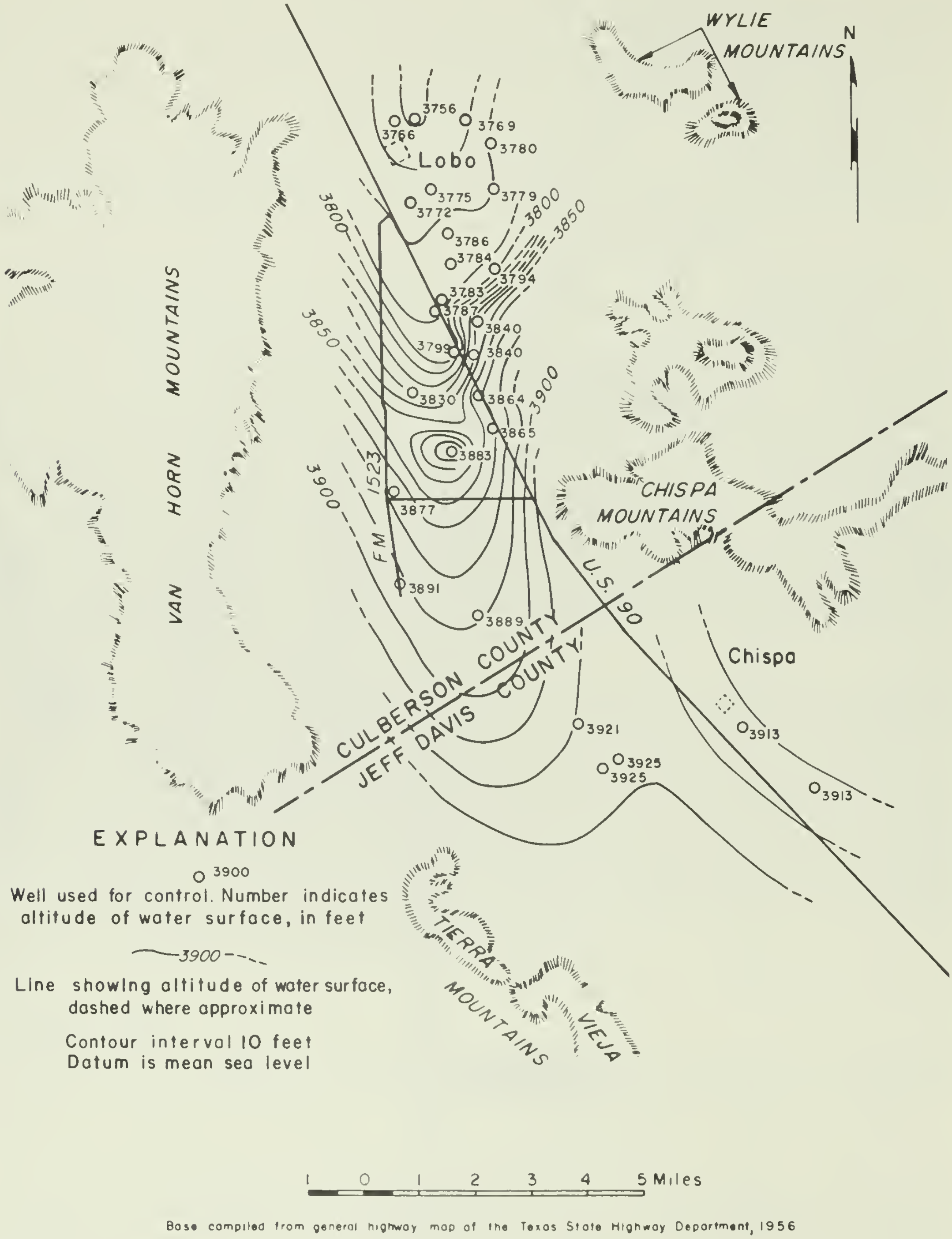

Figure U18

Altitude of the Water Surface in Lobo Flats, 1960

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

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"Recharge occurs primarily during and after heavy rainfall because only then is the rate of precipitation greater than the rate of evaporation."

Ground water that is not withdrawn by wells in the Salt Basin moves generally toward the Salt Lakes where it is discharged naturally to the atmosphere by evapotranspiration from the water table which in 1959-60 underlay the Salt Lakes at a depth of about 3 feet. Some discharge might take place by underflow out of the basin through the southeasterly dipping Bone Spring and Victorio Peak Limestones.

Data are not available to determine accurately the quantity of ground water that is recharged or discharged naturally from the ground-water reservoir in the Salt Basin. However, an estimate of the natural discharge in the Dell City subarea can be made by assuming that the nearly level surface of the water table underlying the Salt Lakes (Figure U17), which occupy at least 60,000 acres, is held down to that level by evapotranspiration. Experiments conducted by Veihmeyer and Brooks (1954, p. 605) in California showed that the annual evaporation was about 8 inches from a water table at a depth of 3 feet below bare soil. On this basis, assuming similar soil structures, the discharge of ground water principally by evaporation from the Salt Lakes is at least 40,000 acre-feet. Actually, this estimate of natural discharge probably is conservative because the evaporation from a free water surface in the experiment area in California was only 70 inches, which is less than that in the Dell City subarea. Furthermore, the estimate does not include the discharge from the Crow Flats area northeast of the Salt Lakes in which the water table also is very shallow, the discharge of ground water by transpiration by small widely scattered growths of phreatophytes, nor the possible subsurface discharge through the Bone Spring and Victorio Peak Limestones, which in the eastern edge of the basin dip southeasterly toward the Pecos River watershed.

Utilization

The pumpage of ground water for irrigation, public supply, and industrial use in the Salt Basin in 1960 is shown in Table U2 (major subdivision 24). Shown also is the estimated pumpage for domestic and livestock supplies, which represents only a small percentage of the 136,000 acre-feet, or 121 mgd, pumped for all purposes.

The withdrawal of ground water for irrigation in 1960 in the Salt Basin was about 136,000 acre-feet, of which 100,000 acre-feet was pumped from 210 wells tapping the Bone Spring and Victorio Peak Limestones underlying the Dell City subarea; an additional amount, probably less than 1,000 acre-feet, was pumped from three wells tapping the bolson sediments overlying or adjoining the limestone aquifer. The estimate of pumpage may be somewhat high because it is based on a duty of water of 4 acre-feet per acre, which includes water in excess of the normal needs of the plants in order to leach the soil of accumulated salt. According to the Western Cotton Oil Co. (written communication, 1961) about 25,475 acres was irrigated in the Dell City subarea in 1960.

In Wildhorse-Lobo Flats subarea, 36,000 acre-feet of water was pumped from the bolson sediments in 1960. Approximately 116 wells were used to irrigate 8,670 acres.

Pumpage of ground water for public supply in the Salt Basin in 1960 was about 410,000 gpd or 460 acre-feet per year. The city of Van Horn pumped about

290,000 gpd from two wells tapping the bolson deposits. The wells were about 600 feet deep and yielded 170 to 500 gpm. Valentine, which obtains its water supply from one well, pumped an estimated 30,000 gpd from the bolson deposits. The public supply of Dell City is obtained from two wells that draw from the limestones underlying the area. The wells, which are 213 and 264 feet deep and yield 100 gpm each, pumped an average of 50,000 gpd in 1960.

In Eagle Flat, which extends westward from the main Salt Basin, Sierra Blanca pumped an average of about 40,000 gpd for public supply in 1960. The city obtains its water supply from one well which is screened in limestone of Trinity age at a depth of 1,100 feet. An additional 27,000 gpd was pumped by privately owned wells for domestic and public-supply purposes at Sierra Blanca. Some of these wells tap the Cox Sandstone.

Small quantities of ground water were pumped by industries in the Salt Basin in 1960. The El Paso Natural Gas Co., at the southern end of the Guadalupe Mountains, pumped slightly less than 250,000 gpd from the Bone Springs and Victorio Peak Limestones, principally for cooling purposes. The Continental Mineral Co., which processes barite about 5½ miles east of Van Horn, uses a small amount of water from the bolson deposits.

The use of water for domestic and livestock supplies accounts for less than 1 mgd, which is less than 1 percent of the total withdrawals from the ground-water reservoirs in the Salt Basin.

Fluctuations of Water Levels

The fluctuations of water levels have been observed periodically in several wells in the Salt Basin since 1948. Hydrographs of selected wells in or near the centers of areas of large ground-water withdrawals are shown in Figure U19 and the approximate change in water levels in these same areas during the period 1955-60 are shown in Figures U20, U21, and U22.

In the Dell City subarea, the water levels in four wells (Figure U19) declined steadily during the period 1948-61. The declines ranged from 16 to 21 feet and averaged 18.5 feet (about 1.4 feet per year). Since 1958 the rate of decline has been less than it was before 1958 and during 1960-61; the decline averaged less than 1 foot.

Since 1955, water levels in the Dell City subarea have declined a maximum of 12 feet in the southern part of the main area of irrigation (Figure U20), where wells are concentrated but also where faulting has limited the southward extension of irrigation. About a mile south of Dell City, the water levels have declined a maximum of 10 feet. Data are insufficient to determine the extent of the area of decline; possibly it extends eastward to and perhaps beneath the Salt Lakes. This is suggested by Figure U23, which shows the altitude of water levels in the limestone aquifer west of the Salt Lakes. The lake floor has an altitude of 3,616 feet at a point just east of the irrigated area (Scalapino, 1950, p. 7), hence the altitude of the water surface below the lake probably is about 3,613 feet, thus indicating a hydraulic gradient from the Salt Lakes westward to the irrigated area. Prior to 1950, the water table sloped eastward toward the Salt Lakes at the rate of about 4 feet per mile (Scalapino, 1950, p. 6).

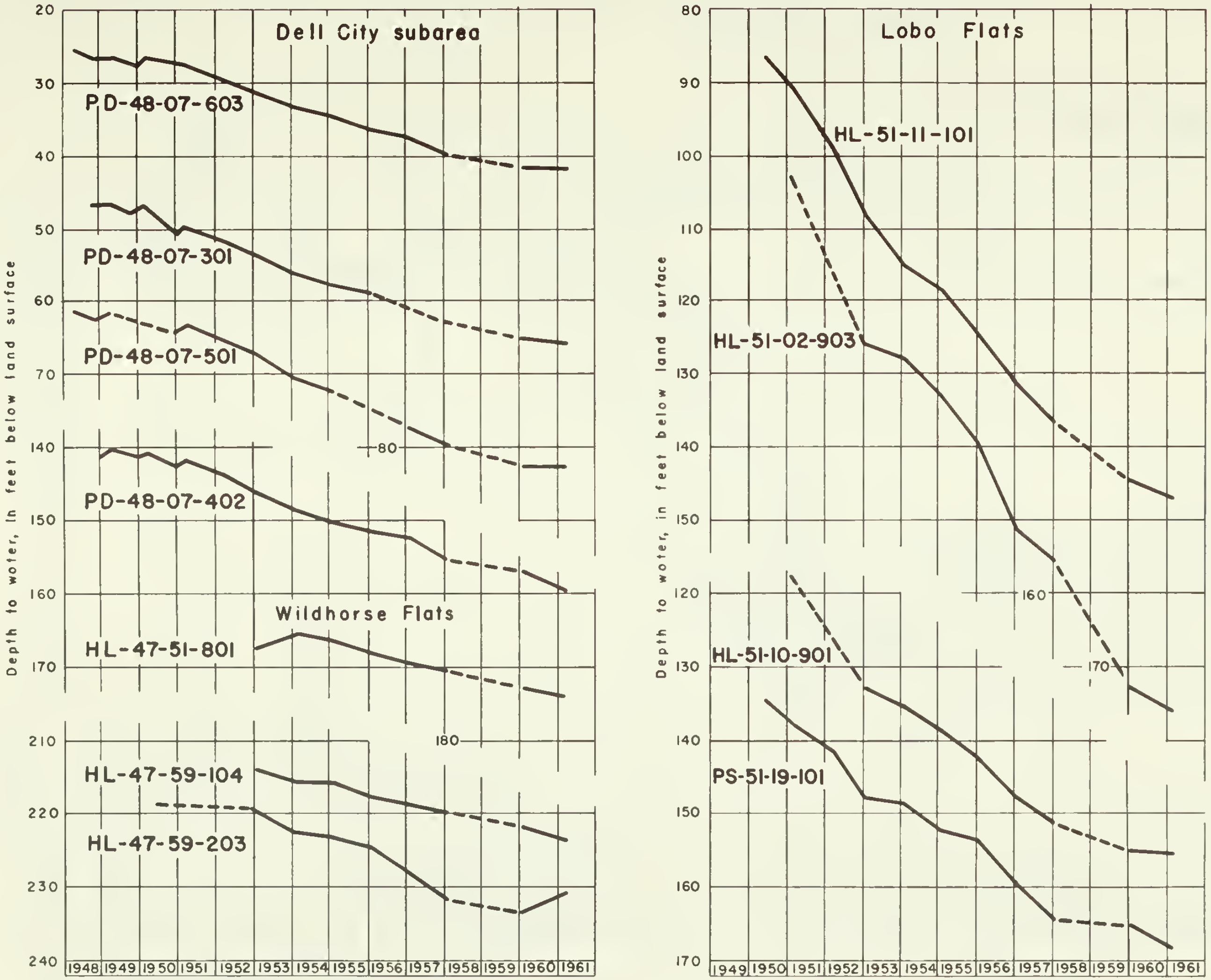

Figure U19

Hydrographs of Selected Wells in the Salt Basin

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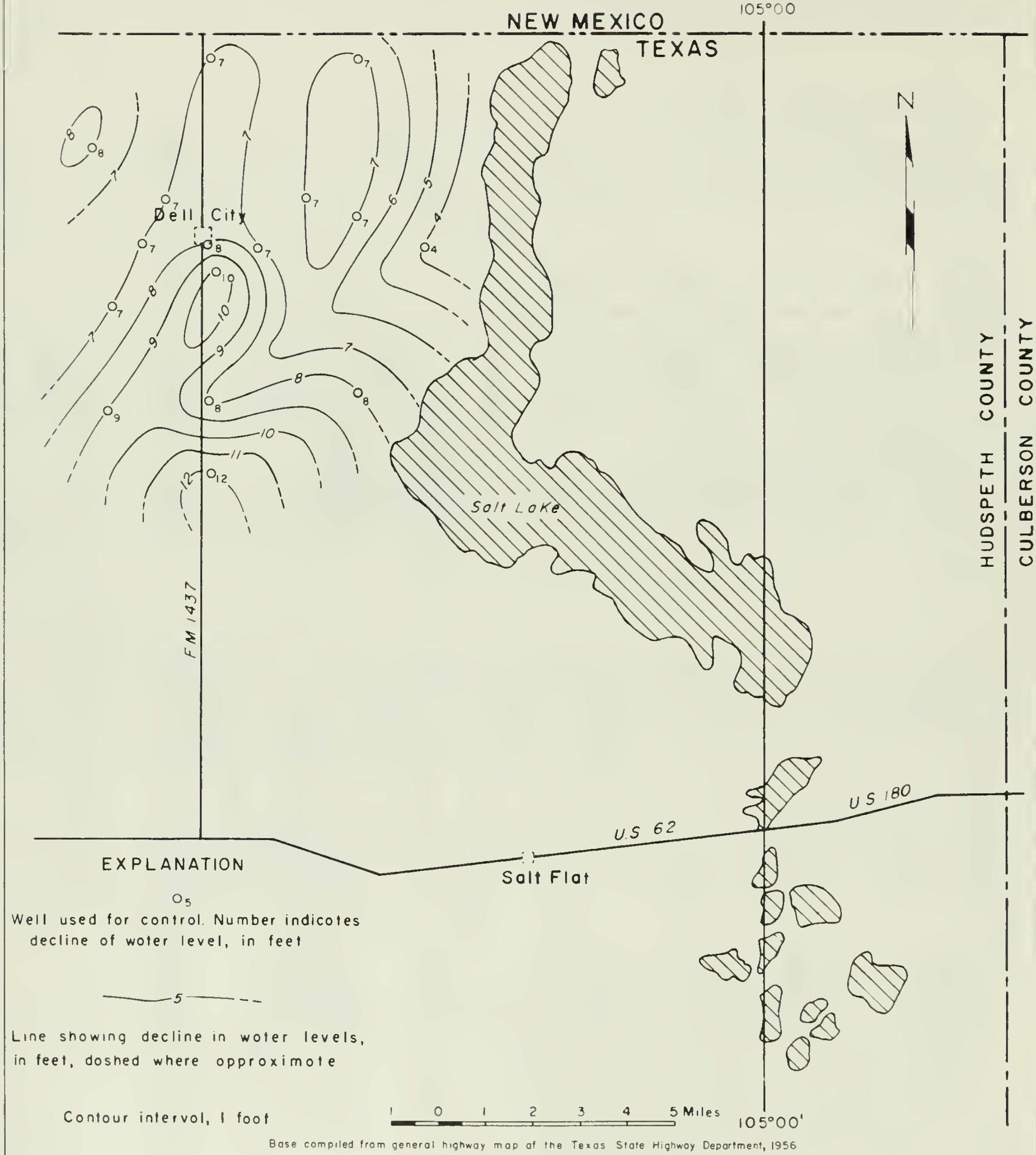

Figure U20
Decline of Water Levels in the Vicinity of Dell City, 1955-60

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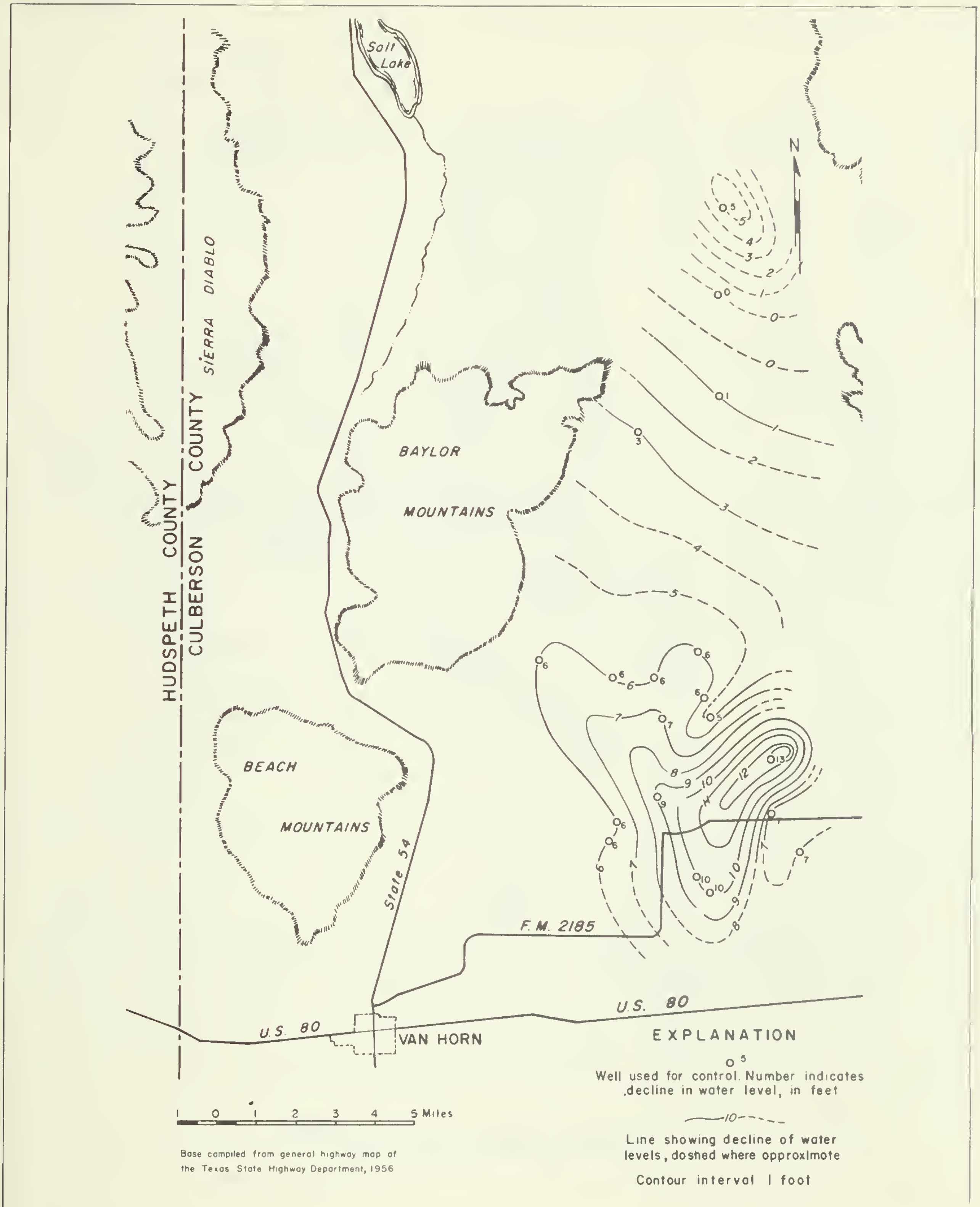

Figure U21

Decline of Water Levels in Wildhorse Flats, 1955-60

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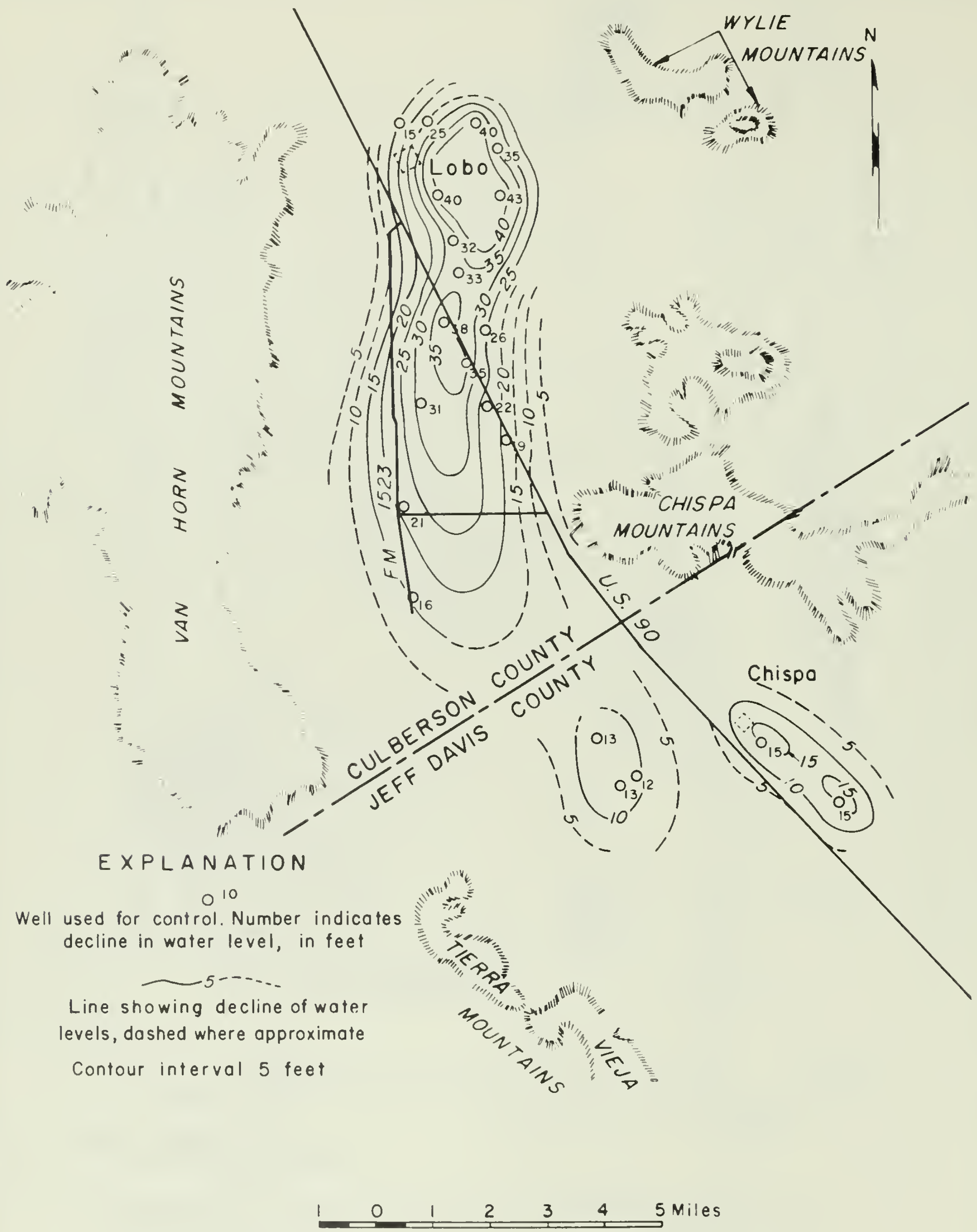

Base compiled from general highway map of the Texas Highway Department, 1956

Figure U22

Decline of Water Levels in Lobo Flats, 1955-60

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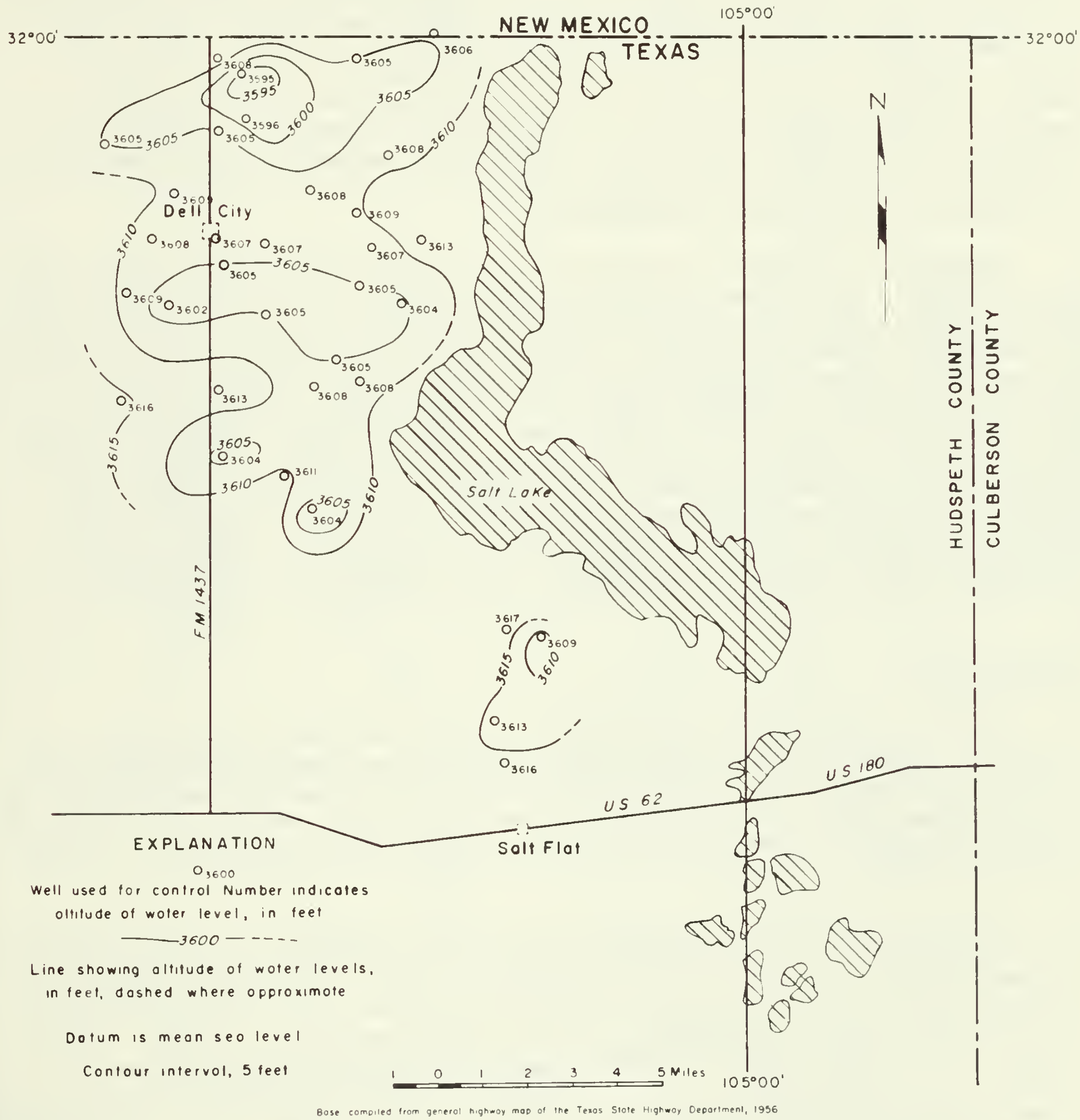

Figure U23

Altitude of Water Levels in Wells in the Vicinity of Dell City, 1960

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In the Wildhorse Flats irrigated area northeast of Van Horn, the water levels in three wells (Figure U19) declined an average of 9.3 feet, or about 1 foot per year during the period 1953-61. Figure U21 shows two widely separated areas of water-level decline that have been created by the concentration of pumpage since 1955; the largest declines are in the southern part of the area where the concentration of wells and pumpage is greatest. Figure U24, which shows the altitude of the water levels in wells in Wildhorse Flats in 1960, reveals that the water table slopes southward from the vicinity of the small salt lake toward the area of concentrated withdrawals. Although this reversal in the natural direction of ground-water movement has not resulted in a change in the quality of the water pumped in the area, it represents a potential threat of salt-water contamination.

The greatest declines in water levels in the Salt Basin have been in Lobo Flats where the bolson deposits consist principally of clay. According to Hood and Scalapino (1951, p. 4), "...the sand and gravel zones form only a fraction of the total volume of alluvium." The hydrographs of wells in Figure U19 show the marked difference in declines between Wildhorse and Lobo Flats. Since 1951, the decline in water levels in four wells in Lobo Flats ranged from 30.8 to 73.2 feet, or an average of 3 to more than 7 feet per year. Figure U22 shows the approximate decline in water levels from 1955 to 1960. The figure shows a large area of decline near Lobo in the heavily irrigated part of the flats, where the water levels have declined a maximum of 43 feet. Southward near Chispa, two smaller areas have been formed. These areas are not so heavily irrigated. The large declines probably can be attributed to the removal of a relatively small quantity of water from a zone of rather low permeability.

Aquifer Tests

Aquifer tests were made in six wells in the Salt Basin to determine the hydraulic characteristics of the bolson deposits and the Bone Spring and Victorio Peak Limestones, undifferentiated. The coefficients of transmissibility were computed from water-level measurements made in the pumped wells during the recovery periods. It was not possible to compute the coefficients of storage from the tests.

The results of the tests, all of which were of short duration, showed that in two wells (HL-51-03-701 and HL-51-10-603) in Lobo Flats the coefficient of transmissibility averaged about 30,000 gpd per foot. In Wildhorse Flats, however, the coefficient of transmissibility ranged from 30,000 gpd per foot in well HL-47-59-201 to about 70,000 gpd per foot in well HL-47-59-102. The wide range in the coefficient of transmissibility emphasizes the heterogeneous nature of the sand, gravel, and clay making up the bolson sediments. The values cannot be considered as representative of the bolson deposits as a whole because the wells do not penetrate the full thickness of the bolson sediments and because the tests were of short duration, thus testing only a small area of the aquifer. Furthermore, the wells tested were not well distributed throughout the Wildhorse and Lobo Flats.

Aquifer tests were made on two wells in the limestone in the Dell City subarea; however, the results are inconclusive. In general, the ability of the aquifer to transmit water in this subarea depends on the number, size, and degree of interconnection of the openings in the limestone. Because of the wide range in yields of the wells tapping the limestones, it may be expected that the transmissibility of the aquifer would vary similarly.

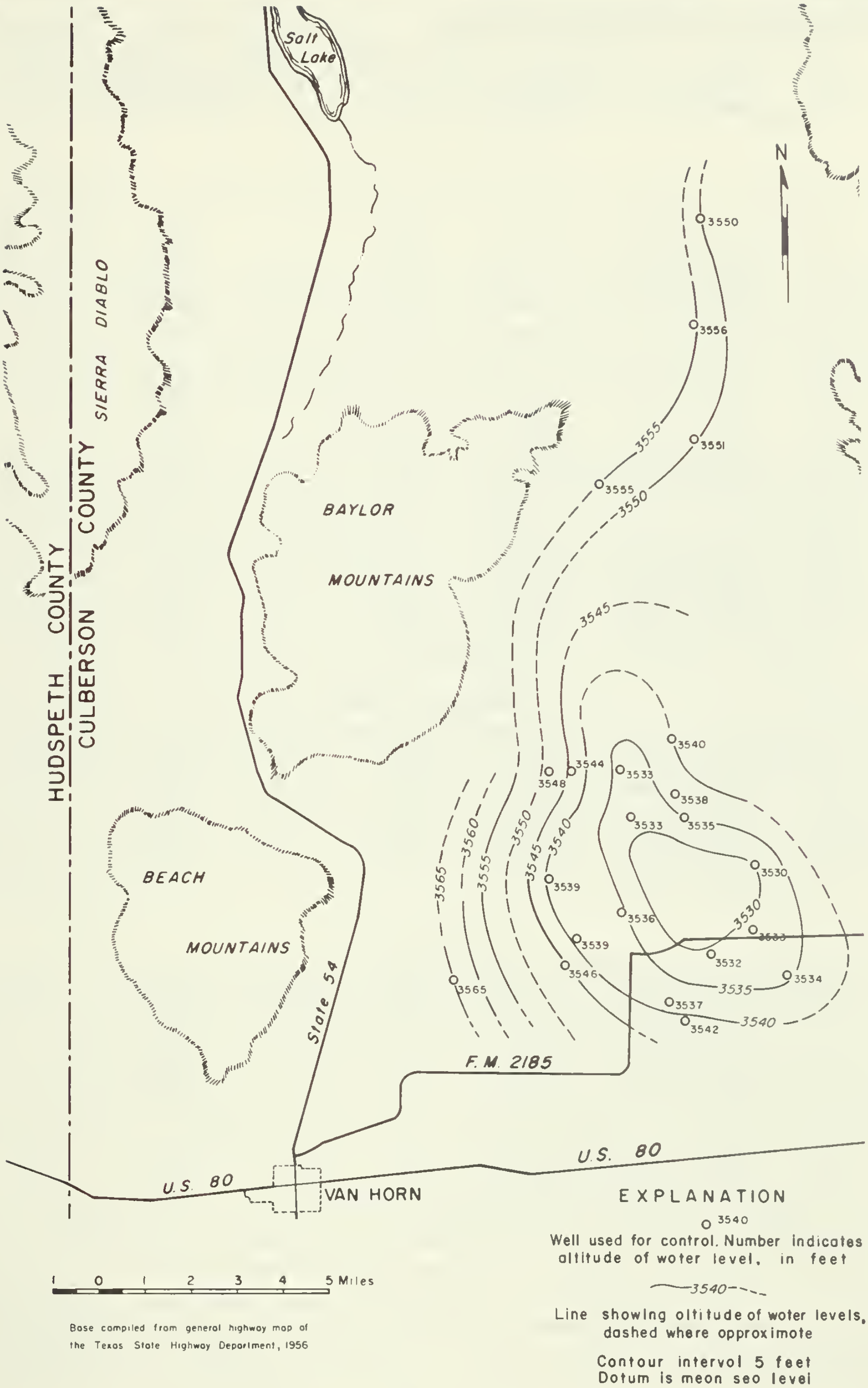

Figure U24

Altitude of Water Levels in Wells in Wildhorse Flats, 1960

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The yields, drawdowns, and specific capacities of 26 wells in the Salt Basin are shown in the following table.

Well number	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft)
Dell City Subarea			
PD-47-17-202	995	21.4	46.5
47-17-204	570	88.2	6.5
48-07-203	323	19.5	16.7
48-07-206	1,750	32.6	53.7
48-07-207	940	30.0	31.3
48-07-302	480	44.1	10.9
48-07-601	1,635	44.5	36.7
48-07-605	660	13.2	50.0
48-07-701	2,240	35.1	63.8
48-07-901	1,300	30.3	42.9
48-15-201	1,470	51.2	28.7
48-16-501	575	13.6	42.3
48-16-701	160	30.9	5.2
HL-47-17-602	410	31.2	13.1
Wildhorse Flats			
HL-47-51-402	1,800	148	12.2
47-51-701	1,600	48	33.3
47-51-702	2,450	111	22.1
47-59-102	1,100	41.0	26.8
47-59-201	600	66.0	9.1
Lobo Flats			
HL-51-03-701	250	18.0	13.9
51-10-304	625	20.5	30.5
51-10-305	600	37.1	16.2
51-10-306	625	17.9	34.9
51-10-603	900	33.6	26.8
51-11-102	475	9.7	49.0
51-11-103	475	18	26.4

The specific capacities of 12 wells tapping the bolson deposits ranged from 9.1 to 49.0 gpm per foot of drawdown, and averaged 25.1. In general, the wells were similarly constructed and developed and most were equipped with slotted casing and ungraded gravel. Thus, the wide range in specific capacities is attributed probably to the equally wide variation in the character of the bolson sediments.

The specific capacities of 14 wells in the Dell City subarea ranged from 5.2 to 63.8 gpm per foot of drawdown, and averaged 32.0. Wells in this subarea generally are cased to the top of the Bone Spring and Victorio Peak Limestones, but are "open hole" throughout the section of limestone penetrated. Thus, wells that penetrated the most permeable rocks, characterized by solution channels that permit almost unrestricted flow, had comparatively high yields with small drawdown effects, hence, large specific capacities. Some wells that had low specific capacities are close to wells having high specific capacities, showing further the wide variation in the hydraulic characteristics of the limestone aquifer.

Quality of Water

Chemical analyses of water from 22 selected wells in the Salt Basin are shown in Table U3 (major subdivision 24). The dissolved-solids, chloride, and sulfate content of the wells and additional wells are shown in Plate U3. In the following discussion of the ranges of various constituents, some of the values were taken from unpublished analyses which are on file in the office of the U. S. Geological Survey at Austin, Texas.

The quality of the ground water in the Salt Basin ranges between wide limits. Most of the water withdrawn from wells in the bolson deposits in Wildhorse and Lobo Flats, including Ryan and Eagle Flats, is of good quality, satisfactory for most industrial uses, for public and domestic supplies, and for irrigation. Water from the Bone Spring and Victorio Peak Limestones, undifferentiated, and the bolson deposits in the Dell City subarea, however, is of poor quality, being used principally for irrigation.

South of Van Horn, the ground water is typically low in dissolved-solids, chloride, and sulfate content (Plate U3). On the basis of the diagram for classification of irrigation waters (Figure U8), the water in Lobo Flats is of good quality. However, although the water is low in dissolved-solids content, the high percent sodium, which ranged from 54 to 85 and averaged 75 in 17 samples, together with the slowly permeable soil has resulted in, according to Longenecker and Lyerly (1959, p. 9), "...a virtually impermeable situation in the subsoils...."

As the ground water moves northward into Wildhorse Flats, it increases in mineralization. The dissolved-solids content in 26 wells (Table U3 and Plate U3) ranged from 413 ppm at Van Horn to 2,900 ppm near the north end of Wildhorse Flats. The chloride and sulfate content increases similarly except east and southeast of the salt lake north of the Baylor Mountains, where the chloride content in water from two wells was less than 15 ppm. According to Longenecker and Lyerly (1959, p. 9-10), the ground water in the bolson deposits underlying Wildhorse Flats is "...usable on soils of good permeability with proper precautions against sodium accumulation....Although the waters contain nearly four times as much salt [as in the Lobo Flats area] and a high percentage of sodium, there is no evidence of serious accumulation of either salt or sodium in these soils."

Ground water in the limestone aquifer in the Dell City subarea is slightly to moderately saline. Chemical analyses of water from 29 wells (Table U3 and Plate U3) show that the dissolved-solids content ranged from 979 ppm in well HL-47-17-301 east of the Culberson County line to 7,970 ppm in well PD-48-16-501 near the southwest edge of the Salt Lakes. The water typically is hard, the hardness ranging from 625 to 2,020 ppm in 26 samples and averaging 1,189 ppm. The fluoride content averaged about 1.4 ppm. Although the dissolved-solids content of water from well HL-47-17-301 was less than 1,000 ppm, indicating that the water would be classified as fresh, the sulfate content exceeded the standard of the U. S. Public Health Service. This relatively fresh water, similar water being obtained from three nearby wells (Plate U3), is recharged locally from the infiltration of stream floodflow as it crosses the permeable and faulted limestone at the foot of the Delaware Mountains.

Although the water from the limestone in the Dell City subarea is considerably higher in salt content than the water in the other irrigated areas in the Salt Basin, it is used satisfactorily for irrigation due mainly to the excellent soil permeability, which permits leaching of salts by the application of excess water. According to the classification in Figure U8, the water is high in salinity hazard but low in sodium hazard.

Results of studies made by the Texas Agricultural Experiment Station at El Paso indicate that the residual salt content of the bolson deposits overlying the limestone in the Dell City subarea has decreased through application of irrigation water (Longenecker and Lyerly, 1959, p. 10). However, chlorographs of water from five wells (Figure U25) show that during the period of irrigation, the chloride content of the ground water from the limestone aquifer has increased. The increase probably indicates that the application of excess irrigation water has leached at least a portion of the residual salts from the surficial deposits, thereby increasing the salinity of the ground water in the underlying limestone. However, it is possible also that a part of the increase in the salinity of the water from the limestone may be due to leakage from the bolson deposits into the wells. In most wells the casings are not cemented opposite the bolson deposits, thus permitting leakage around the casings. The distribution of dissolved-solids content (Figure U26) also shows that the maximum salinity of ground water is in the more heavily pumped parts of the subarea rather than in the eastern part where water from the Salt Lakes might be expected to move into the area in response to the reversal in the hydraulic gradient (Figure U23).

Availability

The quantity of water available to wells in the Salt Basin is dependent largely on the amount of recharge to the aquifers and on the quantity of water in storage. It is not possible to determine the amount of recharge based on the available data; however, the recharge to the Dell City subarea probably is greater than 40,000 acre-feet per year (p. U-67). The recharge to the bolson sediments in the rest of the Salt Basin could not be estimated.

Data are not available to determine accurately the quantity of ground water in storage in the Salt Basin. However, on the basis of the known thickness of the fresh water-bearing bolson sediments that underlie the Wildhorse and Lobo irrigated areas and assuming a specific yield of 15 percent, it is estimated that 385,000 acre-feet of fresh water is in storage. This estimate of the volume of water in storage is conservative because the area includes only the irrigated area and the estimate does not include the fresh water-bearing sediments that underlie the presently pumped sands. Actually, the volume of fresh water in storage probably is much greater; in several wells the saturated thickness was at least twice as much as was used in the computation. Furthermore, an additional but unknown volume is in storage in Ryan Flat south of Valentine and in Eagle Flat west of Van Horn.

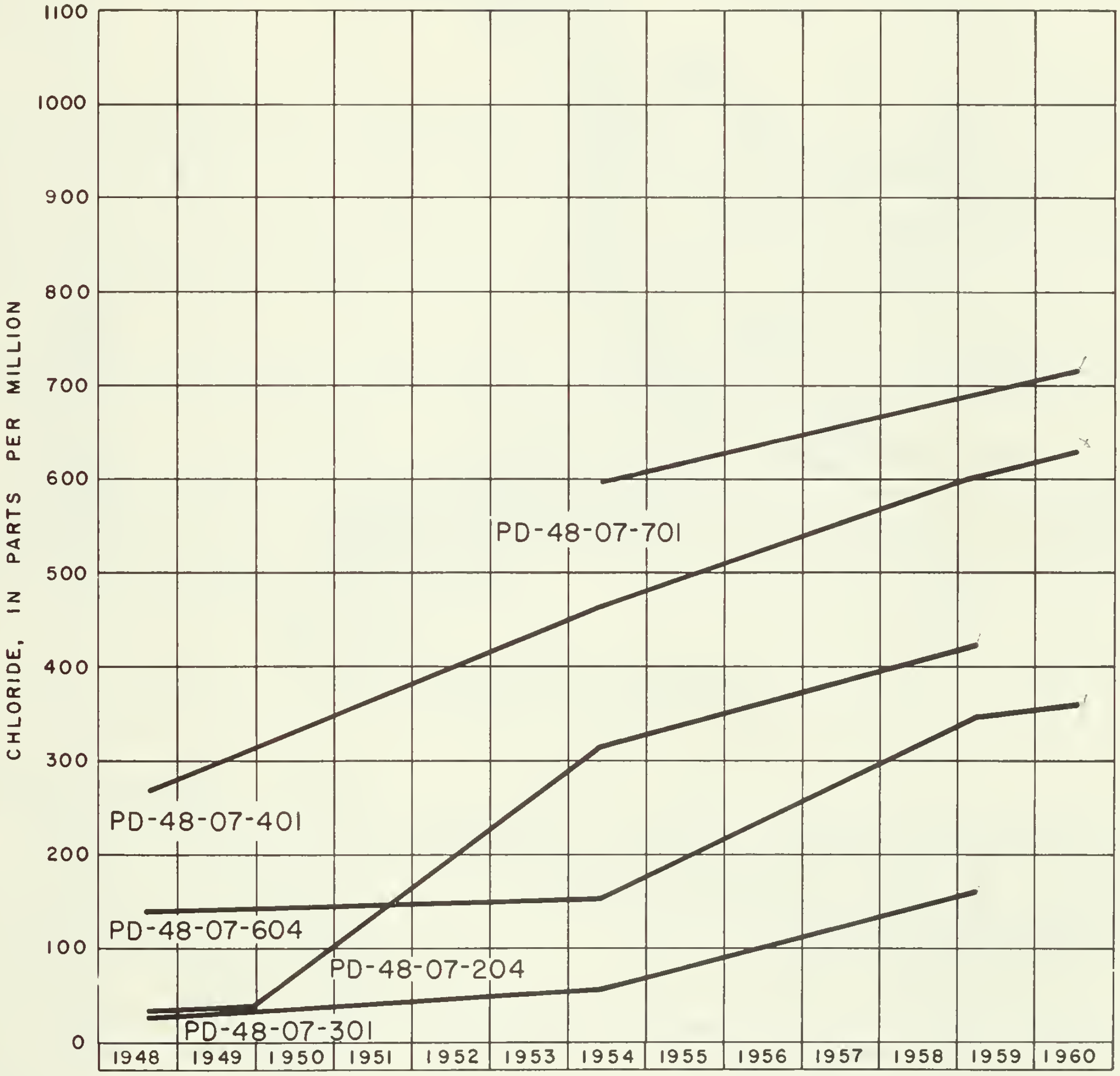

Figure U25

Chlorographs of Selected Wells in the Vicinity of Dell City

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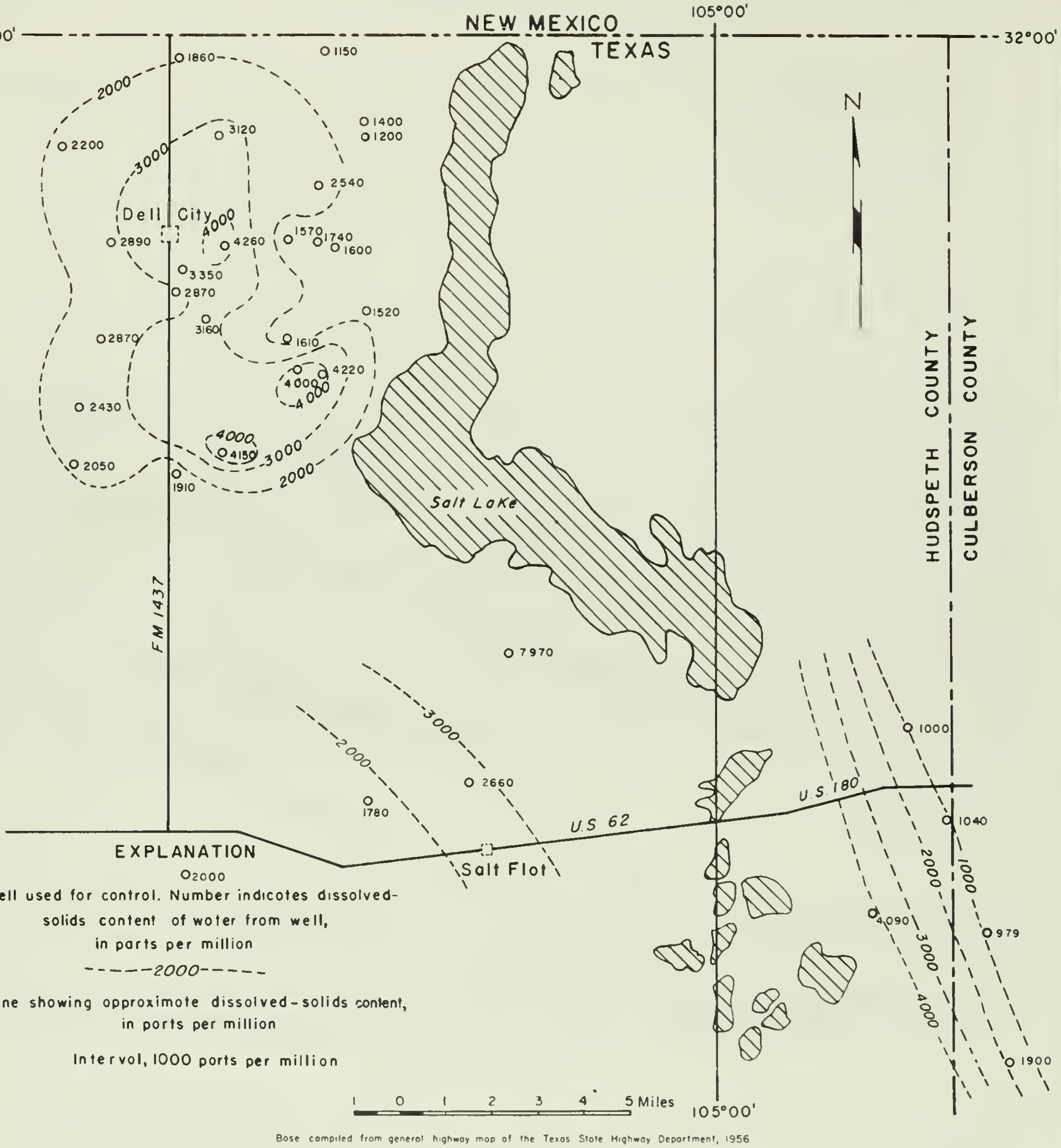

Figure U26

Distribution of Dissolved Solids in Ground Water in the Vicinity of Dell City, 1960

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The quantity of slightly to moderately saline water in storage in the limestone in the Dell City subarea is not known but is probably large. A determination of the volume of water in the aquifer requires a knowledge of the quantity of water pumped over a period of years, the change in the reservoir storage during this period, and the extent of the reservoir.

Problems

The most serious problem concerning the development of ground-water supplies in the Salt Basin is the lack of data with which to determine the water budget. Intensive and detailed studies are needed to determine the rate of natural recharge to and discharge from the bolson and limestone aquifers, to delineate the areas of recharge, to define the limits of the aquifer, to ascertain the depth to which fresh water extends in the Wildhorse-Lobo Flats subarea, and to calculate the volume of water in storage.

Another serious problem is that of a rapidly declining water table. This "mining" of water is most acute in Lobo Flats where the declines have resulted in the lowering of pumps in some wells.

In the Dell City subarea, the increase in salt content of the water in the limestone aquifer is a serious problem. As irrigation continues and ever increasing amounts of excess water are applied in order to leach the accumulated salts from the soil, it may be expected that the salinity of the ground water will increase further.

The Marfa-Presidio Area

General

The Marfa-Presidio area of the upper Rio Grande Basin includes all of major subdivisions 7, 8, 9, and 10, and the western part of 11 (Figure U9). The area is a part of the erosional remnant of the Davis Mountains volcanic field. The Rio Grande forms the southern and western boundary; on the east are the mountains and valleys of the Big Bend National Park; and on the north are the Davis Mountains. It includes most of Presidio County and parts of Brewster and Jeff Davis Counties, encompassing nearly 2,600 square miles. In the following discussion, the Marfa-Presidio area will be considered as being in two parts--the valley of the Rio Grande and the upland part which includes the rest of the area.

The rocks that crop out in the area range in age from Permian to Recent. Consolidated sedimentary rocks of Permian and Cretaceous age are exposed in the Chinati Mountains and in several places near Shafter; in both places they have been deformed and intruded by igneous rocks of Tertiary age. Extrusive volcanic rocks of Tertiary age, consisting of lava flows, tuff, and related sediments are exposed in much of the eastern part of the area. Undifferentiated alluvial and bolson deposits of Tertiary and Quaternary age are exposed near and underlie the valley of the Rio Grande.

The undifferentiated alluvial and bolson deposits, which occupy the Rio Grande Valley from Redford north to above Candelaria, and the Tascotal Formation of Goldich and Seward (1948) are the principal water-bearing formations in the area, although they are secondary aquifers. Only the Tascotal yields fresh water; the alluvial and bolson deposits yield moderate to large quantities of slightly to moderately saline water used chiefly for irrigation.

Occurrence and Movement

Ground water near Marfa in the upland area occurs under both water-table and artesian conditions in different places. Although the ground water is in different aquifers, such as the Tascotal Formation of Goldich and Seward (1948) and the alluvium, under either confined or unconfined conditions, the confined water rises to approximately the same general level as the water table of the area, suggesting that the aquifers are interconnected. This is indicated also by the similarity of the chemical quality of the water from the several water-bearing formations (Davis, 1961, p. 16). In the valley of Alamito Creek near Plata and Casa Piedra, the artesian pressure is sufficient to cause water to flow at the surface in the wells at the Santa Fe Railroad section houses. According to Davis (1961, p. 17, fig. 4), ground water in the area east and southeast of Marfa moves generally south and southwest toward Alamito Creek, thence south toward the Rio Grande.

Data are not available to determine the water-bearing characteristics of the volcanic intrusive and consolidated sedimentary rocks of the upland part of the Marfa-Presidio area. The water in these rocks is confined, and in some of the deeper wells, the water rose several hundred feet above the level where it first entered the wells.

Ground water in the alluvial deposits both in the valley of the Rio Grande and in the upland part generally is under water-table conditions. However, in the bolson deposits that underlie the alluvium in the valley, the water is under artesian pressure because of the substantial thickness of confining layers of clay. A well drilled to a depth of more than 1,320 feet near Presidio penetrated clay from 68 to 1,320 feet, where sand of unknown thickness yielded very saline water. The water reportedly rose to within 110 feet of the surface.

Recharge and Discharge

Ground water in the Marfa-Presidio area is derived from precipitation that falls in the area, runoff from the mountains, underground inflow from outside the area, and by seepage of surface water applied to the land surface for irrigation.

Runoff from the mountains is rapid because of the steep stream gradients and sparse vegetation. As the streams emerge from the mountains onto the more gently alluviated plains and valleys, the abrupt change in gradient allows flood runoff to spread over a wide surface. Most of the recharge takes place near the mountains where the alluvium overlying the aquifers is coarse grained and probably very permeable.

It has been estimated (Davis, 1961, p. 19) that recharge from precipitation in a 350-square mile segment of the upland part of the Marfa-Presidio area is about 8,000 acre-feet per year. It was not possible to estimate the amount of recharge in the rest of the Marfa-Presidio area, but it probably is small because most of the rainfall, which averages 8.39 inches per year at Presidio, occurs during the summer months when evaporation and transpiration are high.

Recharge to the alluvial deposits in the valley of the Rio Grande from seepage of surface water applied to the surface for irrigation or from the Rio Grande itself probably is large when storage space is available in the deposits.

Ground water in the upland part of the Marfa-Presidio area is discharged principally by subsurface flow into the alluvial deposits in the valley where it is discharged by evapotranspiration or by flow into the Rio Grande. It is discharged also to a much lesser extent through wells and springs. The quantity of water naturally discharged by these methods is not known, but a large part probably is discharged by transpiration from the dense growth of salt cedar between Presidio and Candelaria.

Discharge of ground water by irrigation wells in that part of the Rio Grande Valley below Presidio varies from year to year depending upon the availability of surface water for irrigation. However, in the valley between Presidio and Candelaria, where surface water generally is not available for irrigation, wells are the principal source of irrigation water.

Several springs, the largest one being Capote Spring (UW-51-51-601), issue from the volcanic rocks of Tertiary age; the total flow is not known but is probably a small percentage of the total natural discharge of the area.

Utilization

Most of the pumpage of ground water in the Marfa-Presidio area is concentrated in the irrigated area along the Rio Grande between Candelaria and Redford. In the upland part of the area, ground water is pumped for the municipal supply of Marfa, for domestic and livestock use, and for the irrigation of a few acres. In 1960, the estimated pumpage for all purposes was about 8,300 acre-feet or about 7.4 mgd (Table U2, major subdivisions 7-11).

In 1960, two public supplies were using ground water in the Marfa-Presidio area. The city of Marfa pumped 720,000 gpd from three wells tapping the Tascotal Formation of Goldich and Seward (1948). The wells ranged in depth from 841 to 1,100 feet and yielded 375 to 1,000 gpm. The city of Presidio pumped an average of 20,000 gpd from a well in the alluvium; the well was 64 feet deep and yielded an estimated 50 gpm. An additional 57,000 gpd was pumped for domestic purposes from the alluvial deposits by privately owned wells in Presidio.

Ground water is pumped for irrigation in the Rio Grande Valley to supplement surface-water supplies in the Marfa-Presidio area. In that part of the valley between Presidio and Candelaria, where surface water generally is not available for irrigation, about 24 wells were used in 1960 (Elder, C. W., Western Cotton Oil Co., personal communication, June 1961). Based on a duty of water of 3 acre-feet per acre irrigated, about 5,400 acre-feet was pumped in 1960.

The irrigation of approximately 6,000 acres in the valley between Presidio and Redford in 1960 was almost wholly from the Rio Grande, which derives most of its water from the Rio Conchos which enters the Rio Grande from Mexico about 4 miles above Presidio. According to the records of the International Boundary and Water Commission (1959, p. 12, 15), the average flow of the Rio Grande above the confluence of the Rio Conchos in 1959 was 10.0 second-feet (7,220 acre-feet) as compared to 767 second-feet (555,000 acre-feet) in the Rio Grande below Presidio.

In the vicinity of Marfa, Tinaja, Plata, and Casa Piedra in 1960, irrigation wells pumped an estimated 1,500 acre-feet to irrigate about 500 acres.

Water for domestic and livestock purposes is obtained principally from the many ranch wells scattered throughout the Marfa-Presidio area. Based on estimated water requirements of the rural residents and livestock in the area, the wells pumped about 460,000 gpd.

No water was pumped strictly for industrial use in the Marfa-Presidio area in 1960.

Fluctuations of Water Levels

Records of fluctuations of water levels in wells are scarce in the Marfa-Presidio area, the only records covering a period of several years being in the area near Marfa. During the period 1942-59, the water levels in seven wells near Marfa showed an average rise of 2.63 feet (Davis, 1961, p. 20, 25-30). During this same period, wells UW-52-41-901 and UW-52-49-402, which are among the most heavily pumped wells, showed average declines of 1.8 and 6.35 feet respectively.

Quality of Water

The results of chemical analyses of water samples from 11 wells and 2 springs in the Marfa-Presidio area are shown in Table U3 and Plate U4 (major subdivisions 7-11). Wells and springs in the upland part of the area yield water that is generally within the range of the U. S. Public Health standards except for the fluoride content, which exceeded 1.0 ppm in most of the samples. The water is rated generally as soft to moderately hard. The silica content in 11 samples ranged from 26 to 76 ppm, reflecting the environment of silica and intermediate volcanic rocks. The SAR, which is used to classify water for irrigation, ranged from 0.5 to 35. Water from wells UW-74-24-201 and UW-74-16-301 had SAR of 23 and 35, respectively, and the use of this water for irrigation might present problems of sodium accumulation in the soil. The water is low in total salt content, however, and could be used for irrigation if excess quantities were applied to leach the soil of sodium accumulations. The use of chemical amendments also may make the use of the waters feasible for irrigation. The boron content ranged from 0.13 to 0.29 ppm in eight samples, being well within the acceptable limits for irrigation of boron sensitive plants (U. S. Salinity Laboratory Staff, 1954, p. 81).

Water in the alluvium of the Rio Grande Valley between Candelaria and Redford generally is slightly to moderately saline except in widely scattered areas where fresh water suitable for public supply is obtained. In that part of the valley above Presidio, the ground water is more highly mineralized than that below Presidio. Above Presidio, the irrigation supply is principally from ground water because of a generally insufficient supply of water in the Rio Grande. As a result, the salinity of the ground water probably has increased owing to the concentration and accumulation of salt in the soil by evapotranspiration. Because of the relatively large inflow of water of good quality to the Rio Grande from the Rio Conchos near Presidio, the irrigation supply for the valley below Presidio is principally from surface water. The quality of the water in the Rio Grande is considerably better below Presidio than above, therefore the ground water also is better because of the substantial recharge to the reservoir from the infiltration of surface water of good quality applied to the land surface.

This is shown by the comparison of the quality of water from two wells, UW-51-51-801 and UW-74-30-403 (Table U3), which are representative of the ground water in the alluvium above and below Presidio. The dissolved-solids content of water from well UW-51-51-801 was 2,850 ppm as compared to 1,610 ppm in well UW-74-30-403. The SAR of the two samples were 9.0 and 5.1, respectively. According to the classification of irrigation waters (Figure U8), ground water in the alluvium is rated as medium in sodium hazard but medium to high in salinity hazard. Longenecker and Lyerly (1959, p. 17) show that the salt content of 12 water samples ranged between 1.40 and 4.24 tons per acre-foot and averaged 2.85. The SAR of these samples averaged 7.23. The locations of the wells sampled could not be determined, but the analyses probably are representative of the ground water in the alluvial deposits (Longenecker, D. E., personal communication, Feb. 1962).

Although the ground water in the alluvium in most places is unsatisfactory for public supply, fresh water is obtained in a few widely scattered areas. For example, wells UW-51-51-901 and UW-74-30-402, which furnished water to Candelaria and Presidio, respectively, yielded water low in dissolved-solids, sulfate, and chloride content; however, the fluoride content exceeded the standards of the U. S. Public Health Service. The areas containing the relatively good water probably are replenished locally by infiltration of storm runoff at the mouths of streams which emerge from the uplands onto the gently sloping permeable alluvial deposits.

Problems

The principal problem concerning the development of ground water in the Marfa-Presidio area is the inadequacy of data, which precludes a determination of the quantity of water in and the extent and thickness of the various aquifers. Additional chemical analyses are necessary to delineate the areas of fresh water-bearing zones in the alluvial deposits of the Rio Grande Valley. Periodic sampling of water from wells in the valley also is necessary to observe changes in the salt content of the water due to the continued use of ground water for irrigation.

The Marathon Area

General

The Marathon area of the upper Rio Grande Basin consists of major subdivision 16 and the western parts of 19 and 21 (Figure U9). The area includes parts of northeastern Brewster County and southern Pecos County. A large part of the Marathon area is on a structural uplift, the crest of which has been eroded to a lower level than the flanks so that the central part is an irregular basin surrounded by steep escarpments. The basin (Marathon Basin) is underlain chiefly by Paleozoic sedimentary rocks. The Marathon Limestone, which is the principal fresh water-bearing formation in the area, is classed as a secondary aquifer. Although sandstones of Pennsylvanian age also yield small quantities of water mainly to domestic and livestock wells, they are considered of insignificant importance except in local areas.

Occurrence and Movement

The occurrence and movement of ground water in the Marathon area are controlled chiefly by the geologic structure. The Marathon Limestone is productive chiefly in the anticlinal belts that trend northeast through Marathon and southeast of Marathon. Upfolding has brought the Marathon Limestone to relatively shallow depths, and in these areas the water occurs under water-table conditions in crevices, joints, and cavities in the limestone. In the synclinorial belts, the Marathon Limestone is downfolded and occurs at great depths; therefore, in the synclinorial belts, wells generally tap shallower aquifers of Pennsylvanian age. Where the Marathon Limestone is buried beneath younger formations, the water occurs under artesian conditions. In general, the ground water moves down the dip of the beds, but in places where the rocks have been intensively faulted or folded, the movement of water may be retarded or deflected along the strike of the beds.

Most of the ground water in the Marathon area moves south and southeast toward the Rio Grande. In the northern part of the area, however, the water moves northeast and east into the Stockton Plateau, thence to the Rio Grande.

Ground water is found at relatively shallow depths in most of the Marathon area, the depth of most wells being less than 250 feet. Wells drilled to greater depths are mainly in or near the Del Norte and Glass Mountains. The depth to water in most of the wells in the area was less than 150 feet.

Recharge and Discharge

Recharge to the ground-water reservoirs in the Marathon area is principally by infiltration of precipitation and stream runoff and to a much smaller extent by underground inflow from outside the area (DeCook, 1961, p. 16). A large part of the precipitation falls during the summer when the evaporation rate is high, thus only a small fraction of the water escapes evaporation and becomes recharge. Most of the recharge occurs from the torrential rains that fall during the summer. If precipitation at Marathon is considered as representative of the area, the annual precipitation of nearly 18 inches provides about 915,000 acre-feet of water per year. Under similar geologic and hydrologic conditions, Littleton and Audsley (1957, p. 26) estimated that about 5 percent of the annual rainfall in the neighboring Alpine area reaches the ground-water reservoir. On this basis, about 45,000 acre-feet annually reaches the water table in the Marathon area. This figure may be excessive because of the difficulty in determining accurately the area of effective recharge. Recharge by underflow into the area from the north and west probably is negligible because the rocks bounding the area on the north and west dip away from the area.

Ground water is discharged in the Marathon area naturally by springs, evapotranspiration, and underflow southward toward the Rio Grande, and artificially by wells. An undetermined but probably large part of the ground water moves out of the Marathon area as underflow through the alluvium and permeable Paleozoic rocks along the valleys of Maravillas Creek and others that drain in the area. The water flows across the southern boundary of the Marathon area through the Stockton Plateau to the Rio Grande.

A small amount of water is discharged by springs in the Marathon area. Most of the springs are contact springs, but some issue from joints and fractures of consolidated rocks and from the banks of streams where the channels cross outcrops of water-bearing rocks. The largest spring in the area, Peña Colorado Spring, BK-52-54-901 near Marathon, had an average flow of about 300 gpm. The majority of the springs, however, had small flows ranging from about ½ to 40 gpm (DeCook, 1961, p. 17).

The small quantity of artificial discharge of ground water in the Marathon area is through pumped wells. Most of the wells that are used for watering livestock are equipped with windmills and generally yield less than 10 gpm. A few of the domestic wells yield as much as 25 gpm, although most of them also are pumped at rates of less than 10 gpm.

Utilization

The largest use of water in the Marathon area is for domestic and livestock purposes, a substantial part of the water being obtained from relatively shallow wells in the Marathon Limestone. In 1960, the pumpage by domestic and livestock wells probably was less than 400,000 gpd, including pumpage by many privately owned wells in Marathon.

In 1960, part of the public-water supply for Marathon was obtained from two privately owned wells in the Marathon Limestone. The yields of the wells are not known but are probably less than 50 gpm. The wells furnished water for 30 homes and a few stores in Marathon. The average daily consumption in 1960 was reported to be about 6,000 gallons. Other homes in Marathon are supplied by privately owned wells of smaller capacities.

Quality of Water

The chemical quality of the ground water in the Marathon area is shown by the analyses in Table U3 and Plate U4. The water from the Marathon Limestone generally is of good chemical quality except that it is very hard. The dissolved-solids content in water from most of the wells tapping the Marathon exceeded 500 ppm but was less than 1,000 ppm. The fluoride content in many of the samples was about 1.0 ppm, which is nearly the ideal concentration recommended for the prevention of dental caries in children (Dean and others, 1942, p. 1155-1179). The fresh water in the Marathon Limestone has been contaminated northwest and south of Marathon due principally to the natural incursion of saline water, oil, and gas possibly by upward movement along fault planes. According to DeCook (1961, p. 21), "...the contamination appears to be spreading slowly eastward." In at least one well the contaminated zone has been cased off and water of suitable quality has been obtained at a lower level. Most of the ground water in the Marathon Limestone is suitable for irrigation, the analyses comparing favorably with the criteria proposed by the U. S. Salinity Laboratory Staff (1954) for the classification of irrigation waters; however, the boron content of the water was not determined.

The water from the Pennsylvanian rocks (where they occur at relatively shallow depths) is suitable for most purposes although very hard.

Problems

The principal problems in the Marathon area are those associated with the lack of data to determine the quantity of water available in the aquifers. The extent of the Marathon Limestone is not known definitely, but in a part of the area the limestone is downfolded and occurs at great depths. The depth to which fresh water occurs in the limestone has not been determined because in these areas wells are drilled only to the shallower aquifers of Pennsylvanian age.

The hydraulic properties of the Marathon Limestone and the rocks of Pennsylvanian age are not known, although it is known that the transmissibility of the limestone varies widely from place to place because of the nature of the porosity of the rocks.

Detailed studies will be necessary to determine accurately the source and extent of contamination of the ground water in the Marathon Limestone in and near Marathon.

The Stockton Plateau

General

The Stockton Plateau includes subdivisions 18, 22, 23, and the eastern parts of 19 and 21 (Figure U9), and occupies parts of Brewster, Pecos, Terrell, and Val Verde Counties. The area occupies that part of the Stockton Plateau in the upper Rio Grande Basin, the rest of the plateau being in the middle Rio Grande Basin.

The principal water-bearing formations underlying the plateau are included in the Trinity Group and the Fredericksburg and Washita Groups, undifferentiated, although they are classed as secondary aquifers. In general, the aquifers yield small quantities of fresh water for public supply, domestic, and livestock purposes.

Occurrence and Movement

The ground water in the Stockton Plateau in the upper Rio Grande Basin occurs under confined and unconfined conditions in the joints, cracks, and solution cavities of the limestones of the Trinity Group and the Fredericksburg and Washita Groups, undifferentiated, and in the pore spaces in the Maxon Sandstone of the Trinity Group.

In the southern part of the Stockton Plateau, ground water occurs in the Maxon Sandstone and Glen Rose Limestone of the Trinity Group and the Devils River Limestone, which in this part of the plateau consists of both the Fredericksburg and Washita Groups. The wells range in depth from 600 feet in well BK-53-49-301, which probably draws water from the Devils River Limestone, to more than 1,400 feet in well BK-72-18-201, which probably taps the Maxon Sandstone or its equivalent.

In the northern part of the plateau, wells obtain water from the limestones in the Fredericksburg and Washita Groups. Whether these aquifers are equivalent to the Devils River Limestone is not known. Water also is obtained from the Maxon Sandstone principally where it is less than 600 feet below the surface.

In Val Verde County, well YP-71-03-401 at Pumpville yields a small quantity of water from the Devils River Limestone at a depth of 1,000 feet, the depth to water being about 900 feet. In Pecos County, ground water occurs in the alluvial deposits associated with the larger streams and in rocks of the Trinity Group, principally the Maxon Sandstone. The wells in Pecos County range in depth from about 150 feet to as much as 850 feet.

Ground water moves by gravity through openings and porous zones in the rocks from intake areas to areas of natural discharge. The general slope of the land surface as well as the dip of the individual beds of limestone in the Stockton Plateau is south and southeast, and the ground water moves probably in the same general direction.

Recharge and Discharge

The ground-water reservoirs in the Stockton Plateau are recharged principally by stream runoff but also by infiltration of precipitation on the surface and underflow from adjoining areas.

Direct infiltration of precipitation probably is negligible in much of the plateau. The precipitation that falls on the rocks in the mountainous areas becomes stream runoff until it reaches the valleys and there much of it infiltrates to gravels in the canyons and foothills. A considerable amount of recharge probably occurs in places where jointed limestones crop out. The amount of recharge entering the Stockton Plateau by underflow is not known but it probably is not large. Some underflow enters the plateau from the Marathon area in the alluvium along Big Canyon on the north and Maravillas Creek on the south.

Ground water is discharged naturally in the Stockton Plateau by springs, by underflow south and southeast toward the Rio Grande, and artificially by wells. The volume of water discharged by springs probably is small. The springs, most of which are near the base of the plateau at the valley of the Rio Grande, had flows reportedly ranging from 15 to 1,700 gpm. Most of the discharge, however, occurs as underflow through the Cretaceous rocks and through the alluvium in the large drainageways.

The artificial discharge of ground water through wells is a small part of the total ground-water discharge in the Stockton Plateau. Most of the wells that are used for livestock purposes are equipped with windmills and generally yield less than 10 gpm, although a few wells were reported to have yielded as much as 45 gpm. In Pecos County, well US-53-42-301, which taps the Maxon Sandstone, had a reported yield of 300 gpm; however, most of the other wells in this part of Pecos County yielded less than 50 gpm.

Utilization

The total withdrawal of ground water in 1960 in the Stockton Plateau probably was less than 700 acre-feet or 650,000 gpd (Table U2, major subdivisions 18, 19, 21-23). Sanderson, the largest single user of water in the plateau, obtains its public supply from 12 wells which pumped about 220,000 gpd (250 acre-feet) in 1960 principally from the Maxon Sandstone. The wells ranged in depth from 415 to 840 feet and had yields ranging from 7 to 49 gpm. The public supply for Dryden used about 1,500 gpd from one well tapping limestones of the

Fredericksburg and Washita Groups, undifferentiated. The well, which is 850 feet deep, yielded about 40 gpm.

The pumpage of ground water for domestic and livestock supplies in the plateau in 1960 was about 450 acre-feet (400,000 gpd) pumped in about equal amounts from the Trinity Group, including the Glen Rose Limestone and the Devils River Limestone.

Quality of Water

The results of chemical analyses of water from 11 wells and 2 springs in the Stockton Plateau in the upper Rio Grande Basin are shown in Table U3 (major subdivisions 18, 19, 21-23). The dissolved-solids, chloride, and sulfate content of these and several additional wells and springs are shown in Plate U4. In the following discussion of the ranges of various constituents, some of the values used were taken from unpublished analyses, part of which are on file in the office of the U. S. Geological Survey at Austin, Texas, and the rest are in the El Paso office of the U. S. International Boundary and Water Commission.

The wells and springs in the Stockton Plateau yield water that is generally within the standards of the U. S. Public Health Service. The fluoride content in 25 samples ranged from 0.06 to 3.4 ppm; however, in only 5 did it exceed 1.5 ppm. The sulfate content, which ranged from 12 to 451 ppm in 38 samples, exceeded 250 ppm in water from well YR-71-03-101 only, near Pumpville. The chloride content was less than the recommended limit of 250 ppm in all samples. The dissolved-solids content of 31 samples exceeded 1,000 ppm in only one sample (the same that contained the excess amount of sulfate), and most of the water contained less than 500 ppm dissolved solids. The water was moderately to very hard, the hardness ranging from 102 to 264 ppm in 19 samples.

Ground water in the Stockton Plateau generally is satisfactory for the irrigation of most crops, according to the classification of irrigation waters given in Figure U8; however, no water was being used for irrigation in 1960.

Problems

The principal problem concerning the development of ground water in the Stockton Plateau is the lack of data with which to determine ground-water resources. Additional studies are needed to determine the depths and productivity of the aquifers, to outline the areas of recharge and discharge, and to calculate the amount of water that is available for use.

The Big Bend Area

The Big Bend area of the upper Rio Grande Basin includes major subdivisions 12, 14, 15, and 17, and the eastern part of major subdivision 11 (Figure U9). The southern part of the area is occupied by the Big Bend National Park.

In the Big Bend area, ground water occurs chiefly in the alluvium associated with the numerous ephemeral streams that drain the area. Some of these streams probably carry a permanent subsurface flow of water, but in general, the alluvial deposits are thin and yield only small quantities of water. The limestone and sandstone of Cretaceous age and the igneous rocks of Tertiary age are not important sources of water, although they may yield small quantities of water to wells in the vicinity of Terlingua and Lajitas and in some of the mountainous parts of the area.

In the northern part of the Big Bend area, which is underlain by rocks of Cretaceous and Tertiary age, ground water occurs at great depths. For example, during the drilling of well BK-73-11-101, the driller reported water in cavernous limestone probably of Cretaceous age at a depth of 2,200 feet. The well was not tested, but it was reported that the water was unconfined and did not rise in the well.

The amount of recharge and natural discharge in the Big Bend area is not known. The ground water in the area is derived chiefly from infiltration of precipitation but also by seepage of streamflow. The water is discharged naturally through springs, by underflow through the alluvial deposits associated with Terlingua, Tornillo, and Calamity Creeks, and by movement southward through the Cretaceous and igneous rocks, the water ultimately being discharged into the Rio Grande.

The total pumpage in the Big Bend area in 1960 was about 400 acre-feet or about 360,000 gpd (Table U2, major subdivisions 11, 12, 14, 15, and 17). The biggest single use of water (about 90 percent of the total) was for domestic and livestock purposes. Most of the domestic and livestock water is obtained from wells in the alluvium. The wells produce from relatively shallow depths and yield generally less than 10 gpm.

The only public supply in the Big Bend area was at Big Bend National Park where the average daily pumpage was about 16,000 gpd in 1960. The water supply for the park was obtained from five wells and one spring; the wells tap alluvial deposits and have yields of 3 to 50 gpm. A few other wells and springs in Big Bend National Park supply water for domestic and wildlife use; the yields of these are generally small. Hot Springs (BK-72-49-401) and Boquillas Hot Springs (BK-72-49-502), which issue from rocks of Cretaceous age, flowed an estimated 50 and 90 gpm, respectively. The temperature of the water at Hot Springs was 105°F.

The results of chemical analyses of water from three wells and four springs in the Big Bend area are shown in Table U3 (major subdivisions 12, 14, 15, and 17) and the dissolved-solids, sulfate, and chloride content in these and several other samples are shown in Plate U4. The analyses show that the quality of the water in the Big Bend area ranges between wide limits. Where the water is of good quality, the water-bearing unit crops out within a short distance, the ground water having moved only a short distance from the area of recharge. The water from Hot Springs and Boquillas Hot Springs is very hard and contains a large amount of calcium sulfate, which is derived probably from the gypsum that occurs in the rocks of Cretaceous age in the vicinity. The water from the alluvial deposits generally is hard and high in fluoride content, and especially during periods of drought, the water may be unsatisfactory for domestic purposes because of the high sulfate content.

The Quitman Arroyo-Glenn Creek Area

The Quitman Arroyo-Glenn Creek area includes major subdivisions 5 and 6 of the upper Rio Grande Basin, and occupies parts of Hudspeth, Culberson, Jeff

Davis, and Presidio Counties (Figure U9). Quitman Arroyo and Glenn Creek, which are separated by the Eagle Mountains, occupy elongated intermontane basins nearly filled with alluvium.

Ground water in the Quitman Arroyo-Glenn Creek area occurs chiefly in the bolson deposits; the thickness of the sands and gravels are not known but, according to Baker (1934, p. 139), a well at the head of Glenn Creek was still in bolson deposits at a depth of 1,100 feet. The water is unconfined and the water table generally is at relatively shallow depths (200 feet or less), except in the upper part of Quitman Arroyo where the depth to water ranges from about 300 to 500 feet. Of lesser significance are the alluvial deposits overlying the bolson sediments in the valley of the Rio Grande. Other aquifers in the area include rocks of Cretaceous and Tertiary age; they are not important sources of water, although they yield small quantities of water to some of the livestock wells in the mountainous parts of the area.

The quantity of recharge and natural discharge in the Quitman Arroyo-Glenn Creek area is not known. Recharge to the ground-water reservoirs is by infiltration of precipitation that falls in the area and by seepage from stream runoff. The alluvium along the Rio Grande is recharged also by underflow from outside the area. The water is discharged as underflow from the upland part of the area into the alluvium of the Rio Grande Valley, thence into the Rio Grande. Large but undetermined amounts of water are transpired by dense growths of salt cedar along the Rio Grande.

About 3,100 acre-feet or 2.8 mgd of ground water was pumped from the Quitman Arroyo-Glenn Creek area in 1960. Irrigation was the largest user, about 3,000 acre-feet of water being pumped from 13 wells to irrigate 1,000 acres scattered along the Rio Grande. The rest of the water was used for domestic and livestock purposes; no water is pumped for industrial use or public supply in the area. Most of the irrigation wells in the shallow alluvial deposits of the Rio Grande had yields ranging from 500 to 2,100 gpm; two wells in the bolson deposits of Glenn Creek had yields of 2,500 gpm each.

The results of chemical analyses of water from three wells and two springs in the Quitman Arroyo-Glenn Creek area are shown in Table U3 (major subdivisions 5 and 6); the dissolved-solids, sulfate, and chloride content of these and several other samples are shown in Plate U3.

Water from the bolson deposits of the Quitman Arroyo-Glenn Creek area is suitable generally for most purposes. Field analyses showed that water from well PD-51-17-701, tapping the bolson deposits of Glenn Creek, contained about 400 ppm of dissolved solids and 20 ppm of chloride. Water from well PD-48-62-701, tapping the bolson deposits of Quitman Arroyo, contained 626 ppm of dissolved solids and 42 ppm of chloride.

Water from irrigation wells tapping the alluvial deposits of the Rio Grande is slightly to moderately saline. Local residents reported that in 1961, wells in some parts of the valley produced water containing from 7 to 9 tons per acre-foot (5,150 to 6,620 ppm) dissolved solids; however, water from well UW-51-25-101, also in the alluvium but near the point where Glenn Creek discharges into the Rio Grande, contained only 1.9 tons per acre-foot (1,390 ppm) of dissolved solids.

Small quantities of slightly to moderately saline water emerge from springs at the west foot of the Quitman Mountains. Indian Hot Springs, PD-50-14-501, which is the largest spring in the area, flows about 12 gpm from igneous rock. The water contained 6,760 ppm dissolved solids, 2,600 ppm of chloride (Table U3), and had a temperature of 108°F. Less than a mile west, a smaller spring (PD-50-14-502) flowed water that contained 2,490 ppm dissolved solids, 700 ppm of chloride, and had a temperature of 58°F. Although the spring was flowing apparently from igneous rock, a comparison of the quality of water from the two springs indicates a different source.

The Diablo Plateau

The Diablo Plateau includes the northwestern part of major subdivision 24 of the upper Rio Grande Basin (Figure U9). The surface of the plateau is formed principally by southeasterly dipping beds of limestone that range in age from Devonian to Permian. The water-bearing units that underlie the plateau include limestone and sandstone of Pennsylvanian or Permian age and of Trinity (Early Cretaceous) age. In general, the aquifers yield only small quantities of slightly to moderately saline water; consequently they are of local significance only as sources of water supply.

In 1958 and 1959, the city of El Paso drilled two test wells in the northern part of the Diablo Plateau. In one of the wells (PD-48-12-101) water was obtained from a glauconitic sandstone of Pennsylvanian or Permian age between depths of 2,242 and 2,308 feet. The water contained 5,760 ppm dissolved solids and 2,820 chloride. The water level rose to 1,140 feet below the land surface (Leggat, 1962, p. 12). In the other well, which was drilled in the northwest part of the plateau, water-bearing formations were not penetrated to a depth of 2,100 feet. Near the west edge of the plateau, well PD-48-10-601, which was drilled as an oil test in 1930, yields moderately saline water (Plate U3) from a depth of about 2,400 feet. The water level reportedly stands about 1,460 feet below the surface.

The surface of the southern part of the plateau is formed by Cretaceous rocks and the wells are drilled to the sandstone and limestone of Trinity (Early Cretaceous) age. Most of the wells in the southern part of the plateau yield small quantities of water, primarily for watering livestock. The chemical analysis of water from one well (PD-48-30-401, Table U3), which penetrated limestone of Trinity age to a depth of 1,100 feet, showed that the water was moderately saline and high in chloride content. Other wells tapping the Cretaceous rocks in the plateau probably yield water of similar quality.

It is estimated that the pumpage from all sources in the Diablo Plateau in 1960 was less than 300 acre-feet, most of which was used for watering livestock.

Summary of Availability

The reconnaissance studies of the river basins of Texas were made chiefly to determine the order of magnitude of the ground-water supplies available in each basin. A reliable estimate of the availability of ground water in the upper Rio Grande Basin will require much additional data as well as improved techniques for measuring certain segments of the hydrologic cycle. Several important factors concerning which little is known bear greatly on the availability of ground water in the basin. Among these are the amount of recharge to the aquifers, the volume of natural discharge that can be salvaged, and the possible movement of saline water into the fresh-water parts of the aquifers.

The amount of ground water available in the upper Rio Grande Basin has been determined for only the fresh water-bearing bolson deposits in the Hueco and La Mesa bolsons in the El Paso area because the hydrologic and geologic data for the other aquifers and areas are too meager. Even in the bolson deposits, the computations of the potential availability of water may be changed considerably as more data are collected. In the El Paso area, it has been estimated that at least 9.0 million acre-feet of theoretically recoverable fresh ground water is in storage in the bolson deposits. This estimate includes 150,000 acre-feet of relatively fresh ground water in the alluvial deposits in the Lower Mesilla Valley. In the Wildhorse-Lobo Flats subarea, at least 385,000 acre-feet of recoverable fresh water is in storage. However, this estimate may be as much as 100 percent in error as few wells have been drilled to the base of the fresh water and most of the wells for which data are available are concentrated in the relatively small irrigated parts of the subarea.

Throughout a large part of the upper Rio Grande Basin, ground water occurs in crevices, joints, and solution cavities of consolidated rocks; consequently, even a preliminary estimate of the volume of water available in these aquifers will require much additional data.

The areas in which the largest supplies of ground water are available are the same areas in which the supplies are being "mined." However, in these areas large supplies of slightly saline water may be considered as a potential source of ground water for future use by demineralization or mixing with fresh water.

On the basis of the data obtained during the reconnaissance and earlier studies, it seems that the fresh ground-water supply in the upper Rio Grande Basin is insufficient to support additional large-scale development except in the areas where the bolson deposits occur.

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Year	Water-Supply Paper No.	Year	Water-Supply Paper No.	Year	Water-Supply Paper No.
1936	817	1943	989	1950	1168
1937	840	1944	1019	1951	1194
1938	845	1945	1026	1952	1224
1939	886	1946	1074	1953	1268
1940	909	1947	1099	1954	1324
1941	939	1948	1129	1955	1407
1942	947	1949	1159		

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE MIDDLE RIO GRANDE BASIN, TEXAS

By

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Texas Water Commission

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

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS (Cont'd.)

Page

TABLES

ILLUSTRATIONS

Figures

Plates
[All plates in pocket]

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE MIDDLE RIO GRANDE BASIN, TEXAS

ABSTRACT

Determination of the order of magnitude of ground-water supplies potentially available from the water-bearing formations in the middle Rio Grande Basin was undertaken as part of a statewide reconnaissance investigation of ground-water conditions in Texas.

The middle Rio Grande Basin, in western and southwestern Texas, includes all or parts of 24 counties and has an areal extent of 27,562 square miles which represents about 10.4 percent of the total area of the State. Physiographically, the area includes flat to rolling plains, dissected plateaus, and rugged mountains. Altitudes range from about 400 feet above mean sea level in the southeastern part of the area to more than 8,700 feet in the northwestern part. The climate is semiarid with the mean annual precipitation ranging from about 12 to 20 inches.

The 1960 population of the middle Rio Grande Basin was approximately 187,000, representing about 2 percent of the total population of Texas. The economy is based primarily on ranching, farming, and petroleum exploration and production.

In the middle Rio Grande Basin, two primary aquifers, the Cenozoic alluvium and Edwards-Trinity, are capable of supplying large quantities of water over large areas. Three secondary aquifers, the Santa Rosa Sandstone, Rustler Formation, and Capitan Reef complex and associated limestones, are capable of supplying large quantities of water over small areas or small quantities of water over large areas. In addition to the primary and secondary aquifers, other aquifers of limited potential which yield small to moderate quantities of water locally are the Cook Mountain Formation, Carrizo Formation and Wilcox Group, Tertiary volcanic rocks, Navarro and Taylor Groups, and Austin Group.

Approximately 575,000 acre-feet of water is annually withdrawn from aquifers in the middle Rio Grande Basin for municipal, industrial, and irrigation purposes. About 385,000 acre-feet or 67 percent of the total pumpage is from the Cenozoic alluvium, with additional withdrawals of approximately 142,000 acre-feet from the Edwards-Trinity aquifer, 23,000 acre-feet from the Santa Rosa Sandstone, 9,000 acre-feet from the Rustler Formation, 12,600 acre-feet from the Capitan Reef complex and associated limestones, and 3,600 acre-feet from other aquifers.

On the order of 50 to 60 million acre-feet of water is probably available from storage for additional development from Cenozoic alluvium. Approximately 400,000 acre-feet of ground water can probably be developed perennially from the Edwards-Trinity in addition to present pumpage from the aquifer. However, large-scale development from the Edwards-Trinity would undoubtedly curtail base flow of many streams.

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," should be made on the primary and secondary aquifers of the middle Rio Grande 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 MIDDLE RIO GRANDE BASIN, TEXAS

INTRODUCTION

Purpose and Scope

The reconnaissance investigation of the middle Rio Grande Basin, Texas, 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 the purpose of ground-water reconnaissance studies, the State was divided into 13 major river basin areas and a coastal region which embraces all or parts of several river basins and their intervening coastal areas. In planning the development of the State's water resources to meet present and future needs, the quantities of ground water and surface water that can be developed must be known and considered. Because adequate information was lacking for determining the total quantity of ground water available for 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 middle Rio Grande 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 middle Rio Grande Basin reconnaissance investigation provide a generalized evaluation of ground-water conditions over large areas. The amount of water available for development in the middle Rio Grande 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 usable ground water available for development, and to better determine the effects of present and future pumpage.

Location and Extent

The middle Rio Grande drainage basin, in western and southwestern Texas, is bounded on the west and southwest by the upper Rio Grande Basin, on the north by the New Mexico state line, on the northeast by the Colorado River Basin and on the east by the Nueces River Basin (Figure M1). The Rio Grande forms the southern boundary, from a few miles south of Laredo to approximately the western edge of Val Verde County. The middle Rio Grande Basin includes all or parts of 24 counties and has an areal extent of 27,562 square miles, which represents about 10.4 percent of the total area of Texas.

Because of the large areal extent, the middle Rio Grande Basin has been divided into three regions to facilitate discussion. Each region contains a series of principal water-bearing formations and, in most instances, a different type of geologic, topographic, and economic condition. The boundaries of the regions coincide with the topographic limits of the middle Rio Grande Basin and the topographic limits of smaller drainage subdivisions which have been defined by the Planning Division of the Texas Water Commission (Figure M1).

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 geologic cross sections and maps.

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 14 counties that lie within or partly within the middle Rio Grande Basin. Published reports on the ground-water resources of Edwards, Dimmit, Kinney, Pecos, Reeves, Winkler, and parts of Crane, Ward, and Brewster Counties provide thorough and up-to-date information.

Figure M1

Map of Texas Showing the Location of the Middle Rio Grande Basin

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

The remaining investigations are generally out-of-date and of limited value. Figure M2 shows the areas in which ground-water studies had been made prior to this reconnaissance investigation. Ground-water reports that pertain to earlier work in the middle Rio Grande Basin are listed 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 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 $7\frac{1}{2}$-minute quadrangles, each of which is further divided into 9 $2\frac{1}{2}$-minute quadrangles. Each 1-degree quadrangle in the State has been assigned a number for identification. The $7\frac{1}{2}$-minute quadrangles are numbered consecutively from left to right beginning in the upper left-hand corner of the 1-degree quadrangle, and the $2\frac{1}{2}$-minute quadrangles within the $7\frac{1}{2}$-minute quadrangle are similarly numbered. The first 2 digits of a well number identify the 1-degree quadrangle; the 3rd and 4th, the $7\frac{1}{2}$-minute quadrangle; the 5th digit identifies the $2\frac{1}{2}$-minute quadrangle; and the last 2 digits identify the individual well within the $2\frac{1}{2}$-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 $7\frac{1}{2}$-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 investigation of the middle Rio Grande Basin was 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 control and improvement districts, and geological societies, and well owners for their cooperation and contribution of data. Appreciation is also expressed to the many oil companies who not only supplied data on their water supplies, but permitted the use of numerous electrical logs from their files which otherwise were not available.

The assistance and data furnished by members of the U. S. Geological Survey on parts of the middle Rio Grande Basin are 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.

Personnel

Initial planning for the reconnaissance fieldwork and the resulting report on the middle Rio Grande Basin was under the direction of L. G. McMillion,

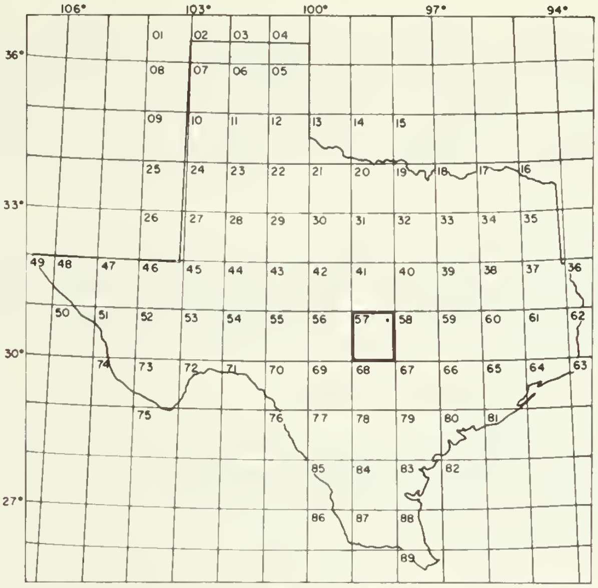
Location of Well 57-15-701

57 1-degree quadrangle

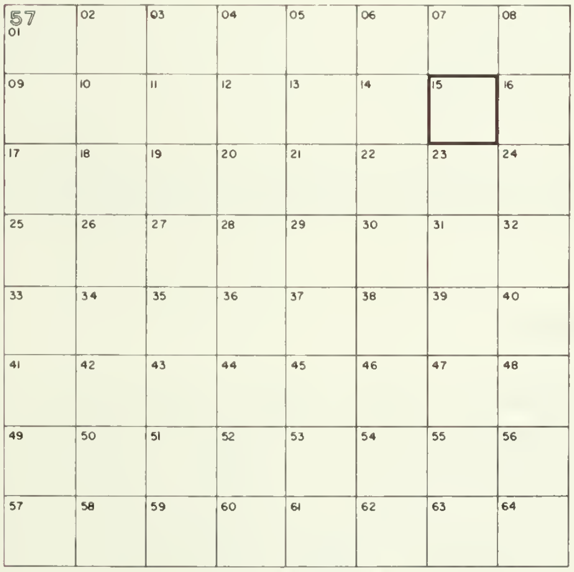
15 7 1/2 minute quadrangle

7 2 1/2 minute quadrangle

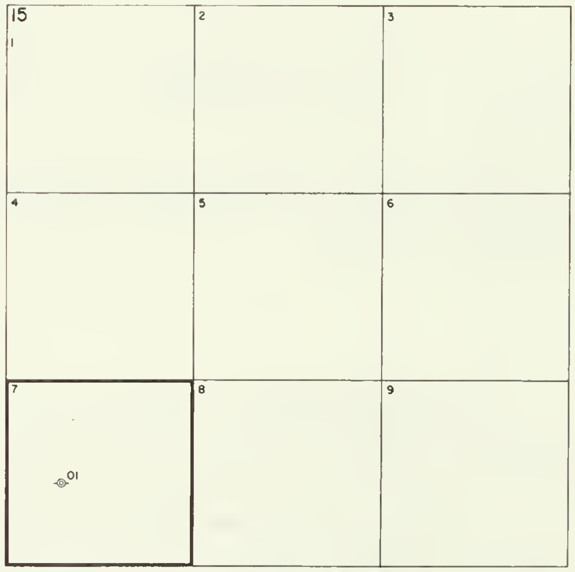
01 Well number within 2 1/2 minute quadrangle



1-degree Quadrangles



7 1/2-minute Quadrangles



2 1/2-minute Quadrangles

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. This report was prepared under the direct supervision of R. C. Peckham, Assistant Director, Ground Water Division.

Fieldwork for this investigation was conducted 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:

Personnel	Counties Worked
L. T. Rogers	Crane, Crockett, Dimmit, Edwards, Kinney, Loving, Maverick, Pecos, Reeves, Terrell, Val Verde, Ward, Webb, Winkler
V. M. Shamburger	Reagan, Upton
F. A. Rayner	Andrews, Ector
J. B. Wesselman John Goodier	Schleicher, Sutton

Basic data on the parts of Culberson, Presidio, Jeff Davis, and Brewster Counties that are included in this report were collected by M. E. Davis, U. S. Geological Survey.

GEOGRAPHY

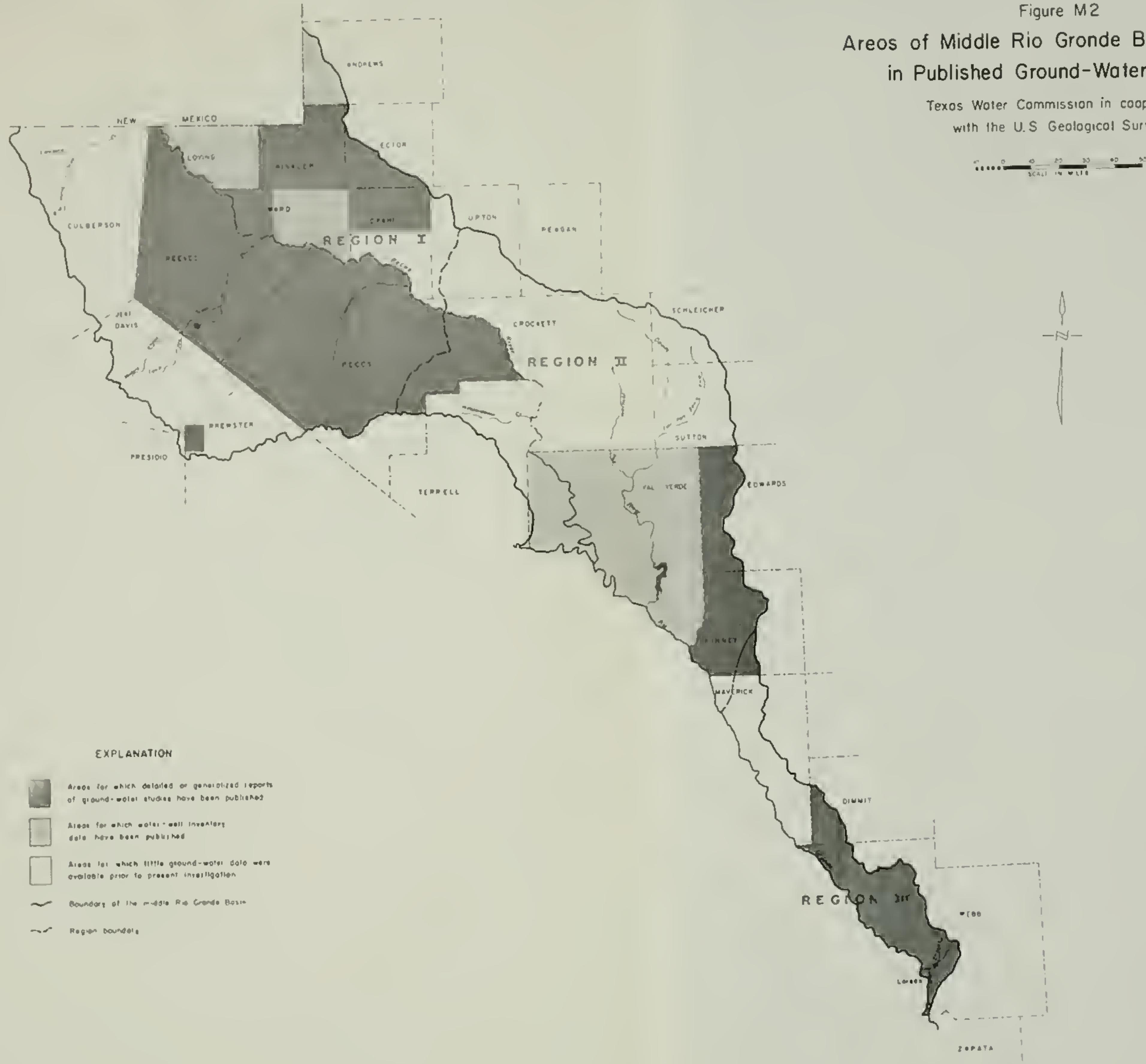
The physiographic features of the middle Rio Grande Basin include flat to rolling plains, dissected plateaus, and rugged mountains. Altitudes range from 400 feet above sea level in the extreme southeastern part to more than 8,700 feet in the Guadalupe Mountains in the northwest part. The Planning Division of the Texas Water Commission has subdivided the middle Rio Grande Basin into smaller drainage areas for water-resources planning. These subdivisions are numbered in accordance with numbers assigned by the Planning Division and are shown on Plates M1, M2, and M3.

The climate of the middle Rio Grande Basin is semiarid, characterized by hot summers and generally mild winters. Mean annual precipitation ranges from about 12 to 20 inches. Figure M3 illustrates the mean annual precipitation of the area and average monthly precipitation at selected stations. Figure M4 shows the annual precipitation for selected stations.

The net lake-surface evaporation rate in the middle Rio Grande Basin ranges from about 65 to 75 inches per year.

In 1960 approximately 186,593 inhabitants lived in the middle Rio Grande Basin, representing about 2 percent of the total population of Texas. About 79 percent of the population lived in urban communities, which are towns of 2,500

Figure M2
Areas of Middle Rio Grande Basin Included in Published Ground-Water Reports
Texas Water Commission in cooperation with the U.S. Geological Survey



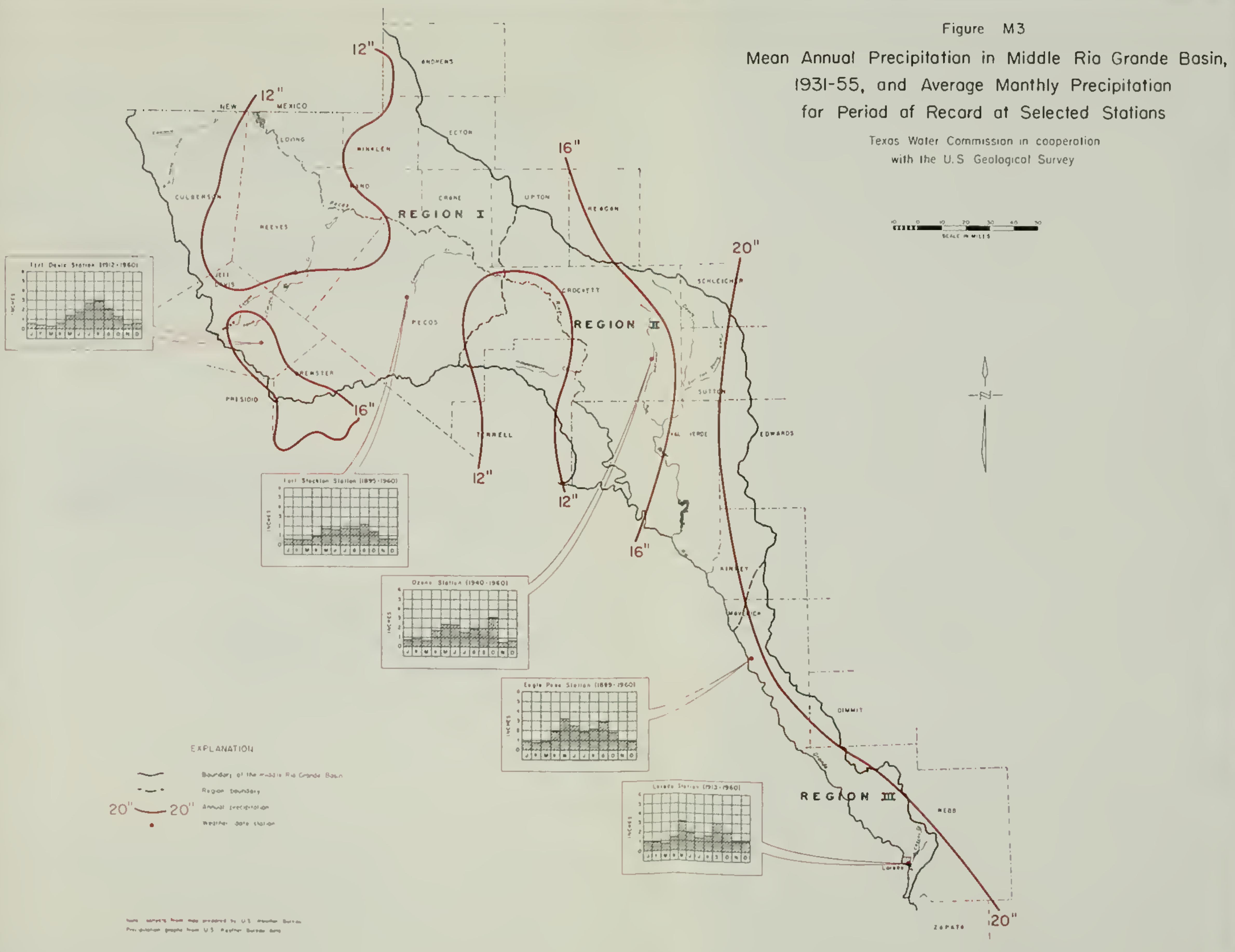


Figure M3

Mean Annual Precipitation in Middle Rio Grande 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

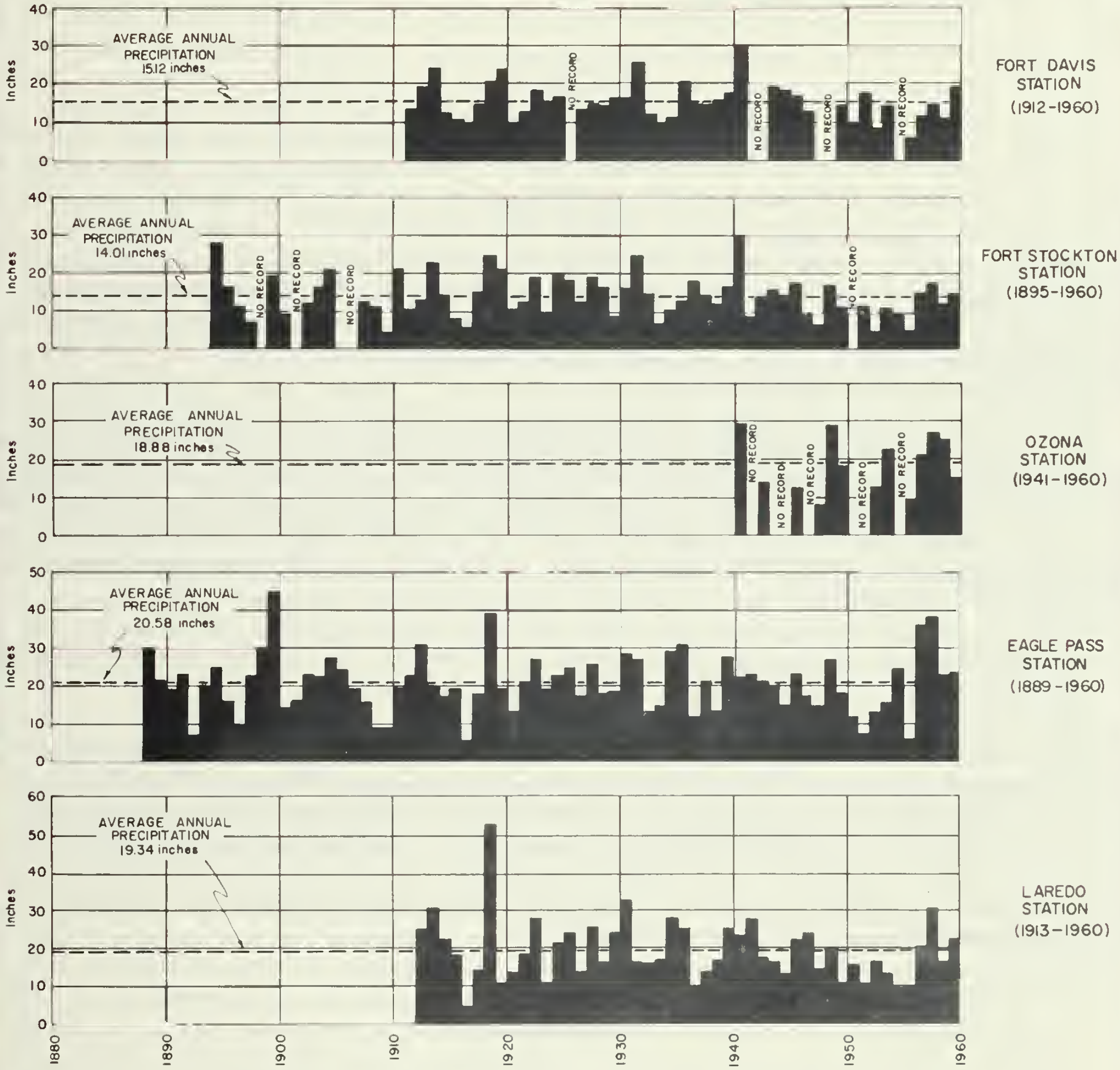


Figure M4

Annual Precipitation for Period of Record at Selected Stations in Middle Rio Grande Basin

(From U. S. Weather Bureau data)

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

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or more inhabitants. The remainder of the population is classified as rural. There are 12 cities and towns in the area with 2,500 or more inhabitants.

The economy of the middle Rio Grande Basin is based primarily on ranching, farming, and oil exploration and production. Some light manufacturing and processing industries are also present.

Region I

Region I of the middle Rio Grande Basin coincides with the upper drainage area of the Pecos River in Texas (Figure M1). The region covers approximately 15,387 square miles. Physiographically, most of the region consists of flat to rolling plains which slope gently toward the Pecos River. A small area in the southeastern part of the region consists of the well-dissected upland known as the Stockton Plateau. Five small mountain ranges occur along the margin of the region on the west and south; they are the Guadalupe, Delaware, Apache, Davis, and Glass Mountains. Altitudes in Region I range from 2,200 to more than 8,700 feet above sea level.

The mean annual precipitation in Region I ranges from less than 12 to more than 16 inches. The highest annual precipitation in the region occurs in the Davis and Glass Mountains, in the southwestern part of the region. Figure M3 shows the average monthly precipitation and Figure M4 shows the annual precipitation for the Fort Stockton station from 1895 to 1960 and the Fort Davis station from 1912 to 1960.

The population of Region I based on the 1960 U. S. Census was about 68,600 with 68 percent of the population classified as urban.

The economy of Region I is based on ranching, farming, and oil production. Ranch livestock consists primarily of cattle, but some sheep and goats are raised. Where water supplies are available for irrigation, the region is intensively cultivated. The main crops include cotton, alfalfa, grain sorghums, and some truck crops. Region I lies partly within one of the most important oil-producing areas of the State, and therefore petroleum exploration and production contribute greatly to the economy.

Region II

Region II of the middle Rio Grande Basin occupies approximately 10,320 square miles and is situated primarily on the Edwards Plateau and a small part of the Stockton Plateau. The region extends southeastward to the western margin of the Gulf Coastal Plain. The region is drained by the Pecos and Devils Rivers and their respective tributaries and a few lesser tributaries of the Rio Grande. The topography of the region is characterized by sparse vegetation, level plains, rolling hills, and steep-walled mesas. The margins of the plateaus are dissected by numerous steep-walled canyons resulting in a rugged topography. Elevations in the region range from 900 feet to about 3,000 feet above sea level.

The mean annual precipitation ranges from about 12 to 20 inches. Figure M4 shows the annual precipitation at the Ozona station from 1941 to 1960. The average monthly precipitation at Ozona for the period of record is shown on Figure M3.

The population of Region II based on the 1960 U. S. Census was about 41,700 with 67 percent of this total classified as urban.

The economy is based chiefly upon cattle, sheep, and goat ranching owing to the generally rugged topography of Region II. Some irrigated cropland on the Rio Grande flood plain produces crops such as alfalfa, sorghums, cotton, small grains, and vegetables. Oil and gas exploration and production contribute to the economy locally. Government installations, such as the Amistad Dam project on the Rio Grande above Del Rio, radar stations at Ozona and Del Rio, and Laughlin Air Base at Del Rio, also contribute significantly to the economy.

Region III

Region III of the middle Rio Grande Basin covers about 1,855 square miles in a long, narrow strip, ranging from 10 to 30 miles in width, along the north side of the Rio Grande from north of Eagle Pass to Laredo (Figure M1). Physiographically, the region lies within a narrow strip of dissected coastal plain commonly known as the "breaks" of the Rio Grande. A narrow irrigated flood plain occurs adjacent to the Rio Grande in most of the region. Most of the tributaries of the Rio Grande are intermittent in Region III; however, some spring-fed streams flow perennially in their lower courses. The surface elevations of Region III range from 400 to 1,000 feet above sea level.

The mean annual precipitation of Region III is about 20 inches. Figure M3 shows the average monthly precipitation and Figure M4 the annual precipitation for the Eagle Pass station from 1889 to 1960 and the Laredo station from 1913 to 1960.

Based on the U. S. Census, the 1960 population of Region III was approximately 76,300 or about 40 percent of the total middle Rio Grande Basin population. About 95 percent of the population of Region III is classified as urban. The cities of Laredo and Eagle Pass are the most important population and commercial centers in the region.

The chief economic base for the region is cattle ranching in the uplands and agriculture on the irrigated flood plains. The most important crops include a large variety of vegetables, grain sorghums, and cotton. Approximately 50,000 acres presently is irrigated in the region. Light manufacturing and processing industries in the region produce such items as clothing, foods, feedstuffs, brick, tile, and dairy products.

GENERAL GEOLOGY

Throughout most of the Paleozoic Era a large part of western Texas and the adjoining part of southeastern New Mexico was an embayment covered by a shallow sea. The embayment probably covered the upper part of the middle Rio Grande Basin. The sediments that were deposited throughout much of Paleozoic time were uplifted and folded prior to Permian deposition. These early Paleozoic sediments are presently exposed southwest of the middle Rio Grande Basin.

During Permian time the area north of the Marathon uplift was divided into a number of provinces (Figure M5) which had different depositional and tectonic environments. A total of 10,000 feet of sediments accumulated in the Delaware basin while the Central Basin platform and shelf areas were covered with 2,000

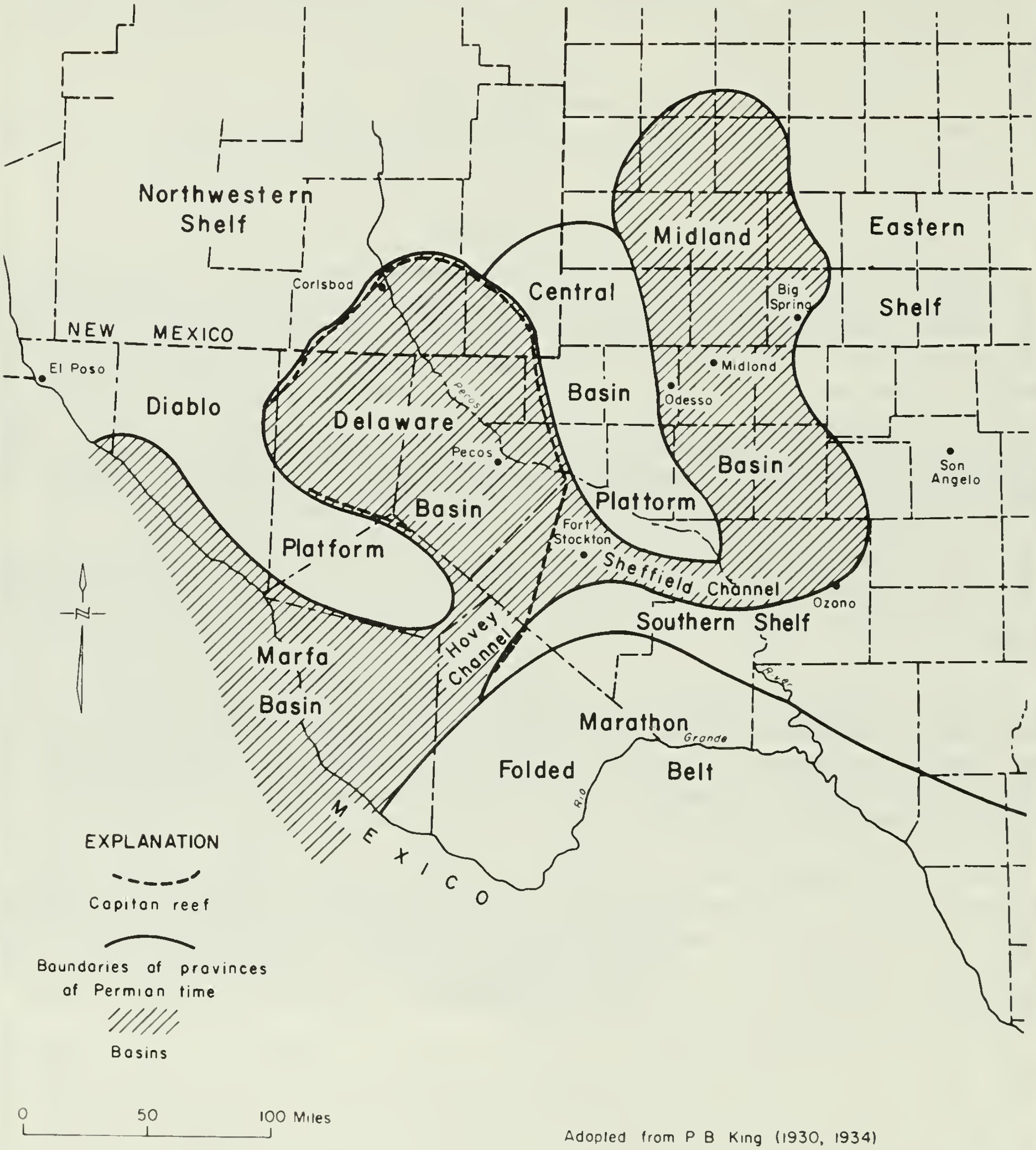

Figure M5
Map of West Texas and Southeastern New Mexico Showing the Structural Features in Permian Times

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

100

to 4,000 feet of sediments (Eardley, 1951, p. 228). Some of the strata deposited in these basin and platform areas presently yield water to wells in the middle Rio Grande Basin (Table M1).

The older Paleozoic rocks were eroded from the Central Basin platform early in the Permian Period. By the end of the Wolfcamp (lower Permian) several hundred feet of conglomerate, sandstone, shale, and limestone had been deposited around the Marathon uplift and several thousand feet of dark-colored shale were deposited in the Sheffield channel. During Leonard deposition, limestone, sandstone, and shale beds were deposited throughout much of Region I. Thick beds of clastics were deposited locally near the Marathon uplift, but only thin beds of limestone were deposited on the Central Basin platform.

During early Guadalupe time the Sheffield channel connected the Midland basin with the Delaware basin. The San Andres Limestone was deposited in the shallow water over the Central Basin platform, and the Cherry Canyon Formation of the Delaware Mountain Group, a shale overlain by a sand, was deposited in the Delaware basin (King, 1942, p. 701-703). In middle Guadalupe time a reef, the Capitan Limestone, formed around the margins of the Delaware basin and across the Sheffield channel, cutting off the Midland basin (Figure M5). This resulted in the deposition of three lithologic sequences: a marine facies in the Delaware basin represented by sandstone, shale, and limestone of the Delaware Mountain Group; a reef zone represented by a massive limestone of the Capitan Reef complex; and the shelf or shallow sea deposits of the Whitehorse Group consisting of limestone, shale, dolomitic limestone, evaporites, and near-shore clastics. In the Delaware basin, sandstone and shale beds of Guadalupe age are overlain by evaporites and limestone of the Castile Formation of Ochoa age. During the time of Castile deposition the Central Basin platform was slightly above sea level and a sequence of evaporites was deposited on the basin side of the Capitan Reef. After the deposition of the Castile, the Salado Formation was deposited in the Delaware basin and across the Central Basin platform. This widespread deposition of evaporites interbedded at intervals with limestone, dolomite, sand, and shale continued through deposition of the Salado and Rustler Formations. The Rustler Formation is overlain by the Dewey Lake red beds, the youngest Permian rocks in the area.

At the end of the Permian Period the region was probably uplifted. The uplift was followed by a long period of erosion which probably extended through much of the Triassic Period. During late Triassic time the nonmarine Dockum Group, consisting of the Tecovas Formation, Santa Rosa Sandstone, and Chinle Formation, was deposited over the older Permian strata. The Dockum Group consists principally of interbedded sand and shale.

No Jurassic deposits have been identified in the middle Rio Grande Basin, and the area was probably emergent and undergoing erosion during this period of geologic history.

During the Cretaceous Period the sea advanced slowly from the southeast and probably covered most of the middle Rio Grande Basin. A thick sequence of sand, shale, and limestone strata of the Comanche and Gulf Series were lain down as the area was inundated by major marine transgressions. Several minor transgressive and regressive phases occurred within each of the major transgressions.

A major lithologic change in the lower Cretaceous (Comanche Series) rocks occurs in the southeastern part of Region I. The limestone and shale sequence

Table M1.--Geologic units and their water-bearing characteristics, middle Rio Grande Basin

Era	System	Series	Group	Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing characteristics
Cenozoic	Quaternary	Recent and Pleistocene		Dune Sand	0- 250	Fine to very fine-grained, gray to red-brown sand.	Important recharge facility in Region I. Yields small to moderate amounts of good quality water.
				Alluvium	0-1,500+	Generally unconsolidated, poorly to moderately sorted gravel, sand, silt, and clay with some caliche.	Yields moderate to large amounts of good quality to moderately mineralized water and is principal irrigation water supply in Region I. Of minor importance in other regions.
	Tertiary	Pliocene		Ogallala Formation	--	Varicolored clay, silt, fine to coarse gray to red sand; contains some quartz gravel and caliche.	Yields small amounts of water in northeastern part of Region I in conjunction with the alluvium.
		Oligocene		Intrusives	--	Dikes, plugs, apophyses, and sills; largely of syenite.	Yields small amounts of water from fractures in southern part of Region I.
		Eocene		Volcanics	0-3,100±	Basalt, rhyolite, trachyte, porphyry, and tuff.	Yields small to moderate amounts of very good quality water in southern part of Region I and facilitates recharge of underlying aquifers.
			Jackson		0-1,400	Sand, clay, lignite, and significant intermittent beds of bentonite, bentonitic clay, and volcanic ash.	Yields small amounts of water in Region III.
			Claiborne	Yegua Formation	0- 350	Gray to yellowish brown interbedded sand, clay, and sandy clay.	Yields small amounts of moderately mineralized water in Region III.
				Cook Mountain Formation	0-1,340	Glauconitic sand, marl, and clay, with some gypsum. Basal sand with concretions and fossiliferous masses.	Basal sands yield small amounts of moderately mineralized water in region III.
				Mount Selman Formation	0-1,165	Dominantly clay with interbedded varicolored sand; also contains coal beds.	Yields small amounts of moderately mineralized water in Region III.
				Bigford Member	0- 660	Dark brown to buff and gray gypsiferous clay, thin-bedded to massive varicolored sandstone, concretionary limestone, lignite, and some coal.	Yields small to moderate amounts of water that is generally moderately mineralized in Region III.
				Carrizo Formation	0- 250	Gray to buff, medium- to coarse-grained sandstone interbedded with clay and shale.	Yield small to moderate amounts of generally good to fair quality water in Region III.
			Wilcox		0- 850	Yellowish brown to buff shaly sand interbedded with clay, shale, and lignite.	Yields small amounts of highly mineralized water in Region III.
			Midway		0- 350	Generally dark shale with lenses of sand and sandy lime.	Contains small amounts of highly mineralized water in Region III.
Mesozoic	Cretaceous	Gulf	Navarro	Escondido Formation	0- 750	Dark clay and sandy clay with thick beds of sandstone, and limestone with porous layers; contains basal sandstone interbedded limestone and clay.	Basal sandstone yields small amounts of mineralized water in Region III.
				Olmos Formation	0- 500	Clay, shale, and sandstone with seams of coal and fire clay.	Yields small amounts of highly mineralized water in Region III.
			Taylor	San Miguel Formation	0- 400	Fossiliferous sand and sandy limestone with interbedded clay.	Yields small amounts of water in Region III.
				Upson Clay	0- 550	Dark greenish-gray clay which weathers to yellow.	Not known to yield usable water in the middle Rio Grande Basin.
			Austin		0-1,200	Gray to white, medium- to massive-bedded limestone.	Fractures yield small to moderate amounts of moderately fresh water in Regions II and III.

Table M1.--Geologic units and their water-bearing characteristics, middle Rio Grande Basin--Continued

Era	System	Series	Group	Stratigraphic unit	Approximate thickness (feet)	Character of rocks	Water-bearing characteristics
Mesozoic	Cretaceous	Gulf	Eagle Ford		0- 300	Interbedded gray to white shale and flaggy limestone.	Yields small amounts of moderately fresh water.
		Comanche	Washita	Buda Limestone	0- 100	Yellow to white, dense, fine-grained limestone.	Yields small amounts of water from fractures in Region II.
				Del Rio Clay	0- 120	Yellowish marl and clay.	Not known to yield usable water in the middle Rio Grande Basin.
				Georgetown Limestone	0- 400	White to gray, thin- to massive-bedded fossiliferous limestone containing rudistid reefs and chert nodules.	Yields large amounts of water from solution openings in Regions I and II.
			Fredericksburg	Kiamichi Clay	0- 70	Marl and clay.	Not known to yield usable water in the middle Rio Grande Basin.
				Edwards Limestone	0- 800	Gray to white, thin- to massive-bedded limestone containing rudistids, chert nodules, and dolomite.	Solution openings yield large amounts of water in Regions I and II.
			?	Comanche Peak Limestone	0- 90	Soft gray thin-bedded argillaceous limestone containing beds of gypsiferous clay.	Yields large amounts of water from solution openings in Region I.
			Trinity	"Trinity Sand"	0- 350	Quartz sand and conglomerate with limestone stringers.	Yields moderate to large amounts of water in Regions I and II.
				Glen Rose Limestone	0- 900	Silty, sandy, and marly indurated limestone	Yields small amounts of mineralized water in Regions I and II.
	Triassic			Chinle Formation	0-1,000	Purple, maroon, and red shale and sandstone.	Yields small amounts of mineralized water in Region I.
			Dockum	Santa Rosa Sandstone	0- 350	Reddish brown to gray, medium- to coarse-grained, cross-bedded, feldspathic, micaceous, conglomeratic sandstone interbedded with shale.	Yields small to large amounts of water in Region I.
				Tecovas Formation	0- 270	Red shale, silt, and fine-grained sandstone.	Not known to yield usable water in the middle Rio Grande Basin.
Paleozoic	Permian	Ochoa		Dewey Lake red beds	0- 580	Thin-bedded siltstone cemented with gypsum.	Yields small amounts of highly mineralized water.
				Rustler Formation	0- 500	Anhydrite, dolomite, and limestone interbedded with some sand and shale.	Yields moderate amounts of moderately mineralized water in Region I.
				Salado and Castile Formations	0-4,000	Dominantly halite with subordinate amounts of anhydrite, sylvite, and polyhalite.	Yields small amounts of highly mineralized water in Region I.

Era	System	Series	Stratigraphic unit: Delaware basin	Stratigraphic unit: Reef	Stratigraphic unit: Central platform and Midland basin	Thickness: Delaware basin	Thickness: Reef	Thickness: Central platform and Midland basin	Character of rocks: Delaware basin	Character of rocks: Reef	Character of rocks: Central platform and Midland basin	Water-bearing: Delaware basin	Water-bearing: Reef	Water-bearing: Central platform and Midland basin
Paleozoic	Permian	Guadalupe	Delaware Mountain Group	Capitan Reef complex and associated limestone	Whitehorse Group: Tansill Formation	700-3,200 ±	3,500	500	Alternating sand and shale	Massive porous reef limestone and bedded limestone	Sandstone, dolomite, anhydrite, gypsum, and shale.	Yields small amounts of water in Culberson County, Region I	Yields large amounts of moderately mineralized water in Region I	Not known to yield usable water in the middle Rio Grande Basin.
					Whitehorse Group: Yates Sandstone			300			Sandstone, dolomite, anhydrite, gypsum, and shale.			Yields small amounts of highly mineralized water.
					Whitehorse Group: Seven Rivers Formation			550			Anhydrite, sandstone, shale, and dolomite.			Yields large amounts of highly mineralized water.
					Whitehorse Group: Queen Formation			400			Sandstone and dolomite with some anhydrite and salt.			Yields small amounts of highly mineralized water.
					Whitehorse Group: Grayburg Formation			300			Dolomite with some sandstone and salt.			Yields large amounts of highly mineralized water.
					San Andres Limestone			900-1,200			Dolomite and limestone interbedded with shale.			Yields large amounts of moderately to highly mineralized water.
		Leonard and Wolfcamp	Undifferentiated			±10,000			Alternating sand, shale, and limestone.			Not known to yield usable water in the middle Rio Grande Basin.		

laterally grades southeastward into a more continuous limestone section indicating different depositional environments. Solution of the obvious nomenclature and correlation problems which exist as a result of this major facies change are beyond the scope of this investigation and has not been attempted.

The close of the Cretaceous Period was marked by the elevation of the land and retreat of the sea.

The history of the Tertiary Period is one of repeated marine transgressions and regressions in the present Coastal region resulting in the deposition of a sequence of alternating marine and continental deposits. Some uplift accompanied by volcanic activity occurred in the Davis Mountain region, Jeff Davis County, in the late Eocene and Oligocene Epochs.

During late Tertiary and Quaternary time much of the middle Rio Grande Basin was probably emergent. Streams flowing across the area laid down extensive, and in places very thick, deposits of alluvium. Later the prevailing winds deposited a cover of sand in part of the area. These deposits are extensive only in Region I (Plate M1).

Stratigraphy

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

Table M1 illustrates the stratigraphic sequence of geologic units in the middle Rio Grande Basin. This table lists the geologic units in descending order, their approximate thickness, lithologic character, and a brief summary of their water-bearing properties. Plates M1, M2, and M3, geologic maps of Regions I, II, and III, respectively, show the outcrops of the geologic units listed in Table M1. A geologic section (Plate M4), drawn generally along the axis of the middle Rio Grande Basin, shows the stratigraphic position and structural relationship of the geologic units in the subsurface.

Structure

The structural features which have a primary influence on the occurrence of ground water in the middle Rio Grande Basin were formed in late Paleozoic and Cenozoic Eras.

The major Permian structural features of the middle Rio Grande Basin are illustrated in Figure M5. The Central Basin platform is a structural high separating the Delaware basin on the west and the Midland basin on the east. The Sheffield channel is a structural trough which connects the Delaware and Midland basins. The Permian and older strata dip gently north and east into the Delaware basin from the Marathon folded belt and the Guadalupe, Delaware, Davis, and Glass Mountains which occur on the south and west. Cretaceous strata overlie parts of the Permian structural features. These strata are generally horizontal or dip gently from the structural highs. To the southeast, Cretaceous as well as Tertiary formations generally dip toward the coast.

During the Tertiary Period, uplift accompanied by igneous activity formed the Davis Mountains in the western part of the middle Rio Grande Basin.

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 capable of yielding water in sufficient quantities to constitute a usable supply. For the purpose of this report, the term "aquifer" refers only to that part of the stratigraphic units containing usable-quality water. A geologic unit that 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. Three of the State's major aquifers, the Carrizo-Wilcox sands, Edwards Limestone and Trinity sands, and the Cenozoic alluvium occur in the middle Rio Grande Basin. A minor aquifer has been defined as one that yields large quantities of water in small areas or relatively small quantities in large areas of the State. Four aquifers of this classification occur in the middle Rio Grande Basin. They are the Rustler Limestone, Capitan Reef and San Andres Limestones, Santa Rosa Sandstone, and the Mount Selman Sands.

Aquifers that are important on a statewide basis may or may not be of equal importance as a source of ground water in an individual river basin. Their importance in a river basin depends in large part on the amount of water they can supply in relation to the total amount of available ground water that can be developed in the basin. An aquifer that is important on a statewide basis may have within a river basin, 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 middle Rio Grande 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 that make up the two primary aquifers of the middle Rio Grande Basin are: (1) Edwards Limestone and "Trinity sand" (Edwards-Trinity aquifer), and (2) Cenozoic alluvium.

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 that make up the three secondary aquifers of the middle Rio Grande Basin are: (1) Santa Rosa Sandstone, (2) Rustler Formation, and (3) Capitan Reef complex and associated limestones.

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 their varying geologic and hydrologic characteristics, primary and secondary aquifers of the middle Rio Grande Basin might not be given the same classification in adjacent basins.

The areal relationship of the primary and secondary aquifers of the middle Rio Grande Basin and the areas in which they produce usable-quality water are shown on Figure M6.

In addition to the primary and secondary aquifers, there are other aquifers of limited potential which yield small to moderate quantities of water locally for municipal, industrial, irrigation, and domestic and livestock uses.

GENERAL GROUND-WATER HYDROLOGY

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

Hydrologic Cycle

The hydrologic cycle is the sum total of processes and movements of the earth's moisture from the sea through the atmosphere to the land, and eventually, with numerable delays enroute, back to the sea. Figure M7 illustrates a number of the courses which the water may take in completing the cycle. All water occurring in the middle Rio Grande Basin, whether surface water or ground water, is derived from precipitation.

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, 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 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 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 of an aquifer, ground water generally occurs under water-table

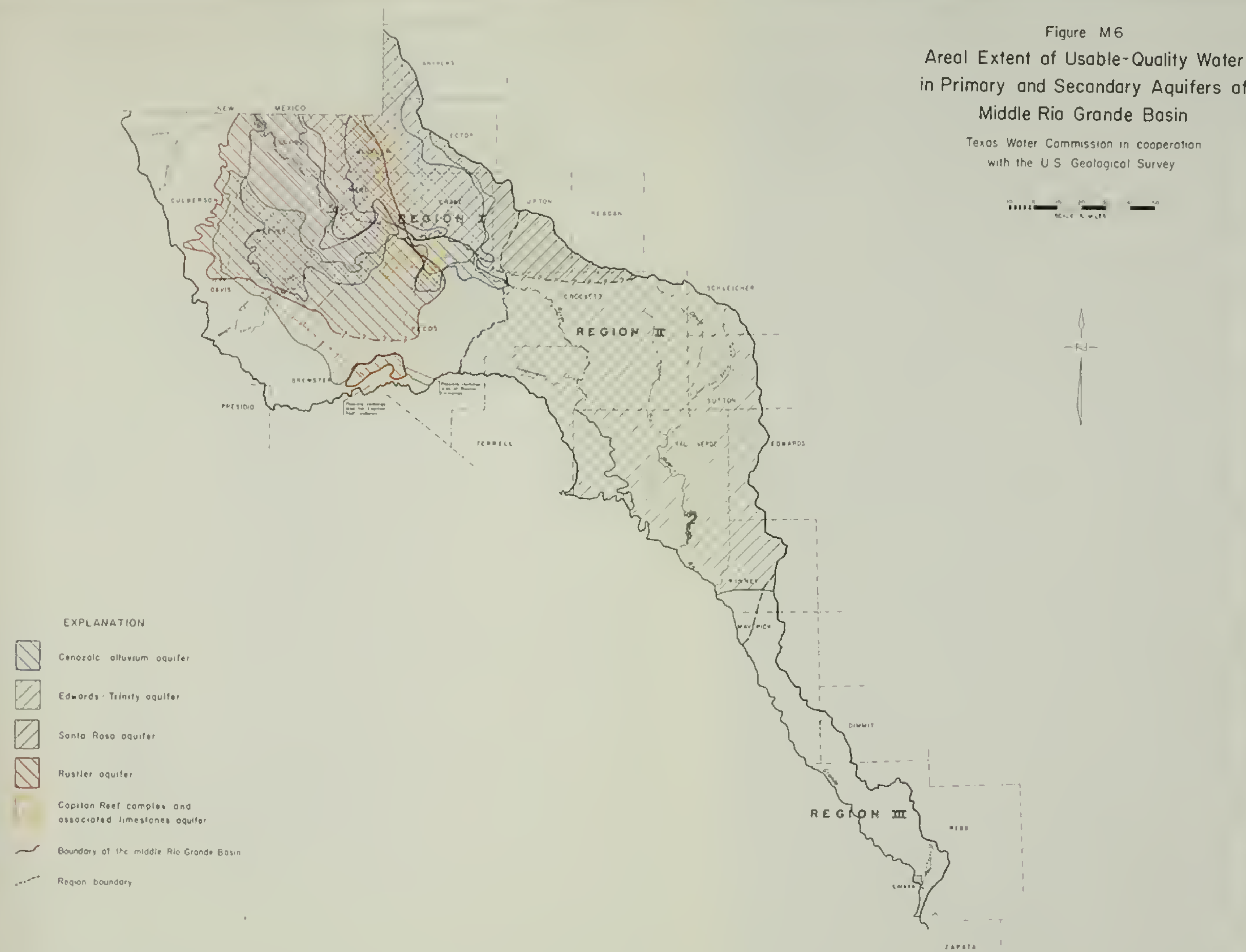
Figure M6
Areal Extent of Usable-Quality Water in Primary and Secondary Aquifers of Middle Rio Grande Basin
Texas Water Commission in cooperation with the U S Geological Survey
NEW MEXICO
CULBERSON
ECTOR
UPTON
REAGAN
REGION I
REGION II
REGION III
DAVIS
PECOS
BREWSTER
PRESIDIO
TERRELL
CROCKETT
SCHLEICHER
SUTTON
VAL VERDE
EDWARDS
KINNEY
MAVERICK
DIMMIT
WEBB
ZAPATA
EXPLANATION
Cenozoic alluvium aquifer
Edwards-Trinity aquifer
Santa Rosa aquifer
Rustler aquifer
Capitan Reef complex and associated limestones aquifer
Boundary of the middle Rio Grande Basin
Region boundary

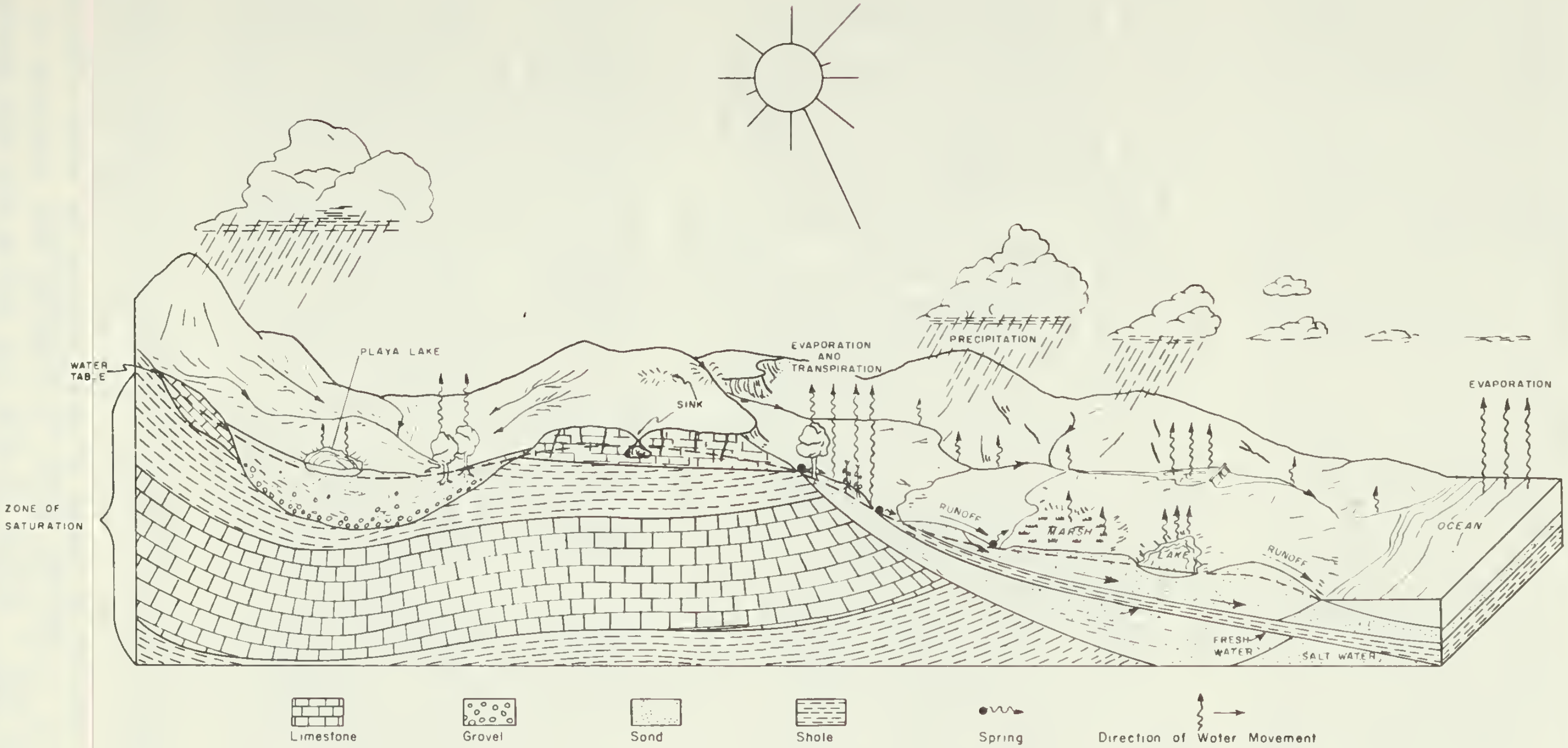

Figure M7

The Hydrologic Cycle in the Middle Rio Grande Basin

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

100

conditions, that is, the water is unconfined. The hydraulic gradient in an unconfined aquifer is the slope of the water table. Downdip from the outcrop or recharge area, ground water commonly 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 in a well. Pressure head is expressed as the height of a column of water that can be supported by the artesian 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 pressure resulting in lower elevations of the piezometric surface in the direction of water movement. The hydraulic gradient of an artesian aquifer is determined from the slope of the piezometric surface.

The water-bearing characteristics of an aquifer depend 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 forces 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 piezometric surface is lowered. The weight of the overlying sediments, which were partially supported by the artesian 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 can be calculated from data obtained 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. 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 rate. However, the type of well construction and the thoroughness of well development also have an effect on the specific capacity that is not directly related to the hydraulic characteristics of the aquifer.

Recharge, Discharge, and Movement

Recharge is the addition of water to an aquifer. Natural recharge in the middle Rio Grande Basin is derived from infiltration of runoff, direct infiltration of precipitation that falls on the outcrop, and interformational leakage. Recharge is the limiting factor in the amount of water that can be developed perennially from an aquifer, because 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 that 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 artesian conditions, movement of ground water normally is in the direction of regional dip. Under water-table conditions, the slope of the water table and consequently the direction of ground-water movement generally 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 except in cavernous limestones where the rate of movement is commonly much greater.

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 the rate of 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 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 of 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 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 ground water. Water is an effective solvent which dissolves minerals from the soil and the component rocks of the aquifer. 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 saline or brackish water, the flushing action of fresh water moving through the aquifers has not been complete. Therefore, at some distance downdip, and in some cases in limited areas, highly mineralized water is commonly 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 waste material into improperly constructed wells or onto the land surface. 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 faulty well construction which allows water of poor quality to enter the well or move into a fresh-water aquifer having a lower hydrostatic head.

The quality of uncontaminated ground water, unlike surface water, remains relatively constant. This, in addition to its constant 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:

Substance	Concentration (ppm)
Chloride (Cl)	250
Fluoride (F)	(*)
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Total dissolved solids	500

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

Annual average of maximum daily air temperatures (°F)	Recommended control limits of fluoride concentrations (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. Maxcy (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. 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. Water hardness is expressed in parts per million as calcium carbonate. Water having a hardness of 60 ppm or less is generally considered soft, 61 to 120 ppm is considered moderately hard, 121 to 200 ppm is considered hard, and more than 200 ppm is regarded as 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 that 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).

A number of factors are 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 acreage. According to a report by the U. S. Salinity Laboratory Staff (1954, p. 69), the characteristics of water that are important in determining its suitability for irrigation are: (1) Total concentration of soluble salts, expressed in terms of specific conductance, (2) the relative proportion of sodium to the other principal cations (magnesium, calcium, and potassium) expressed as percent sodium or sodium-adsorption ratio (SAR), (3) residual sodium carbonate (equivalents per million of carbonate in excess of calcium and magnesium), and (4) concentrations of boron or other elements that may be toxic. The report also includes a method for classifying irrigation waters.

Treatment

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

The occurrence and availability of ground water in the middle Rio Grande Basin is discussed by regions, beginning with Region I. The primary aquifers of each region are discussed first, secondary aquifers next, and other aquifers of limited significance are noted briefly at the end of the discussion for each region.

Region I

Primary aquifers in Region I of the middle Rio Grande Basin are the Cenozoic alluvium and the Edwards-Trinity. The Edwards-Trinity extends into Region II and is the primary aquifer in that region. Secondary aquifers in Region I are the Santa Rosa Sandstone, Rustler Formation and the Capitan Reef complex and associated limestones. Other aquifers which presently supply small amounts of water and have limited potential for further development include the Tertiary volcanic rocks.

Primary Aquifers

Cenozoic Alluvium Aquifer

Geologic Characteristics

The Cenozoic alluvium in Region I consists of stream and wind deposited sediments of Tertiary and Quaternary age. The Cenozoic alluvium unconformably overlies rocks of Permian, Triassic, Cretaceous, and Tertiary ages in this region. In some areas where the Cenozoic alluvium is in contact with "Trinity sand" of Cretaceous age, the "Trinity sand" has been included in the alluvium aquifer because of the hydraulic connection and lithologic similarity of the strata.

The Cenozoic alluvium consists of unconsolidated to partially consolidated sand, silt, gravel, boulders, clay, gypsum, and caliche. The lithic character and thickness of the beds differ widely within short distances. Sample logs of wells penetrating the entire thickness of Cenozoic alluvium in Region I average about 50 percent sand and gravel. The greatest thickness of the alluvium is found in north-south slumpage troughs that developed as a result of solution of underlying evaporites. Where alluvium fills a slumpage trough, thicknesses of 600 to 700 feet are common and exceed 1,500 feet in the deepest troughs. Plate M5 showing the altitude of the base of the alluvium illustrates the approximate areal extent of the major slumpage troughs in the region. Thinner deposits of the alluvium, ranging from less than 100 to 300 feet, are found in the areas adjacent to these troughs.

Occurrence and Movement of Ground Water

Ground water in the Cenozoic alluvium usually occurs under water-table conditions; however, it is in places confined beneath a layer of clay and exhibits artesian characteristics. The greatest quantities of ground water in the alluvium occur in the major slumpage troughs where the saturated thickness is greatest (Plate M6).

The movement of ground water in the alluvium is generally towards the Pecos River as indicated by the configuration of the water table shown by contour lines on Plate M7. However, because of heavy development of irrigation wells, the direction of ground-water movement has been altered in some areas. Heavy pumpage of ground water in central Reeves County, northwestern Pecos County, and other extensively developed areas has lowered the water table so that the hydraulic gradient slopes toward these areas. This results in ground water moving toward the heavily pumped areas from all directions.

The hydraulic gradient of the Cenozoic alluvium ranges from about 4 feet per mile in central Ward County to more than 100 feet per mile along the western flank of the heavily pumped area in central Reeves County. The hydraulic gradient probably averages about 25 feet per mile outside the heavily developed areas (Plate M7).

Recharge and Discharge

Natural recharge of the Cenozoic alluvium aquifer is derived from precipitation, runoff, and underflow from older formations.

The rate and amount of recharge depends upon factors such as the rate and amount of precipitation, temperature, permeability of the soil and subsoil, vegetation and topography. One of the most favorable areas for recharge by precipitation is a belt of sand dunes extending from southwestern Andrews County through parts of Winkler, Ector, and Ward Counties into central Crane County (Plate M1). The permeable nature of the sand dunes allows maximum infiltration into the underlying formations except where the sandy mantle is underlain at shallow depths by finer material that retards downward percolation. In the outcrop of the alluvium (Plate M1), direct infiltration of precipitation is generally thought to be negligible and probably occurs only during those rare times when the soil moisture is high after several days of steady rain and when the evaporation rate is low. Part of the precipitation is usually lost by evaporation shortly after it reaches the ground; the remainder is absorbed by the soil, but most of it is returned to the atmosphere by transpiration of plants.

Much of the precipitation that falls in the mountainous areas in the southern and southwestern parts of the region becomes overland runoff until it reaches the valleys and there infiltrates the sands and gravels in the valleys and foothills. The alluvium is recharged locally by direct infiltration of precipitation and by subsurface inflow from the truncated or eroded surfaces of Cretaceous formations. Before the extensive development of irrigation, large springs supplied by Cretaceous rocks contributed a considerable amount of recharge to the alluvium. However, this source of recharge has been reduced because of pumpage of ground water from the Cretaceous rocks.

Plate M7 indicates that the alluvium may be receiving recharge from the Pecos River where large cones of depression caused by heavy pumpage near the river have reversed the gradient of the water table. This recharge is not entirely desirable because most of the time the Pecos River water is of poorer quality than the ground water. However, due to this source of recharge, water levels have probably been sustained at higher levels.

It is also possible in some parts of the region, especially in northwestern Brewster County and near Imperial in northwestern Pecos County, that poor quality water from older strata moves into the alluvium aquifer.

Recirculation of water withdrawn from the Cenozoic alluvium aquifer occurs in some areas due to excessive applications of irrigation water. In many places the infiltrating water accumulates above a layer of clay, forming a perched ground-water body. Perched ground water moves laterally until it spills over the edge of the supporting layer and descends to the main zone of saturation. The quality of this recharged water has deteriorated because the mineral content has been concentrated by evapotranspiration, and because of salts and fertilizer from the soil.

In some parts of the region, especially in an area about $4\frac{1}{2}$ miles west-southwest of Kermit in Winkler County, the Cenozoic alluvium has received substantial amounts of recharge from oil-field brines which were disposed into unlined surface pits. This recharge apparently has been of sufficient quantity to create a large mound in the water table beneath the area (Plate M7). Generally the oil-well waste water produced in this region is highly mineralized, and its recharge to the alluvium is a source of serious contamination.

Terraces and levees have been constructed on several ranches to retard runoff and spread it over wide areas of grassland. Undoubtedly some of this water also infiltrates to the zone of saturation.

Before intensive irrigation development, ground water was discharged naturally from the Cenozoic alluvium by evapotranspiration where the water table was close to the surface, by seeps and springs, and by underflow into the Pecos River. The bulk of the discharge now is from wells supplying water for irrigation, industrial, and municipal uses. The annual discharge from the aquifer is now undoubtedly much greater than the average annual recharge.

Water Levels

In Region I, depths to water in the Cenozoic alluvium range from less than 10 feet to more than 365 feet. Fluctuations of water levels are due mainly to seasonal variations in pumpage. However, water levels in the extensively developed irrigation areas are declining because of heavy pumpage. Figures M8 and M9 are hydrographs of water levels of wells in heavily pumped areas of Pecos and Reeves Counties.

Fluctuations of water levels of wells in the Cenozoic alluvium in Crane, Ector, Loving, Upton, Ward, and Winkler Counties appear to be small to moderate. Maximum declines in the water level do not exceed 50 feet and are local in extent. Slight rises in water levels were reported in 1961 and possibly were the result of heavy rainfall during the spring of that year.

Water-Bearing Characteristics

Pumping tests to determine the coefficient of transmissibility of the Cenozoic alluvium have been conducted in several areas within the region. The

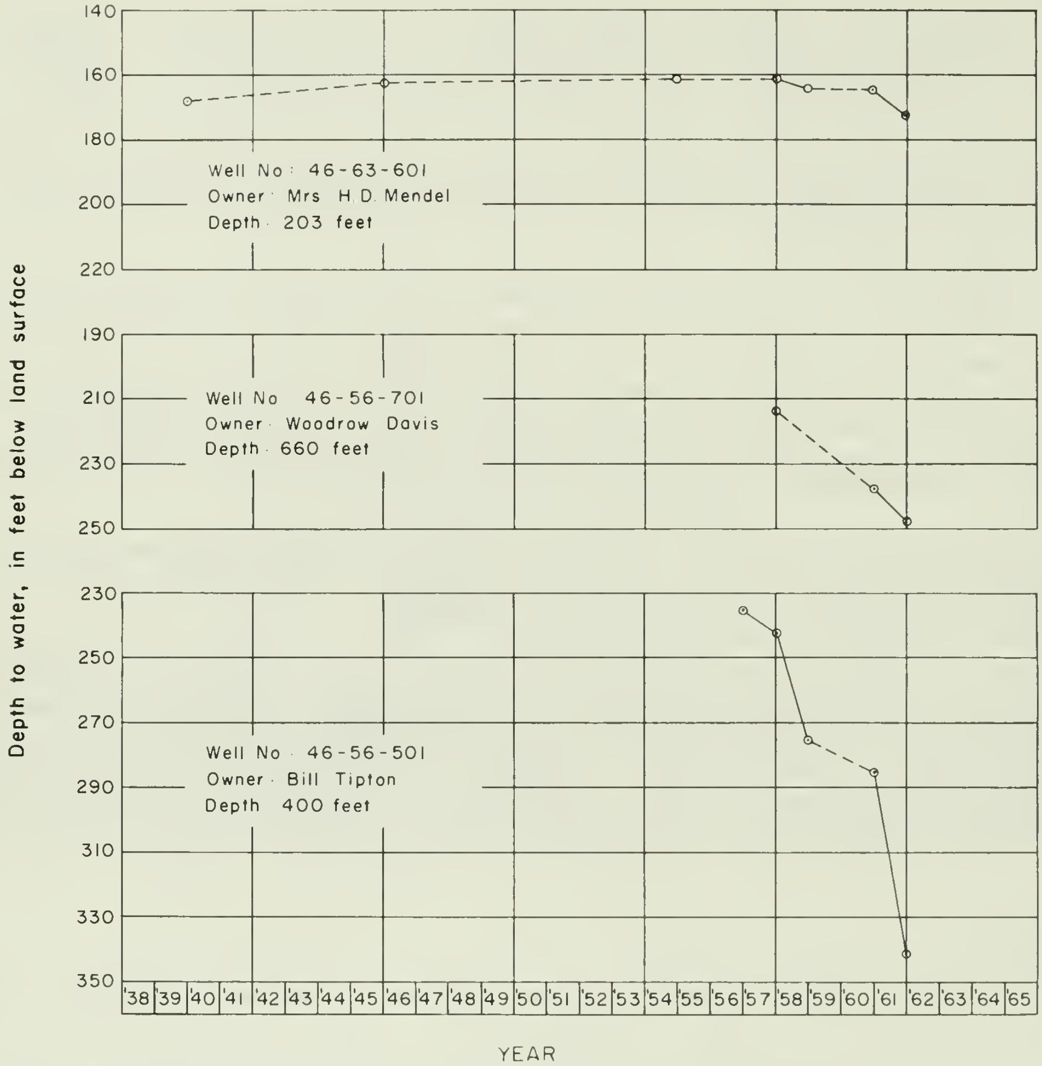

Figure M8

Hydrographs of Wells Screened in Cenozoic Alluvium Aquifer, Pecos County, Region I, Middle Rio Grande Basin

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

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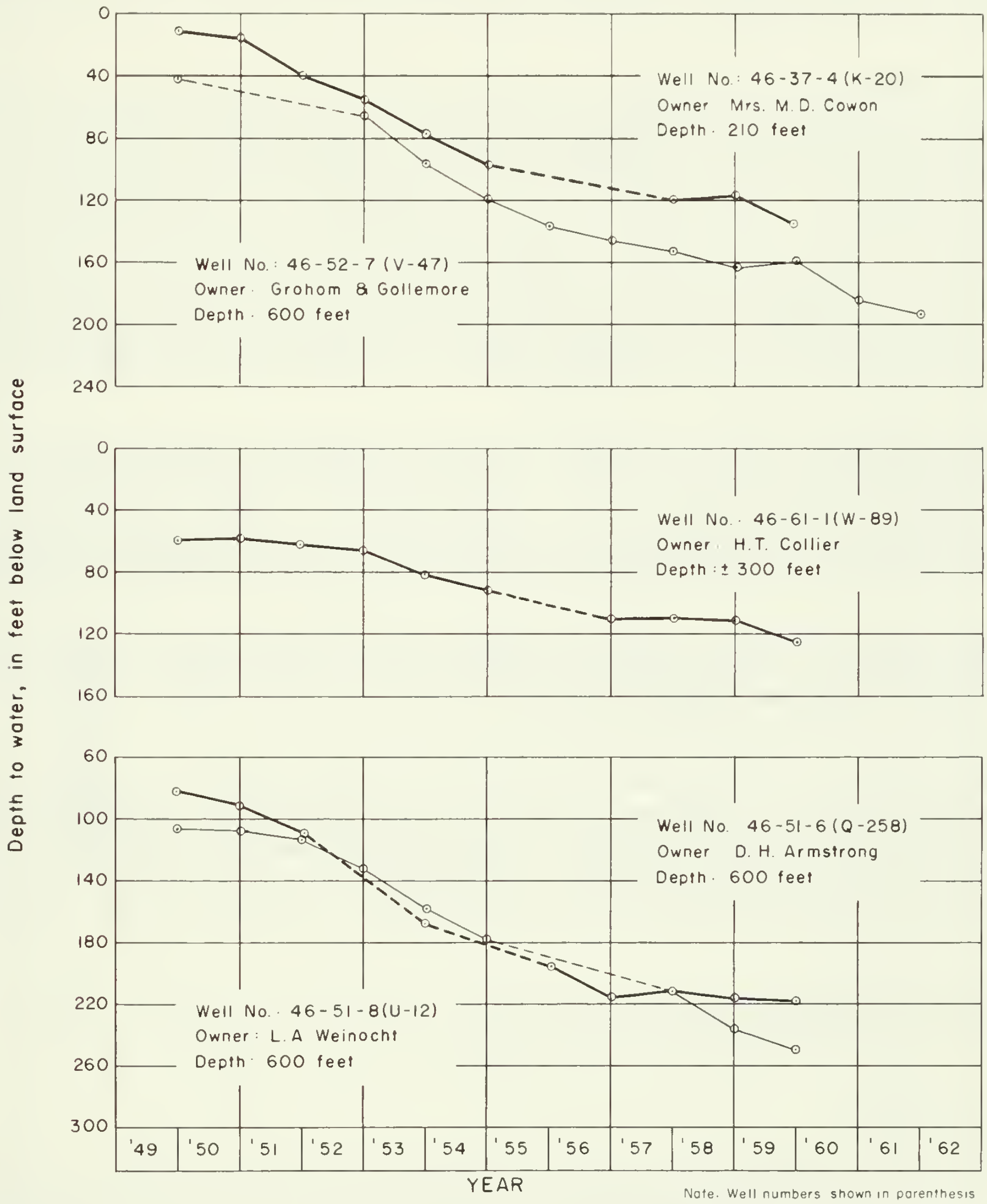

Note. Well numbers shown in parenthesis correspond with those of Texas Water Commission Bulletin 6214 (Ogilbee and Wesselmon, 1962).

Figure M9

Hydrographs of Wells Screened in Cenozoic Alluvium Aquifer, Reeves County, Region I, Middle Rio Grande Basin

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

Cenozoic alluvium is typified by fairly high coefficients of transmissibility. However, variations in the coefficients of transmissibility have been noted in the region. Some of the causes of variations in the coefficients of transmissibility are lensing and interbedding of sands and clays, and variations in sorting of the alluvium.

The coefficient of transmissibility of the Cenozoic alluvium in Reeves County, as computed from eight of ten aquifer tests, ranged from 24,000 to 86,000 gpd/ft (gallons per day per foot) and averaged about 40,000 gpd/ft. Transmissibility values of 150,000 and 160,000 gpd/ft were obtained for the other two alluvium wells tested, but it is believed that these values are not representative of a large area. The coefficients of transmissibility in Reeves County were computed from data obtained from short-duration recovery tests which may give coefficients that differ appreciably from those obtained from tests of long duration. Because of local variations in the characteristics of water-bearing materials, the coefficients of transmissibility determined from the tests should be used with caution.

In the North Coyanosa irrigation area, northwestern Pecos County, aquifer tests were made at four sites. The coefficient of transmissibility ranged from about 19,000 to 41,000 gpd/ft. The coefficient of storage determined from a pumping test was 0.0008, which is typical of artesian conditions; however, water in the alluvium most commonly occurs under water-table conditions.

In Winkler County a pumping test was made in 1957 on a well which screens the deep Cenozoic alluvium in the trough about 5 miles south of Wink. The coefficient of transmissibility as determined by the recovery of the water level in the well was 25,000 gpd/ft.

Near the city of Monahans, Ward County, aquifer tests were conducted on a well which screened 53 feet of alluvium. The coefficient of transmissibility was calculated to be 91,000 gpd/ft. The thickness of the alluvium is much greater than the screened section, and therefore the coefficient of transmissibility for the entire thickness of the Cenozoic alluvium should be greater than 91,000 gpd/ft.

In southwestern Crane County, on the Tubb Ranch, a coefficient of transmissibility of 27,000 gpd/ft was reported.

Chemical Quality

The quality of water in the Cenozoic alluvium may vary with location and depth. Normally, wells penetrating the deeper parts of the alluvium yield water with higher mineral concentration than wells tapping the shallower alluvial material.

The dissolved solids as shown in chemical analyses on Table M2 range from less than 200 to more than 13,000 ppm. Wells penetrating the Cenozoic alluvium near the Pecos River generally have much higher dissolved solids than those in other areas of the region.

In the northwestern part of Pecos County the dissolved solids generally are less than 1,000 ppm. However, in the northern part of this area the concentration increases, indicating that water of poorer chemical quality near the Pecos River is moving into the area due to the heavy pumpage (Plates M5 and M7).

Table M2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, middle Rio Grande Basin

(Analyses expressed in parts per million except specific conductance and pH.)

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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
								Cenozoic Alluvium Aquifer									
27-57-3	Ratliff & Bedford	90	9-29-36	--	--	--	--	--	140	562	500	--	--	1,693	--	--	--
27-58-2	University of Texas	45	do	--	--	--	--	--	281	307	76	--	--	784	--	--	--
45-01-8	Larry Fernandez	60	11- 2-56	30	--	44	6.9	89	192	64	44	4.4	42	418	138	599	7.8
45-09-2	C. O. Wheeler	140	1-28-57	34	--	48	12	49	144	125	19	--	2.5	374	170	544	8.1
45-10-8	W. D. Amburgey	100	10- 8-56	44	--	128	13	100	168	314	77	1.2	18	789	373	1,080	7.8
45-17-5	Sealy & Smith Foun.	60	do	38	--	31	3.3	11	121	7.6	4.5	.4	.5	156	90	210	7.9
45-18-5	do	60	2-12-57	73	--	153	33	95 5.3	165	288	180	.7	56	997	516	1,430	7.8
45-19-8	McKnight Bros.	94	11-17-54	30	--	502	128	139	137	1,800	50	3.2	21	2,740	1,780	3,030	7.5
45-25-5	Texas Highway Dept.	7,163	5- 3-40	--	--	100	46	354	398	185	488	--	1.2	1,406	--	221	--
45-25-7	The Texas Co.	160	5-29-40	--	--	64	21	76	201	153	60	--	2.0	528	--	82.6	--
45-27-8	McKnight Bros.	120	12-20-54	70	--	113	38	98	216	347	75	1.0	4.2	890	438	1,180	8.0
45-29-2	Phillips Petroleum Co.	--	9-30-54	68	--	31	5.5	--	92	15	4.0	1.4	15	196	100	233	7.9
45-29-7	do	--	9-22-54	66	--	80	11	40	194	89	50	.8	9.9	460	244	676	7.4
45-30-4	--	68	9-26-54	68	--	648	33	47	203	1,500	75	2.2	18	2,490	1,750	2,680	7.1
45-33-8	Monroe Est.	62	4- 2-40	--	--	102	33	358	228	281	487	--	2.0	1,377	--	246	--
45-35-1	A. H. Scott Estate	58	10-29-54	38	--	110	37	132	206	418	72	1.4	4.8	937	426	1,330	7.9
45-35-201	City of Crane	154	6-10-59	--	0.05	31.0	5.2	--	110	13	21	--	--	243	99	266	--
45-35-7	Ell Long	51	11-17-54	64	--	320	95	803	183	1,060	1,180	2.2	14	3,630	1,190	5,390	7.6
45-36-7	T. C. Barnsley	100	do	79	--	60	11	37	192	23	58	2.8	3.8	390	194	562	7.7
45-37-1	McElroy Ranch	52	9-16-54	66	--	124	32	105	173	254	173	2.4	14	908	441	1,320	7.7
45-37-6	do	--	12-20-54	40	--	248	81	726	256	1,340	650	1.8	4.2	3,220	952	4,450	7.9
45-41-7	J. C. Trees Estate	60	10-24-46	--	4.7	254	93	420	288	851	570	--	4.5	2,330	1,020	3,530	--
45-43-9	J. F. McKee	37	4- 1-41	--	--	844	301	1,740	222	2,730	2,920	--	--	8,640	3,340	--	--
45-50-5	Odom & Cochran	127	9-11-48	29	--	414	261	1,300	338	1,800	1,970	--	6.0	5,950	2,110	8,690	--
45-51-5	George Atkins Estate	173	9-20-48	32	--	595	404	2,250	209	3,050	3,330	--	--	9,760	3,150	13,500	--
45-53-4	A. H. & J. T. Ray	170	7- 9-48	46	--	612	527	3,220	263	4,290	4,270	--	--	13,100	3,690	17,500	--
45-61-6	Wes Poole	68	2- 3-47	--	--	636	232	992	228	1,960	1,750	--	1.0	5,680	2,540	8,090	--

Table M2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, middle Rio Grande 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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
44-63-7	H. B. Thompson	197	6- 1-50	23	--	181	69	237	314	457	365	--	2.2	1,490	735	2,400	7.5
46-02-103	W. D. Johnson	160	9-23-40	--	--	617	42	91	50	1,602	131	--	21	2,760	--	285	--
46-03-501	Sid D. Kyle	160	6-28-61	--	--	--	--	--	134	604	390	--	--	1,680	800	2,400	7.1
46-06-3	J. B. Tubb Estate	220	9- 7-56	22	--	75	29	147	180	395	45	--	4.5	816	306	1,200	7.4
46-07-1	W. P. Edwards	260	9- 8-56	12	--	86	50	418	253	854	165	--	.0	1,710	420	2,500	7.5
46-07-4	J. B. Walton	165	9-10-56	44	--	49	26	126	242	152	103	--	4.0	630	230	1,010	7.6
46-07-6	Sun Oil Co.	143	do	52	--	187	31	138	183	496	158	1.2	2.0	1,200	594	1,640	7.4
46-09-6	Hall Olds	84	6-14-40	--	--	524	245	253	154	2,520	76	--	8.3	4,200	2,320	4,030	--
46-11-5	T. P. Lands Trust	135	7-24-40	--	--	476	142	316	71	2,030	203	--	1.0	3,520	--	380	--
46-15-2	Jack Lineberry	90	9-11-56	70	--	646	100	481	198	1,270	1,120	--	6.0	3,790	2,020	5,300	7.1
46-15-4	L. W. Anderson	184	9-12-56	40	--	139	118	1,410	356	2,110	1,000	--	2.5	4,990	832	6,950	7.6
46-16-3	Seth Campbell	155	10-24-56	26	--	38	5.9	25	125	44	15	--	5.0	220	119	350	8.1
46-17-6	M. Madera	180	11-17-48	24	--	610	143	286	134	1,960	410	--	4.2	3,500	2,110	4,140	--
46-20-1	F. P. Hubbard	84	6-28-40	--	--	584	34	18	82	1,467	30	--	--	2,388	--	2,237	--
46-23-1	University of Texas	136	4-10-40	--	--	254	97	900	203	1,040	1,240	--	4.0	3,640	--	5,570	--
46-23-3	A. C. Morton et al	90	10-11-56	48	--	78	19	67	240	121	62	2.2	2.0	518	272	778	8.2
46-23-901	J. D. Cole	260	3- -56	--	--	256	111	385	195	674	759	--	--	2,380	6.41	--	--
46-25-1	M. Madera	180	11-17-48	25	--	256	67	328	135	1,230	167	--	.2	2,140	914	2,680	--
46-26-4	H. R. Burden	350	8- 7-59	26	--	268	58	270	143	1,180	101	--	8.7	1,980	907	2,430	6.7
46-29-7	Cedar Vale Irr. Dist.	115	5-17-40	--	--	476	135	1,238	191	1,802	1,700	--	4.5	5,690	--	793	--
46-30-301	Mrs. L. W. Anderson	168	6-22-61	--	--	--	--	--	207	90	37	--	--	400.2	--	667	7.6
46-30-401	John L. Dunnigan	235	do	--	.48	--	--	--	76	1,640	345	--	--	2,478	1,640	3,540	7.0
46-31-9	T. & P. R.R.	160	11-20-39	--	--	382	157	493	126	976	1,100	--	--	3,170	--	493	--
46-32-501	Pyote Air Base	182	42	--	--	--	33	230	231	167	307	--	5.3	994	--	--	--
46-33-1	Shelby Brooks	--	8- 6-59	25	--	610	64	92	242	1,640	24	--	55	2,630	1,780	2,710	--
46-35-1	R. F Kelton	500	3-14-40	--	--	585	144	431	67	2,360	338	--	--	3,890	2,050	4,510	--
46-35-7	W. A. Halamiecik, Jr.	--	5-16-40	--	--	658	96	211	104	1,750	385	--	55	3,210	2,040	3,920	--
46-36-5	Leo Schneider	400	10- -48	32	--	340	97	345	172	940	620	--	5.0	2,460	1,250	3,580	--
46-37-3	Bobby Allgood	120	9- -56	--	--	678	465	1,323	207	2,522	2,613	--	--	7,808	210.87	--	--

Table M2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, middle Rio Grande 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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
46-37-5	Marvin Clark	51	5-15-40	--	--	710	167	594	187	1,760	1,240	--	23	4,590	2,460	6,260	--
46-39-6	J. Henson	82	11-28-39	--	--	512	135	739	200	1,840	865	--	--	4,290	--	582	--
46-40-1	T. W. Roberts	200	1- -60	--	--	224	130	378	165	611	847	--	--	2,375	67	--	--
46-43-6	Macha & Sons	1,508	8-28-59	35	--	365	95	365 19	182	1,310	450	--	1.2	2,730	1,300	3,430	6.7
46-45-3	Cecil Lee	--	11- 2-39	--	--	744	258	1,180	234	2,450	1,950	--	--	6,700	2,920	9,100	--
46-47-9	H. F. Anthony	86	10- 5-40	--	--	88	21	125	382	170	59	--	4.5	656	306	838	--
46-48-3	C. E. Davis	557	3-13-56	19	--	538	98	868 19	180	1,840	1,110	--	112	4,690	1,750	6,200	7.3
46-50-9	W. O. Johnson Estate	43	7-31-40	--	--	406	118	465	323	1,200	705	--	7.4	3.060	1,500	4,380	--
46-51-5	Jerry Jenkins	720	8-29-59	34	--	265	83	437 17	249	776	700	--	3.0	2,440	1,000	3,560	6.8
46-52-5	L. M. Prater	580	7-28-59	32	--	408	184	803 26	269	1,230	1,440	1.5	17	4,270	1,770	--	--
46-53-8	H. T. Collier	115	3-13-59	--	22	238	44	108	160	355	407	.3	2.2	1,510	780	2,520	6.8
46-56-2	Battle Estate	228	6- 6-50	34	--	105	19	88	193	266	62	--	12	717	340	1,040	7.4
46-56-7	Paul Ivey	613	3-19-56	12	--	95	13	61	192	198	36	--	13	522	290	821	7.6
46-59-5	W. E. Moore	687	8-14-59	30	--	235	97	535 22	272	800	790	1.7	4.0	2,650	986	3,930	7.0
46-62-1	Minnie McCorter	106	8-21-40	--	--	84	32	71	239	160	87	--	13	567	341	972	--
46-62-2	E. G. Bowles	117	3-23-59	--	2.0	60	12	72	174	80	57	3.0	69	379	200	632	7.5
46-63-1	Mrs. H. D. Mendel	160	11-26-46	--	--	120	21	54	224	206	70	--	8.4	605	386	875	--
46-63-6	John McIntyre	193	11-25-46	--	--	43	15	44	109	97	52	--	2.0	363	169	628	--

Edwards-Trinity 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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
45-21-7	W. D. Edwards	137	4- 1-37	--	--	--	--	--	140	240	56	--	--	543	--	--	--
45-31-501	Mesquite Gas Products	180±	7- -60	4.93	0.48	--	12	--	--	662	48	--	--	1,234	524	--	7.5
45-46-601	Jacob Livestock Co.	--	7-26-60	11	--	111	36	47	260	222	50	--	17	622	425	951	7.1
45-57-8	R. H. Price	500	11-23-46	--	--	82	52	148	113	266	262	--	1.5	948	418	1,670	--
45-58-5	San Pedro Ranch	81	10-30-46	--	--	648	218	891	256	2,110	1,430	--	33	5,460	2,510	7,430	--
45-60-9	Agriculture Inc.	400	1-27-59	12	--	462	88	248 9.3	256	1,220	425	--	12	2,600	1,510	3,430	7.2
45-61-9	Roy McDonald	200	1-31-47	--	--	180	57	154	238	424	270	--	.8	1,200	684	1,880	--
46-33-6	Tri-State Cre. Mens Asn.	Spring	5-28-40	--	--	563	186	182	156	2,170	130	--	.0	3,300	2,170	3,670	--
46-41-2	B. R. Parker	Spring	do	--	--	375	104	285	148	1,250	394	--	2.5	2,490	1,360	3,360	--

Table M2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, middle Rio Grande 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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
46-50-701	Mrs. J. Bryan Cambest & Mr. Garland Odom	409	9- 6-61	12	--	215	110	328	243	1,140	220	2.2	0.0	2,150	989	2,850	6.9
46-61-4	Balmorhea Ranches, Inc.	410	4- 8-59	--	--	106	20	41	207	144	104	.3	.7	568	350	947	7.2
47-64-6	Griffin Estate	700	10- 3-39	--	--	190	83	413	284	626	588	--	--	2,040	815	3,270	--
52-01-401	Shields & Morris	350	4-20-61	34	--	88	5.8	7.6 2.3	257	17	14	.3	16	311	244	502	6.8
52-02-9	Joe Kingston	200 ?	6-30-59	9.6	--	56	32	295	314	3.0	462	--	.2	1,010	271	1,930	7.0
52-06-2	J. R. Alexander	310	11-27-46	--	--	77	20	55	236	95	70	--	1.5	435	274	677	--
52-07-6	Raymond Tyler	630	1-19-56	22	0.00	102	27	104 6.4	252	177	144	1.1	1.8	710	366	1,170	7.4
52-12-3	Popham Land & Cattle	--	4- 8-59	--	.52	104	25	116	265	180	171	.8	.4	948	365	1,580	7.2
52-13-7	J. W. Stone	620	5-14-47	--	--	37	12	45	104	131	12	--	.0	331	142	509	--
52-15-4	M. R. Kennedy	270	5- 5-47	--	--	88	21	79	193	139	124	--	1.2	606	306	1,020	--
52-16-7	Pete McIntyre	450	5- -47	--	--	148	49	236	253	365	352	--	.5	1,280	571	2,110	--
52-29-801	Carl Pfluger	1,700	4-21-61	14	--	13	8.4	119	293	56	16	1.6	2.0	374	67	630	7.4
53-02-1	T. B. Rhodes	147	4-21-49	--	--	296	103	453	299	922	660	--	13	2,620	1,160	3,910	7.2
53-04-5	Hinyard Land & Cattle	250	1-30-47	--	--	144	54	167	236	366	262	--	.8	1,160	582	1,840	--
53-07-8	Mary Lea McKenzie	535	4-28-47	--	--	68	32	10	210	94	34	--	6.0	437	301	592	--
53-10-7	Jeff B. Wade	360	1-14-50	18	.01	151	53	206	243	446	268	--	.0	1,260	594	1,950	8.2
53-14-1	University of Texas	125	4-19-47	--	--	111	38	82	267	170	148	--	7.5	810	433	1,210	--
53-18-7	Jack Allison	700	4- 4-58	24	--	98	20	64 8.0	259	104	103	--	12	560	326	923	--
53-19-8	Floyd Henderson	700	10-28-58	11	--	45	14	80	272	86	20	1.7	.1	392	170	640	7.7
53-28-5	Guy S. Rachel	630	10-20-58	21	--	78	6.9	10	256	12	7.0	.1	16	284	223	457	7.3
								Santa Rosa Aquifer									
45-10-3	Stanolind Oil & Gas	1,113	1-28-57	12	--	5.6	3.4	406	459	342	119	4.4	0.0	1,110	28	1,760	7.2
45-11-4	J. D. Amburgey	680	7- 9-58	10.0	--	11	6.2	701	561	442	465	--	1.0	1,910	53	3,090	7.9
45-11-7	Millard Edison	640	7-23-58	9.6	--	24	13.0	1,110	527	694	975	--	.5	3,090	114	4,980	7.9
45-20-1	Jack Rhodes	773	7-11-58	11.0	--	14	8.1	811	598	678	450	--	2.0	2,270	68	3,580	7.9
45-20-2	Cosden Petr. Co.	630	7-23-58	9.6	--	12	7.0	736	680	630	315	--	.8	2,040	59	3,220	8.0
45-20-5	do	680	7-11-50	9.8	--	40	20.0	1,030	592	1,170	505	--	2.8	3,070	182	4,510	7.7
45-25-3	City of Monahans	120	4-29-41	--	--	--	7.5	36	135	69	25	.8	3.0	292	--	47.8	--

Table M2.--Representative chemical analyses of water from primary and secondary aquifers, Region I, middle Rio Grande Basin--Continued

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium and potassium (Na + K)	Bicar-bonate (HCO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Dis-solved solids	Total hardness as $CaCO_3$	Specific conduct-ance (micromhos at 25°C.)	pH
45-28-5	W. E. Connell Estate	560	12-20-54	6.6	--	45	26	1,160	253	1,720	530	1.8	0.2	3,610	220	5,110	7.9
46-07-3	Tom Lineberry	--	1-12-57	1.5	--	5.6	5.1	208	283	129	80	3.4	.0	572	35	974	9.1
46-07-4	Sinclair Oil & Gas Co.	455	10-22-56	11	--	53	41	291	325	465	130	--	.0	1,150	300	1,790	7.9
46-08-6	Carter Foundation	200	2-14-57	30	--	21	2.9	9.4 1.5	80	7.4	3.2	1.4	6.9	128	64	175	7.7
46-16-1	City of Kermit	700	6- 3-40	29	0.12	34	6.0	14 2.4	96	44	6.0	1.1	3.4	197	110	280	--
46-22-8	University of Texas	151	9-20-56	50	--	51	19	21	243	25	10	1.6	10	309	205	464	7.4
46-30-4	L. N. Anderson	188	8-21-40	--	--	321	87	150	118	1,165	116	--	15	2,030	--	241	--
46-32-6	E. L. Lanehart	172	5- 3-40	--	--	78.1	17	66	186	162	60	--	2.5	558	--	--	--
46-38-201	City of Barstow	95	10- -58	--	.1	260	118	156	--	950	185	1.4	9.0	1,890	--	3,150	--
								Rustler Aquifer									
45-35-8	W. N. Waddell	461	12- 7-54	41	--	906	224	1,840	98	2,220	3,390	1.6	--	8,670	3,180	--	7.4
45-35-9	T. C. Barnsley	243	10-26-54	39	--	592	78	67	101	1,720	44	1.8	3.8	2,600	1,800	2,730	7.4
45-50-1	George Atkins Estate	--	7-25-49	26	--	1,160	653	13,900	72	4,080	22,300	--	.0	42,200	5,580	56,500	7.8
45-52-8	Neal & Ratliff	452	12-23-48	8.5	--	388	259	1,820	320	2,350	2,320	--	--	7,300	2,030	10,200	--
45-57-8	D. J. Sibley	1,680	3-16-48	20	--	581	210	262	296	2,280	190	--	.0	3,690	2,310	3,910	--
46-07-9	Tex Pacific Coal & Oil	1,234	9-25-56	10	--	1,380	1,400	57,400	56	7,140	89,700	2.3	--	157,000	9,200	--	6.5
46-08-8	Standard Oil Co. of Tex.	195	5-14-47	--	--	33	4.0	10	117	15	5.0	--	3.8	215	97	250	--
46-40-8	Troy Eiland	1,125	3- 4-59	20	--	600	242	348 25	99	2,620	365	--	.5	4,270	2,490	4,800	--
46-45-7	Billie Prewit	1,360	6- 7-40	--	--	595	227	170	77	2,480	94	--	.8	3,610	2,420	3,870	--
46-53-9	Barilla Farms	1,405	8-21-40	--	--	605	216	5.3	130	2,180	24	--	2.5	3,100	2,400	--	--
46-55-6	Ben & Bob Burkholder	1,500	7-16-56	17	--	542	211	209 19	145	2,240	197	--	.0	3,510	2,220	3,880	7.2
46-60-9	The Chandler Co.	1,500	do	18	--	555	184	54 12	170	2,020	41	--	.2	2,970	2,140	--	7.3
46-62-3	E. G. Bowles	5,615	4- 4-40	--	--	611	224	44	143	2,210	87	--	.8	3,250	2,450	3,570	--
52-08-9	Chandler Co.	1,756	4-11-46	--	--	504	115	133	154	1,480	250	--	.5	2,560	1,730	--	--
52-16-3	do	1,550	do	--	--	327	83	184	149	960	308	--	.5	1,940	1,160	--	--
53-02-4	Lee O. White	1,480	4- 6-56	15	--	599	230	225	160	2,410	205	--	.0	3,760	2,440	4,110	7.1
								Capitan Reef Complex and Associated Limestones Aquifer									
45-49-1	Harlan Black	4,000	7-17-56	84	--	602	153	336 1.0	281	1,830	550	--	0.2	3,690	2,130	4,450	7.7

In the heavily pumped areas of central and north-central Reeves County the dissolved solids usually range from a little less than 2,000 ppm to about 4,000 ppm. Typically, wells completed in the alluvium yield water containing 700 to 800 ppm of sulfate and of chloride, about 300 ppm of calcium, and a little less than 100 ppm of magnesium. Some shallow wells may contain 20 to 30 ppm nitrate, although the nitrate content of the Cenozoic alluvium water is usually about 5 ppm or less.

Around the southern margin of the alluvial trough in Reeves County (Plate M5), the water has a sulfate and chloride content of only 500 to 600 ppm each and the other constituents are proportionally lower. The lower mineral content probably indicates that in this area the water is nearer its recharge area.

In a large part of western and northern Reeves County and western Loving County the quality of water has a general similarity. The mineralization of the water differs from place to place, ranging from a little less than 2,000 ppm to about 6,000 ppm dissolved solids. The water is characterized by low bicarbonate content (generally less than 200 ppm, although in some places as much as 300 ppm), a high ratio of sulfate to chloride concentration, and a high calcium content (500 to 600 ppm). The water normally has about 2,000 ppm sulfate, although many analyses show smaller concentrations, and not more than 200 to 300 ppm chloride. In many analyses the chloride concentration was less than 100 ppm.

The dissolved-solids content of water from wells around Barstow, southwestern Ward County, has increased from 4,950 ppm in 1939 to more than 7,000 ppm in 1956. The increase in mineral concentrations in this area is probably due primarily to the recirculation of irrigation water.

In the northeastern part of Region I the dissolved solids are usually less than 1,000 ppm with the other concentrations being proportionally lower. However, in some areas (Plate M5) waste water from oil production and possibly other sources has apparently contaminated the alluvium aquifer, resulting in higher mineral concentrations than normally is expected.

Utilization and Development

Water from wells tapping the Cenozoic alluvium in Region I is used for irrigation, industrial, municipal, and domestic and livestock purposes. Irrigation use accounts for the greatest part of the total withdrawal from this aquifer.

The development of ground-water supplies in the alluvium began in the latter part of the 19th century. In the following years most development was limited to shallow alluvial wells which supplied the needs for irrigation, municipal, and industrial purposes as well as domestic and livestock demands. Soon after World War II ground-water supplies were developed rapidly. At first, wells were drilled to supplement surface-water supplies, but later, irrigation spread to areas where no surface water was available.

The size of the wells in the Cenozoic alluvium vary according to need. The larger irrigation wells commonly contain 16- to 18-inch surface casing. Slotted casing is generally placed opposite the water-bearing stratum and the annulus of the well is gravel packed. Depths of wells vary depending upon the quantity and quality of water needed, lithologic character of the alluvium, and thickness of the alluvium. Yields of irrigation wells in Region I generally range between 200 and 2,500 gallons per minute.

The principal irrigated areas of Region I, which use large amounts of water from the Cenozoic alluvium, are located in drainage subdivisions 37 and 33, in central and north-central Reeves County, and drainage subdivision 42, northwestern Pecos County (Plate M1). The areas are readily identified on Plate M7 by the depressions in the water levels that have resulted from heavy pumpage.

An estimated 378,000 acre-feet of ground water is pumped annually from the Cenozoic alluvium in Region I of the middle Rio Grande Basin. The estimates of pumpage were determined from data collected for the years 1956 to 1960. Approximately 361,000 acre-feet, or 95 percent of the total, is pumped for irrigation. In addition about 7,400 acre-feet of water is pumped from the alluvium for irrigation in Region II.

About 14,000 acre-feet of ground water is pumped from the aquifer for industrial purposes. Industrial pumpage is concentrated mainly in subdivisions 42, 44, and 49 (Plate M1). Waterflooding of oil fields consumes the greatest amounts of ground water used for industrial purposes, with carbon-black, pipeline, and compressor plants and several oil refineries using lesser amounts.

Several municipalities in Crane, Pecos, Ward, and Winkler Counties obtain a portion or all of their water supplies from wells tapping the Cenozoic alluvium aquifer. The estimated pumpage for municipal purposes from the aquifer amounts to about 3,400 acre-feet annually in Region I.

Table M3 lists the estimated annual pumpage for municipal, industrial, and irrigation purposes from the Cenozoic alluvium aquifer in Region I by drainage subdivisions.

Numerous domestic and livestock wells within the region tap the alluvium, but the total pumpage for these purposes is comparatively small.

Ground Water Available for Development

The amount of water available for future development from the Cenozoic alluvium aquifer determined during this study is correct only in its order of magnitude and cannot be considered an exact figure. The available quantity of water in the aquifer was computed from the volume of saturated alluvium in the aquifer (Plate M6) and by assuming an average specific yield of about 10 percent.

The total computed saturated volume of alluvium in Region I is 947 million acre-feet. Based on a specific yield of about 10 percent, the available volume of water in storage is on the order of 90 million acre-feet. Under present well operation limits the quantity of water that can be economically withdrawn from the aquifer is probably not more than two-thirds of the total volume of water available in storage. Under these conditions the quantity of water in storage available for recovery is probably on the order of 50 to 60 million acre-feet.

Table M3.--Annual ground-water pumpage from aquifers in Region I, middle Rio Grande Basin 1/

(Pumpage expressed in acre-feet 2/)

Subdivision	30	31	32	33	34	37	40	41	42	44	49	51	Total
Cenozoic Alluvium Aquifer													
Municipal	--	--	--	6	--	--	--	--	846	2,508	--	--	3,360
Industrial	3	7	25	5	--	--	--	--	5,191	7,525	1,503	--	14,259
Irrigation	--	--	394	48,904	10,620	181,900	12,200	--	95,034	1,029	3,991	6,582	360,654
Total	3	7	419	48,915	10,620	181,900	12,200	--	101,071	11,062	5,494	6,582	378,273
Edwards-Trinity Aquifer													
Municipal	--	--	--	--	3	--	--	--	--	--	1,408	--	1,411
Industrial	--	--	--	--	--	--	--	--	--	16	938	33	987
Irrigation	--	--	--	--	--	24,000	--	1,200	8,580	0	79,226	4,101	117,107
Total	--	--	--	--	3	24,000	--	1,200	8,580	16	81,572	4,134	119,505
Santa Rosa Aquifer													
Municipal	--	--	--	86	--	--	--	--	2,422	2,219	--	--	4,727
Industrial	--	--	--	--	--	--	--	--	336	1,703	--	--	2,039
Irrigation	--	--	--	--	--	2,758	3,350	--	9,942	--	--	--	16,050
Total	--	--	--	86	--	2,758	3,350	--	12,700	3,922	--	--	22,816

See footnotes at end of table.

Table M3.--Annual ground-water pumpage from aquifers in Region I, middle Rio Grande Basin [1]--Continued

Subdivision	30	31	32	33	34	37	40	41	42	44	49	51	Total
Rustler Aquifer													
Municipal	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial	--	--	--	--	--	--	--	--	626	--	386	--	1,012
Irrigation	--	--	--	--	--	1,182	394	--	210	--	6,235	--	8,021
Total	--	--	--	--	--	1,182	394	--	835	--	6,621	--	9,033
Capitan Reef Complex and Associated Limestones Aquifer													
Municipal	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial	--	--	--	--	--	--	--	--	--	4,000	1,000	--	5,000
Irrigation	--	--	--	--	--	--	--	--	1,600	--	6,000	--	7,600
Total	--	--	--	--	--	--	--	--	1,600	4,000	7,000	--	12,600
Other Aquifers [3]													
Municipal	--	--	--	--	--	2	3	964	--	--	--	--	969
Industrial	--	--	--	--	--	--	--	--	--	--	--	--	--
Irrigation	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	--	--	--	--	--	2	3	964	--	--	--	--	969

See footnotes at end of table.

Table M3.--Annual ground-water pumpage from aquifers in Region I, middle Rio Grande Basin [1]--Continued

Subdivision	30	31	32	33	34	37	40	41	42	44	49	51	Total
Summary of Pumpage in Region I													
Municipal	--	--	--	92	3	2	3	964	3,268	4,727	1,408	--	10,467
Industrial	3	7	25	5	--	--	--	--	6,153	13,244	3,827	33	23,297
Irrigation	--	--	394	48,904	10,620	209,840	15,944	1,200	115,366	1,029	95,452	10,683	509,432
Total	3	7	419	49,001	10,623	209,842	15,947	2,164	124,787	19,000	100,687	10,716	543,196

1/ Municipal and industrial pumpage reported 1960; Irrigation pumpage on 1958 data.
2/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.
3/ Includes Tertiary volcanic rocks.

Geologic Characteristics

The Edwards-Trinity aquifer is composed of the water-bearing lower Cretaceous strata in the Washita, Fredericksburg, and Trinity Groups of the middle Rio Grande Basin. The Cretaceous strata in Region I unconformably overlie rocks of Mesozoic and Paleozoic age. Outcrops of formations included in this aquifer are shown on Plate M1.

The Georgetown Limestone comprises the water-bearing part of the Washita Group in Region I, and is of primary importance as an aquifer in the Leon-Belding irrigation area of southwestern Pecos County. In this area, as a result of faulting, limestones of the Washita Group are downthrown and are in contact with the Comanche Peak Limestone of the underlying Fredericksburg Group. Solution cavities in the Washita Group limestones yield large amounts of water in the part of the area that lies south of an eastward-trending fault located approximately 10 miles southwest of Fort Stockton. In normal sequence, the Washita Group limestones are separated from the Comanche Peak Limestone in this area by about 100 feet of clay. Because the natural gradient of the ground water is toward the north, water from the limestones of the Washita Group moves into the Comanche Peak Limestone in the faulted area. Where present north of the fault, the Washita Group limestones generally are above the water table (Armstrong and McMillion, 1961, p. 57).

The Fredericksburg Group formations contributing to the Edwards-Trinity aquifer in Region I are the Comanche Peak Limestone and Edwards Limestone. The Comanche Peak is a soft, gray, thin-bedded, argillaceous limestone and comprises the principal part of the limestone aquifer in Region I. The Edwards consists of a hard, light-gray, thick-bedded limestone containing brown nodular chert and yields little water in the region.

The "Trinity sand" underlies the younger Fredericksburg rocks. This formation consists predominantly of fine- to coarse-grained quartz sand, commonly cross-bedded, and having varying amounts of calcareous cement. At some localities limestone and shale is interbedded with the sand. A conglomerate is sometimes present at the base of these sands. The "Trinity sand" in this area is possibly the equivalent of the Paluxy Formation. The formation is the basal Cretaceous unit in much of the region.

In the southern part of Region I the basal formation of the Trinity Group is the Glen Rose Limestone. The Glen Rose consists predominantly of thin-bedded, pure to argillaceous limestone and calcareous shale and may yield some water in conjunction with the overlying beds.

Contours drawn on the base of the Edwards-Trinity aquifer (Plate M8) indicate that the unit dips generally north-northeast in the southern and western parts of the region and dips southeast in the eastern part of the region. Variations in direction of dip may be expected in local areas.

The Edwards-Trinity aquifer attains a thickness of more than 400 feet in Pecos County in the south-central part of the region.

Occurrence and Movement of Ground Water

Most of the ground water in the Edwards-Trinity aquifer occurs in solution cavities of the limestones and in the underlying "Trinity sand". The ground water is under both artesian and water-table conditions, and in some areas the aquifer is hydraulically continuous with the overlying Cenozoic alluvium aquifer. The solution cavities in the limestones of the Edwards-Trinity aquifer yield the greatest quantities of water to wells.

The movement of ground water in the Edwards-Trinity aquifer is generally toward the Pecos River as indicated by the gradient of the water levels shown on Plate M9. Like the Cenozoic alluvium aquifer, declining water levels in areas of heavy pumpage have caused local reversals in the hydraulic gradient of the Edwards-Trinity aquifer. The hydraulic gradient in the Edwards-Trinity aquifer ranges from less than 8 feet per mile in east-central Reeves County to 50 feet per mile in northern Brewster County (Plate M9).

In several areas within the region, principally in southern Reeves County, near Balmorhea, and in west-central Pecos County, near Fort Stockton, springs issue from the lower Cretaceous limestones. However, because of pumpage from wells in these areas discharge from some of the springs has been reduced.

Recharge and Discharge

Recharge of the Edwards-Trinity aquifer is derived from precipitation and runoff. In the outcrop, a part of the precipitation and runoff percolates directly into the aquifer. In other areas, where the Edwards-Trinity aquifer is overlain by a thin veneer of Cenozoic alluvium, precipitation moves downward through the alluvium into the Cretaceous strata. Some recharge of the Edwards-Trinity aquifer may occur from runoff infiltrating through the volcanic rocks in the Davis and Barilla Mountains in the southwestern part of the region. However, the quantity of recharge from this source is probably small because of the relatively impervious upper Cretaceous strata which overlie the aquifer. Some recharge may also occur from underflow where pre-Cretaceous strata are in contact with the Edwards-Trinity aquifer. Ground-water discharge occurs naturally from springs, by evapotranspiration where the water table is near the surface, and by underflow into the overlying alluvium. Pumping from wells comprises the artificial discharge from the Edwards-Trinity aquifer in Region I.

Data are not available to determine the recharge-discharge relationship of the Edwards-Trinity aquifer in Region I. However, according to Armstrong and McMillion (1961, p. 60), in 1958 in the Fort Stockton and Leon-Belding area of Pecos County the total discharge from the Edwards-Trinity aquifer exceeded the total recharge.

Water Levels

Winter water levels of the Edwards-Trinity aquifer ranged from above land surface at several springs in the region to move than 800 feet below the land surface in the southern part of the region. In the Fort Stockton and Leon-Belding area the water-level recovery in successive winters is progressively less (Armstrong and McMillion, 1961, p. 59). Hydrographs in Figure M10 shows the annual variations in water levels of wells in the Edwards-Trinity aquifer in the Fort Stockton and Leon-Belding area of Pecos County.

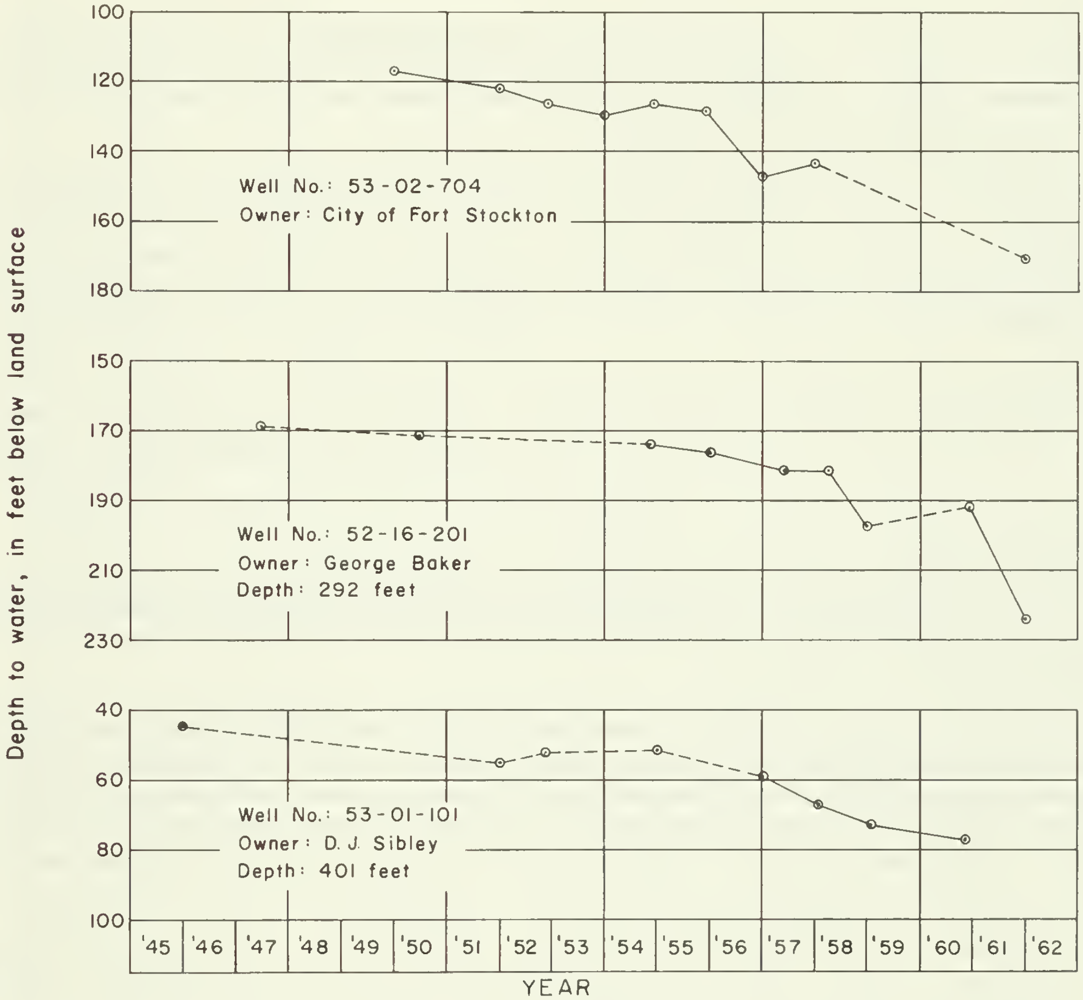

Figure M10

Hydrographs of Wells Screened in Edwards-Trinity Aquifer, Region I, Middle Rio Grande Basin

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

100

Water-Bearing Characteristics

The transmissibility of the Edwards-Trinity aquifer varies greatly owing to the different lithologies found in the aquifer. Because solution channels in the limestone differ greatly in size and are irregularly distributed, the transmission capacity of the limestone part of the aquifer is much greater in some places than in others.

The coefficients of transmissibility and storage of the "Trinity sand" were determined from an aquifer test made near Fort Stockton in west-central Pecos County. The coefficient of transmissibility was 7,000 gpd/ft, and the coefficient of storage was 0.0001.

Near Toyah in west-central Reeves County, an aquifer test was made on a well tapping the Edwards-Trinity aquifer. The coefficient of transmissibility was computed to be about 2,700 gpd/ft. The well produced 460 gpm with about 140 feet of drawdown, giving the well a specific capacity of 3.3 gpm per foot of drawdown.

Yields of large wells drawing from the Edwards-Trinity aquifer normally range from 500 to 2,000 gallons per minute. Generally wells drawing from the limestone cavities have much greater yields than wells drawing from the sands.

Chemical Quality

Water from the Edwards-Trinity unit is generally very hard and has a wide range in dissolved solids. Table M2 includes selected chemical analysis from Cretaceous wells in Region I.

Water of less than 500 ppm dissolved solids is found in the southern part of the region and generally the concentrations of dissolved solids increase northward (Plate M8). The dissolved solids ranged from 284 to 5,460 ppm. Of 49 Edwards-Trinity analyses examined, 13 contained less than 500 ppm dissolved solids, 8 contained from 500 to 1,000 ppm dissolved solids, 25 contained from 1,000 to 3,000 ppm dissolved solids, and 3 contained more than 3,000 ppm dissolved solids. The sulfate concentrations ranged from 11 to 2,170 ppm with 27 containing more than 250 ppm; 20 contained over 500 ppm sulfate, 12 contained over 1,000 ppm sulfate, and 2 contained more than 2,000 ppm sulfate. The chloride concentrations in the 49 analyses ranged from 7 to 1,430 ppm with 31 containing less than 250 ppm. The magnesium concentrations were generally less than 125 ppm although they ranged up to 218 ppm. Fluoride concentrations were available in a few analyses and generally did not exceed 1.5 ppm; however, locally concentrations of fluoride ranged up to 2.8 ppm.

Utilization and Development

The most heavily developed parts of the Edwards-Trinity aquifer are the irrigation areas in drainage subdivisions 37 and 49 (Plate M1). Table M3 shows the annual pumpage from the Edwards-Trinity aquifer for each major drainage subdivision. As noted from Table M3, irrigation pumpage accounts for about 117,000 acre-feet or 99 percent of the total withdrawal from the aquifer. In the heavily developed irrigation areas in subdivisions 37 and 49 annual withdrawals are approximately 24,000 and 79,000 acre-feet, respectively. The combined withdrawals from these two areas amounts to approximately 88 percent of the total irrigation pumpage from the aquifer in Region I.

The only municipal water supplies being withdrawn from the Edwards-Trinity aquifer in Region I are at Fort Stockton, in Pecos County, and Kent in southeastern Culberson County. Total pumpage from the aquifer for municipal purposes is about 1,400 acre-feet annually.

Industrial wells tapping the Edwards-Trinity aquifer pump about 1,000 acre-feet per year. More than 900 acre-feet annually is pumped at the West Texas Utility Company plant near Girvin in northern Pecos County. In the southeastern part of the region, in Pecos County, approximately 30 acre-feet per year of ground water from the aquifer is used by the petroleum industry, chiefly for waterflood projects. About 16 acre-feet annually is pumped by a portland cement plant in southwestern Ector County near the northeastern border of the region.

Total pumpage from the numerous domestic and livestock wells tapping the Edwards-Trinity aquifer is probably negligible when compared to the total pumpage from the aquifer for other purposes.

Ground Water Available for Development

The amount of water in storage and the amount of water available on a perennial basis from the Edwards-Trinity aquifer is not known for the entire region. However, in the Fort Stockton and Leon-Belding area it has been suggested that approximately 45,000 acre-feet of water can be withdrawn on a perennial basis (Armstrong and McMillion, 1961, p. 60).

Additional development of the Edwards-Trinity aquifer may be possible in western Reeves County, southwest of Toyah, where a recently drilled well flowed approximately 800 gpm from the aquifer. The quality of the water in this well is above the recommended limits of the U. S. Public Health Service for public water supplies, but it appears suitable for irrigation of salt-tolerant crops on well drained soils.

Secondary Aquifers

Santa Rosa Aquifer

Geologic Characteristics

The Santa Rosa Sandstone of upper Triassic age lies under the Chinle Formation and overlies the Tecovas Formation. The Santa Rosa Sandstone in Region I of the middle Rio Grande Basin is composed of reddish-brown and gray, medium- to coarse-grained, typically cross-bedded sandstone cemented with calcite and some silica. The Santa Rosa commonly contains soft, red and green shale and siltstone.

The Santa Rosa is overlain by Cenozoic alluvium or Cretaceous strata in parts of the region where the Chinle Formation is absent. The Santa Rosa Sandstone is present on the surface or in the subsurface in most of the region north of the Pecos River and is also present in eastern Reeves and part of northwestern Pecos Counties south of the Pecos River. The outcrop extent of the formation is included as part of the undifferentiated Triassic rocks as shown on Plate M1.

The dip of the Santa Rosa Sandstone in Region I varies considerably and is controlled primarily by the deep troughs which developed due to solution of the underlying evaporites. The general location of the major solution troughs is shown on the map showing the base of Cenozoic alluvium, Plate M5.

In Region I the formation ranges in thickness up to about 350 feet with maximum thickness attained in the structural trough located in Winkler County.

Occurrence and Movement of Ground Water

Ground water in the Santa Rosa aquifer occurs under both artesian and water-table conditions. Available data indicates that artesian conditions are the most common and that water-table conditions occur where the Santa Rosa Sandstone crops out or where a thin mantle of permeable alluvial material overlies the aquifer.

The Santa Rosa is commonly a consolidated sandstone that yields small amounts of water. However, in some parts of Region I the Santa Rosa Sandstone is fractured which greatly increases the permeability of the formation allowing moderate to large amounts of water to be drawn from the aquifer.

Insufficient data are available to contour the water levels in the Santa Rosa. However, in areas where heavy pumpage has resulted in declining water levels the hydraulic gradient may be reversed.

Recharge and Discharge

The Santa Rosa Sandstone is recharged by direct infiltration of precipitation on the outcrop and, probably more substantially, by inflow from overlying eolian sands where the two strata are in contact.

Ground water from the Santa Rosa aquifer is discharged principally through wells; however, in the outcrop some water is undoubtedly lost through evapotranspiration. Where the aquifer is underhydrostatic head, some discharge by means of upward leakage through confining beds probably occurs. The heaviest concentration of pumpage is in central Winkler and eastern and northeastern Reeves Counties.

Water Levels

Information is sparse concerning water levels in the Santa Rosa Sandstone. However, the available data suggest that generally water levels have declined very little and in areas of Winkler County rises in water levels have been recorded. Some of the water-level rises may be the result of infiltration of oil-field waste water which could contaminate usable-quality water in the aquifer. In the city of Pecos well field in eastern Reeves County, water levels in the aquifer have declined owing to the heavy withdrawals created by increasing demands of the city of Pecos.

Water-Bearing Characteristics

Hydraulic characteristics of the Santa Rosa aquifer were determined from pumping tests made on five wells in Winkler County. Three were municipal wells in Kermit, one was located 5½ miles north of Kermit, and the other was located 4 miles east of Wink.

In the city of Kermit wells, the entire thickness of Santa Rosa Sandstone was tested in only one well; one well penetrated about two-thirds of the formation, and the other well penetrated less than half of the formation. In this area the coefficient of storage ranged between 0.00024 and 0.00029. The coefficient of transmissibility ranged from about 12,000 to about 37,000 gpd/ft. The available data suggests that the average coefficient of transmissibility in this area is about 25,000 gpd/ft. It has been suggested that the transmissibility of the Santa Rosa in the Kermit area is probably high for the aquifer as a whole. The transmissibilities are possibly due to fracturing of the formations associated with the structural pattern of the area, and where these fractures do not occur the transmissibilities are expected to be much lower (Garza and Wesselman, 1959, p. 36-41).

Chemical Quality

The Santa Rosa Sandstone is commonly characterized by hard water, high in sulfate and fluoride. Table M2 includes selected chemical analyses of water from Santa Rosa wells. Thirty analyses were examined from Santa Rosa wells in this region. The dissolved-solids concentrations ranged from 55 to 3,610 ppm with 20 analyses showing concentrations higher than 1,000 ppm. The sulfate concentrations ranged from 7.4 to 1,720 ppm with 21 over the recommended 250 ppm. Chloride concentrations ranged from 3.2 to 975 ppm, and in 11 of the analyses the concentrations were greater than 250 ppm. The fluoride content of 23 water samples was determined and the range was from 0.8 to 4.4 ppm with 8 of the analyses having more than 1.5 ppm. Concentrations of magnesium and nitrate were all within the recommended limits set forth by the U. S. Public Health Service.

Utilization and Development

Ground water drawn from the Santa Rosa is used in supplying a part of the municipal, industrial, and irrigation requirements within Region I as well as some domestic and livestock needs. The areas in Region I where ground water is drawn from the Santa Rosa aquifer include parts of drainage subdivisions 33, 37, 40, 42, and 44 (Plate M1).

The annual pumpage from the Santa Rosa is approximately 23,000 acre-feet. Irrigation use accounts for about 16,000 acre-feet, municipal supply approximately 4,700 acre-feet, and industrial requirements about 2,000 acre-feet (Table M3). Some wells penetrate both the overlying alluvium and the Santa Rosa aquifer and produce water from both sources.

The areas where ground water from the Santa Rosa aquifer is used for irrigation purposes include parts of subdivisions 37, 40, and 42, located in eastern and northeastern Reeves County (Plate M1).

The city of Pecos obtains its municipal supply from the Santa Rosa Sandstone. In 1933, Pecos drilled a test well about 10 miles southeast of the city. The well penetrated three water-bearing sands and pumped an average of about 500,000 gpd for about a week. The water was of satisfactory quality for public supply, and a pipeline was constructed to carry the water to the city. By 1952 a total of eight wells had been drilled to supply the growing population of Pecos. Between 1952 and 1959, the city drilled several wells about 2 miles southeast of the original well field and in 1959 the two well fields had a total of 17 operational wells, 7 in the original well field and 10 in the new well field. The 1960 pumpage of water was approximately 2,400 acre-feet.

The city of Barstow in southwestern Ward County (subdivision 33) obtains water from wells tapping a part of the Santa Rosa where it is hydraulically connected with alluvium which contains water of poor quality. These wells are located approximately 4 miles east of Barstow. The quality of the water produced from these wells has steadily deteriorated over a period of several years, indicating that the water of poor quality in the alluvium is moving toward the wells (Ogilbee and Wesselman, 1962, p. 59). The annual pumpage for the city of Barstow is about 86 acre-feet per year (Table M3).

The cities of Kermit and Wink in Winkler County and Monahans in northeastern Ward County (subdivision 44) obtain a part of their municipal requirements from wells tapping the Santa Rosa aquifer. The total pumpage of these three cities from the Santa Rosa aquifer is approximately 2,200 acre-feet annually (Table M3).

Consumption of ground water from the Santa Rosa aquifer for industrial purposes occurs in Winkler, Ward, Crane, and Andrews Counties of Region I. The estimated average annual pumpage is about 2,000 acre-feet. Waterflood projects consume the largest amounts of water, with electrical power, gasoline, carbon-black, and pipeline compressor plants accounting for the remainder of the pumpage.

A few domestic and livestock wells in the region draw water from the Santa Rosa aquifer. Yields are generally very small, averaging 1 to 5 gpm. The total pumpage from these wells is small in comparison to the total withdrawal for all uses and probably does not exceed a few acre-feet per year.

Ground Water Available for Development

The total quantity of water in storage or the quantity that can be produced on a perennial basis from the Santa Rosa has not been determined. The quantity of water that can be pumped from the aquifer probably varies greatly from place to place because of the varying hydraulic characteristics. Future development of the aquifer in this region should be preceded by test drilling with aquifer tests conducted to determine the hydrologic characteristics in the areas to be explored.

Geologic Characteristics

The Rustler Formation consists mainly of dolomite and anhydrite with a basal zone of sand, conglomerate, and shale. Locally, the Rustler Formation contains minor amounts of halite and limestone. The dolomite and limestone beds have vugular porosity and in some places are reported to be cavernous.

The Rustler Formation unconformably overlies the Salado Formation and its thickness ranges up to 500 feet in Region I. The Rustler crops out in the Rustler Hills area near the eastern border of Culberson County (Plate M1) and regionally dips eastward. However, local variations in the dip direction are common as a result of structural deformation. Permian (undifferentiated) rocks crop out in southern Pecos and northern Brewster Counties which are probably hydraulically connected with the Rustler Formation and underlying Salado Formation.

Occurrence and Movement of Ground Water

Water in the Rustler Formation occurs under artesian conditions in Region I, except in the outcrop. Most production from the Rustler is reported from solution openings in the dolomite or limestone. Some water is also withdrawn from the basal sand. Wells tapping the basal sand usually yield highly mineralized water and have comparatively small yields unless abundant water is encountered in the overlying carbonate strata.

Many attempts to obtain water from the Rustler Formation were unsuccessful before the practice of acidizing wells drilled into the formation became common in 1955. The yields of pumped wells penetrating cavernous carbonate rocks generally range from 500 to 1,000 gpm.

The movement of water in the Rustler Formation generally follows the dip of the beds. In the southern part of the region movement of water is from the south, probably from the Glass Mountains where Permian rocks which are equivalent to the Rustler are exposed. In other parts of Region I, movement is generally toward the east; however, movement in a given area of the region is controlled by the local geologic structure as well as by influences exerted on the piezometric surface by pumping or flowing wells.

Recharge and Discharge

The Rustler is recharged by precipitation and by seepage from streams in its outcrop in the Rustler Hills in eastern Culberson County. Also, water entering the equivalent Permian rocks may eventually percolate into the Rustler in the southern part of Region I.

Ground water is discharged artificially from the Rustler by wells, some of which flow; and is discharged naturally by seeps and springs in the outcrop, and also probably by means of upward leakage into the overlying strata.

Water Levels

Depths to water range from above land surface in flowing wells to more than 400 feet in heavily pumped areas. Several wells drawing from the Rustler aquifer in central and northern Pecos County and southern Ward County flowed when completed. However, owing to pumpage from the aquifer, many of the wells have ceased to flow or the discharge has been curtailed considerably.

From the data available, water levels in the Rustler have shown an overall decline since the initiation of heavy pumpage from the aquifer. However, local areas have maintained relatively stable water-level conditions and in a few wells rises in water levels have been recorded. Water-level declines in Rustler wells ranged up to 133 feet in Pecos County for the period January 1958 to January 1960. Between January 1959 and January 1960 recorded water-level declines in Reeves County ranged from 57 to 91 feet.

Water-Bearing Characteristics

Although the hydraulic properties of the Rustler Formation are not well known, the large declines of the piezometric surface indicate that the transmissibility and storage coefficients for the aquifer as a whole are probably small. However, locally the coefficient of transmissibility can be relatively high.

Chemical Quality

The water in the Rustler Formation is generally higher in mineral concentration in the northern part of Region I. Rustler water is unsuitable for human consumption but is used for irrigation and livestock in some parts of eastern Reeves County and central and northern Pecos County. In these areas the mineralization of the water differs from place to place, ranging from a little less than 2,000 to about 6,000 ppm dissolved solids. The common characteristics of the Rustler water are low bicarbonate (generally less than 200 ppm, although higher in places), a high sulfate to chloride ratio, and a high calcium content (500 to 600 ppm). Normally the water has about 2,000 ppm sulfate and not more than 200 to 300 ppm chloride. In many analyses the chloride concentration is less than 100 ppm. Hydrogen sulfide is commonly present in the water but dissipates soon after being exposed to the atmosphere.

Selected analyses of water from the Rustler aquifer in Region I are given in Table M2.

Utilization and Development

Water from the Rustler aquifer is used for irrigation, industrial, and livestock purposes. Table M3 includes the estimated annual pumpage from wells tapping the Rustler of each subdivision in Region I. Pumpage from wells supplying domestic and livestock requirements were not included in the table because of their small total withdrawals. The annual withdrawal from the Rustler aquifer is about 9,000 acre-feet. Irrigation accounts for about 8,000 acre-feet and industrial uses amount to about 1,000 acre-feet annually.

Ground Water Available for Development

Data are not available at the present time to determine the amount of water available from storage or the amount that can be produced perennially from the Rustler aquifer.

From data available, it seems probable that moderate to small additional supplies of ground water can be developed from the aquifer in Region I. The hydrologic characteristics of the Rustler probably vary considerably throughout the region. Where vugular porosity is present, wells of large yield can perhaps be completed in the aquifer. However, large withdrawals are likely to result in large declines in water levels.

Capitan Reef Complex and Associated Limestones Aquifer

Geologic Characteristics

The Capitan Reef complex and associated limestones are Permian in age. The aquifer is composed of the Capitan Limestone, the reef limestone (Goat Seep) underlying the Capitan, and the back-reef deposited San Andres Limestone and Whitehorse Group, which are known to yield water of usable quality in Region I (Table M1). The Whitehorse Group consists of alternating beds of dolomite, limestone, sand, shale, and evaporites; however, the dolomite and limestone are predominate. Lithologically, the aquifer consists of limestone and dolomite strata deposited as reef, fore-reef, and back-reef facies.

The reef facies of the aquifer in Region I occurs in a belt about 5 or 6 miles wide extending in a south-southeast direction through western Winkler, central Ward, western Pecos, and northern Brewster Counties. The back-reef limestones of the aquifer occur east of the reef belt. The equivalent Delaware Mountain Group that was deposited west of the reef belt in the Delaware basin yields only small amounts of usable-quality water to wells in Culberson County.

The Capitan Reef complex and associated limestones crop out in the Guadalupe Mountains of Texas and New Mexico and the Sacramento Mountains in New Mexico. Also, equivalent stratigraphic units crop out in a small area of the Glass Mountains in southern Pecos and northern Brewster Counties of Region I. The aquifer occurs at depths up to 4,000 feet in Region I and attains a thickness of up to 3,500 feet.

Occurrence and Movement of Ground Water

Ground water in the Capitan Reef complex and associated limestones aquifer occurs under artesian conditions and data available indicate that most wells tapping the aquifer flowed when drilled.

Movement of ground water in the Capitan Reef complex and associated limestones aquifer in Texas is probably primarily southeastward along the axis of the reef. Some ground water probably moves through equivalent formations, which crop out in the Glass Mountains, northward into the aquifer.

Recharge and Discharge

The Capitan Reef complex and associated limestones aquifer is recharged primarily by precipitation which occurs on the outcrop area in the Guadalupe and Sacramento Mountains and by precipitation falling on the equivalent formations that crop out in the Glass Mountains.

Ground water from the aquifer is probably discharged naturally in Region I by slowly percolating into the overlying formations. Most discharge from the aquifer in recent years has been from wells tapping the aquifer to supply industrial and irrigation requirements. Also large quantities of water are produced from the aquifer with oil production.

Water Levels

Most wells drawing from the Capitan Reef complex and associated limestones aquifer flowed when drilled. However, due to uncontrolled discharge and heavy development in local areas the static pressures have declined considerably.

Water-Bearing Characteristics

The limited information available suggests that wells producing water from the Capitan Reef complex and associated limestones generally have relatively low specific capacities; however, high yields can be obtained because of the large amount of drawdown available.

Some wells which penetrate the aquifer in Ward, Winkler, and northern Pecos Counties flow at rates ranging from 300 to over 1,000 gpm.

Chemical Quality

Water from the Capitan Reef complex and associated limestones aquifer is not suitable for human consumption. The water generally contains fairly high concentrations of dissolved solids, sulfate, and chloride. Concentrations of dissolved solids range from about 3,000 to 6,000 ppm, sulfate ranges from about 1,000 to 2,600 ppm, and chloride ranges from about 500 to 2,600 ppm. The water contains hydrogen sulfide which usually escapes into the air, and oxidation of the gas results in the precipitation of elemental sulphur from the water in open ditches. Water from the aquifer is very corrosive; after a few years the casings usually are so weakened that they cannot withstand the shut-in pressure of the water.

Utilization and Development

Water from the Capitan Reef complex and associated limestones is used primarily for irrigation and industrial purposes. Table M3 gives the estimated annual pumpage for Region I to be about 12,600 acre-feet.

Irrigation from the aquifer in Pecos County averaged 7,600 acre-feet annually. The water is applied on very permeable soil, and only salt-tolerant crops, principally cotton, are grown. In some areas water from the aquifer has been mixed with water from younger rocks for irrigation purposes.

Pumpage for industrial purposes in Ward and Winkler Counties is used primarily for waterflooding. The average pumpage for this purpose was approximately 5,000 acre-feet per year.

The Capitan Reef complex and associated limestones aquifer is capable of providing considerable quantities of water in Region I. Because the aquifer lies at considerable depth below the surface, the cost of completing wells will probably limit its development. The aquifer provides a good source of water for waterflooding operations.

Ground Water Available for Development

At the present time, sufficient data are not available to make a valid estimate of the quantity of water available from the aquifer. A detailed study of the Capitan Reef complex and its associated limestones will be necessary before the order of magnitude of ground water available for development can be established.

Other Aquifers

Volcanic Rocks

In the southern part of Region I, volcanic rocks of Tertiary age unconformably overlie Upper Cretaceous strata (Plate M1). A thin veneer of Cenozoic alluvium overlies much of the volcanic strata.

Wells drawing from the volcanic rocks are confined primarily to Jeff Davis and Brewster Counties within the region. However, springs in southwestern Reeves and southwestern Pecos Counties are reported to issue from volcanic strata.

In the Alpine area of Brewster, Jeff Davis, and Presidio Counties, water for municipal, domestic, and livestock use is obtained from wells tapping the volcanic rocks. Most of the wells yield only small quantities of water. The municipal water supply for the city of Alpine is obtained primarily from volcanic strata. The well yields in most places are less than 75 gpm, and some wells produce less than 50 gpm. The maximum yield was reported to be 200 gpm with considerable drawdown. Coefficients of transmissibility reported on two city of Alpine wells were 5,100 and 8,200 gpd/ft (Littleton and Audsley, 1957, p. 21).

The estimated annual withdrawal from volcanic rocks in Region I is about 1,000 acre-feet with all of the pumpage for municipal purposes (Table M3). Water demands of Alpine account for 964 acre-feet annually. Although domestic and livestock wells penetrating the volcanic strata are numerous, the total pumpage from these sources is probably less than 1 acre-foot per year.

The chemical quality of ground water from the volcanic strata, in general, is excellent for all purposes. The water characteristically contains rather low concentrations of dissolved solids, ranges widely in hardness, and contains beneficial to somewhat undesirable amounts of fluoride.

According to Littleton and Audsley (1957, p. 34), future development of additional ground-water supplies from volcanic rocks appears most favorable in the immediate vicinity of Alpine and an area about 2 to 5 miles northwest of Alpine at the mouth of Sunny Glen Canyon.

Region II

The Edwards-Trinity is the only primary aquifer in Region II. However, in the northwestern part of the region about 7,400 acre-feet of water is pumped annually from the Cenozoic alluvium aquifer. The Cenozoic alluvium which occurs in Region II is a continuation of the alluvium aquifer in Region I and is included in the discussion of the aquifer in Region I. A breakdown of the pumpage from the alluvium in Region II is given in Table M5. No secondary aquifers are present in the region. The only other aquifer in Region II is the Austin Group. It occurs in parts of Kinney and Maverick Counties in the southeastern part of the region.

Primary Aquifers

Edwards-Trinity Aquifer

The Edwards-Trinity aquifer in Region II of the middle Rio Grande Basin includes the water-bearing Cretaceous strata of the Washita, Fredericksburg, and Trinity Groups. The aquifer is comprised of the following formations: the Georgetown Limestone, Edwards Limestone, Comanche Peak Limestone, "Trinity sand," and Glen Rose Limestone (Table M1). The formations that comprise the aquifer extend throughout the region except in a few small isolated areas where pre-Cretaceous rocks are exposed at the surface. Water of usable quality in these formations extends downdip in Region II as far as southern Kinney County (Plate M10). The approximate southern extent of known usable water marks the boundary of the aquifer in Region II.

In the northern part of the region sands of Triassic age underlie the "Trinity sand." In this area the Triassic sands are considered as part of the Edwards-Trinity aquifer because of their hydraulic connection with the overlying Cretaceous strata.

Geologic Characteristics

The Georgetown Limestone is the lowermost formation of the Washita Group. The formation crops out extensively in the region, and commonly is found capping steep escarpments. In Region II, the Georgetown Formation is overlain by the Del Rio Clay or Buda Limestone and is underlain by the Edwards Limestone. The Georgetown Formation is composed of medium- to thick-bedded limestone interbedded with marl and clay. The limestone beds commonly exhibit well developed joint and fracture patterns and associated solution cavities. The Georgetown Limestone ranges in thickness from 0 to more than 400 feet.

The Edwards Limestone generally crops out in the steep-wall canyons and is overlain by the Georgetown Limestone and underlain by the Comanche Peak Limestone. The Edwards Limestone consists of thick to massive-bedded limestone and dolomitic limestone containing many fractures and solution openings. The thickness of the formation ranges up to about 800 feet in the subsurface.

In the canyons of the lower Pecos and Devils Rivers, the physical characteristics of the Georgetown and Edwards Limestones are remarkably similar. This similarity in lithology prompted Udden (1907, p. 56-60) to apply the name Devils River Limestone to this uniform sequence of strata. This stratigraphic distinction is undoubtedly valid in this area; however, the use of this terminology is not considered essential in accomplishing the purpose of this report.

The Comanche Peak Limestone consists of thin- to medium-bedded nodular limestone interstratified with marl. It lies beneath the Edwards Limestone and overlies the "Trinity sand" or Glen Rose Limestone. The Comanche Peak Limestone ranges in thickness from about 15 feet in the northern part of the region up to about 65 feet in the southern part of the region.

The "Trinity sand" in this region is probably equivalent at least in part to the Paluxy Formation. Lithologically the "Trinity sand" consists of fine- to coarse-grained quartz sand, often cross-bedded and cemented with calcite. The formation underlies the Edwards Limestone and Comanche Peak Limestone and overlies older Cretaceous, Triassic, or Permian strata in this region. The "Trinity sand" ranges in thickness from 0 to about 150 feet and pinches out downdip from a line extending approximately from grid 55-12 in Schleicher County southwest through southern Crockett County.

The Glen Rose Limestone ranges from 0 to more than 900 feet in thickness. It occurs only in the southern part of Region II.

All of the Cretaceous strata in Region II dip gently to the southeast at an angle slightly greater than the general slope of the land surface (Plate M4).

Occurrence and Movement of Ground Water

Ground water in the Edwards-Trinity aquifer generally occurs under water-table conditions. Artesian conditions are reported in western Kinney County and other local areas.

Regionally, water in the Edwards-Trinity aquifer moves from north to south (Plate M11). In areas adjacent to the Pecos and Devils Rivers, ground water moves toward these drainage systems. It must be emphasized that the ground-water movement is in part controlled by the complex system of solution channels and fractures in the limestone of the aquifer. Therefore, the direction of movement locally may vary greatly from the overall regional movement. The hydraulic gradient ranges from about 5 feet per mile in northern Crockett County up to approximately 100 feet per mile in southeastern Val Verde County.

Perched water is known to occur in parts of northeastern Crockett and northern Val Verde Counties, probably due to thin widespread marl beds which retard downward percolation of water to the aquifer. It is likely that similar perched water occurs in other areas of Region II.

Recharge and Discharge

Recharge of the Edwards-Trinity aquifer in Region II is derived from precipitation and runoff. The largest amount of recharge is probably from the direct infiltration of precipitation which falls on the high limestone-capped plateaus. These plateaus are characterized by numerous fractures and solution cavities in the limestone bedrock and are covered by thin soil.

Ground water is discharged naturally from the Edwards-Trinity aquifer by springs, seeps, and evapotranspiration along drainage courses. Pumping from wells constitutes the artificial discharge from the Edwards-Trinity aquifer.

Water Levels

Water levels in wells screening the Edwards-Trinity aquifer range from above the land surface to more than 600 feet. In the northwestern part of the region depths to the water levels are commonly more than 350 feet. Water levels of more than 600 feet below the land surface have been measured near the Val Verde-Terrell County line. Fluctuations in water levels are small and no regional changes have been noted. Wide variations in water levels in wells may occur where perched water exists.

Water-Bearing Characteristics

The only data available concerning the hydraulic properties of the Edwards-Trinity aquifer in Region II were obtained from a "Trinity sand" aquifer test conducted in the city of McCamey well field, in eastern Pecos County. Analysis of the recovery of the water level in the pumped well, by the Theis recovery formula (Theis, 1935, p. 522), gave a coefficient of transmissibility of 3,700 gpd/ft. Changes in water level in the observation well caused by the pumping well, analyzed by the Theis non-equilibrium method (Theis, 1935, p. 520-522), gave a coefficient of transmissibility of 6,100 gpd/ft and a coefficient of storage of 0.000016 (Armstrong and McMillion, 1961). Although no data are available in other parts of Region II, the transmission values of the "Trinity sand" probably decrease southeastward because the unit thins downdip.

The hydraulic characteristics of the limestones in the Edwards-Trinity aquifer probably vary considerably throughout the region because of the irregular distribution of fractures and solution cavities in these formations. The hydraulic characteristics of the limestones are best where the fractures and solution cavities are well developed and areally extensive.

Chemical Quality

The quality of ground water in the Edwards-Trinity aquifer is generally good in Region II. Table M4 lists selected chemical analyses from Cretaceous wells in the region.

Dissolved-solids concentrations range from less than 200 to 2,900 ppm. Generally higher concentrations of dissolved solids are found west of Howards Creek, in western Crockett and northwestern Val Verde Counties. (The location

Table M4.--Representative chemical analyses of water from the Edwards-Trinity aquifer in Region II, middle Rio Grande Basin

(Analyses expressed in parts per million except specific conductance and pH.)

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)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
44-41-902	Rankin #12	--	3- 1-54	58	3.4	152	72	98 --	336	469	75	2.8	24	1,206	675	--	7.5
44-49-301	Upton County	--	6-29-60	--	.22	90	64	71 --	240	335	116	2.4	24	852	490	1,420	7.8
44-50-501	University Lands	375±	8-29-61	12	--	115	73	115	285	484	64	1.5	6.6	1,010	587	1,440	6.5
44-59-801	Ted Harris	385	12- -58	--	--	176	166	144 --	183	781	159	--	--	1,627	54	--	--
44-61-601	Phillips Petroleum	450	10-26-60	18	--	63	30	58	281	75	65	--	6.7	454	280	769	7.4
44-63-701	Buck Owens	130	10-25-60	20	--	62	9.5	22	222	18	24	--	10	274	194	459	7.2
45-47-501	Rosa H. Barnett	547	50	--	--	230	77	231 --	252	1,050	90	--	--	1,930	--	--	7.5
45-63-8	T. C. Fortson	123	7-29-47	26	--	254	133	569	302	876	890	--	4.0	2,900	1,180	4,550	--
45-64-601	Burk Royalty Oil Co.	100	7-23-60	12	--	206	126	179	242	880	192	.8	11	1,720	--	--	--
53-14-7	Lloyd Ligon	565	5- 3-47	--	--	70	14	7.2	219	28	25	--	5.0	280	232	473	--
53-22-7	Claude Owen	450	10-20-58	17	--	94	25	99	252	164	122	.8	2.8	668	338	1,070	7.6
53-24-1	Arthur Harral	560	5- 5-47	--	--	73	21	13	236	62	26	--	2.0	317	268	569	--
53-31-601	David Mitchell	250	11-16-60	--	--	--	--	--	259	225	166	--	--	798	--	1,330	--
54-04-301	Charles Black	400	9-21-60	6	--	96	109	469	306	596	588	2.3	1.0	2,020	688	3,200	7.3
54-07-901	University Lands	400>	7-15-60	17	--	55	20	21	246	21	25	.8	6.5	287	219	485	7.0
54-10-201	Ambassador Oil Co.	--	10-26-60	13	--	72	29	38	264	92	48	--	1.2	423	298	714	7.3
54-11-301	Mr. Fikes	275	10-15-60	12	--	90	52	89	263	282	85	1.5	.0	740	438	1,150	7.0
54-13-101	Humble Oil Co.	490	do	11	8.3	82	54	299	278	193	452	2.0	7.0	1,240	426	2,150	7.0
54-14-201	Hunt Oil Co.	--	--	--	--	--	--	--	--	--	--	--	--	600	--	--	--
54-18-5	Mrs. H. C. Noelke, Jr.	180	6- 7-46	--	--	70	16	13	254	26	18	--	9.1	277	240	--	--
54-23-101	Crockett Co. WC&ID	418	7-22-47	15	.16	72	17	11 5.0	272	16	22	.8	7.8	299	250	50.9	7.7
54-23-901	C. E. Davidson, Jr.	430	7-28-60	18	--	57	31	30	252	27	60	2.0	13	362	270	621	6.9
54-32-201	Sam Schueber	378	10-25-60	11	--	42	19	26	218	15	26	1.2	6.0	253	183	440	7.7
54-33-901	Turk Est.	644	11-18-60	9.8	--	90	32	84	244	186	100	1.7	.0	624	356	1,020	7.0
54-35-202	Mrs. Ray Dunlap	93	9-14-60	23	--	88	18	38	275	42	68	--	13	425	294	722	6.9
54-38-201	Paul Holcomb	570	7-26-60	18	--	49	30	9.4	238	20	20	3.0	18	284	246	499	7.0

Table M4.--Representative chemical analyses of water from the Edwards-Trinity aquifer in Region II, middle Rio Grande Basin--Continued

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium and potassium (Na + K)	Bicar-bonate (HCO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Dis-solved solids	Total hardness as $CaCO_3$	Specific conduct-ance (micromhos at 25°C.)	pH
54-38-601	V. I. Pierce	400	7-27-60	--	--	--	--	--	256	632	538	--	--	2,275	260	3,250	8.5
54-46-502	"Cap" West	360	10- 5-60	16	--	52	26	18	277	12	20	--	9.6	290	236	497	7.0
54-51-6	J. B. Malone	Spring	5-17-39	--	--	--	--	--	195	13	17	--	>20	205	--	--	--
54-52-5	H. J. Y. Mills	69	5-10-39	--	--	83	14	14	256	25	34	0.3	>20	308	263	--	--
54-55-5	Masey West	130	5-31-39	--	--	48	20	7	220	10	10	--	>20	218	202	--	--
54-56-401	B. E. Wilson	220	do	--	--	37	15	14	177	10	15	.4	>20	188	154	--	--
54-60-801	J. Cox	500	4-19-39	--	--	89	25	50	250	85	100	--	>20	472	325	--	--
54-61-8	Murrah Ranch	--	5- 4-39	--	--	56	20	16	232	16	35	--	>20	257	222	--	--
54-62-7	Tom Everett	400	5- 3-39	--	--	82	30	36	317	26	84	--	>20	414	328	--	--
54-63-8	C. B. Hudspeth	Spring	6-14-39	--	--	72	11	10	275	10	10	.3	>20	248	227	--	--
54-64-2	V. Cauthorn	325	6-15-39	--	--	37	14	13	189	> 10	10	.3	>20	175	149	--	--
55-02-801	Henry Moore	410	7-13-60	14	--	47	23	18	222	26	22	2.2	7.0	268	212	466	7.3
55-10-601	Parker Foods Estate	520	9- 9-60	11	--	50	31	401	332	364	332	--	5.8	1,360	252	2,190	7.2
55-11-601	--	400	5- 5-52	18	--	6	18	18	177	41	24	--	7.7	275	189	433	7.9
55-18-101	R. D. Mayer	220	7-13-60	17	--	63	16	17	248	18	21	.6	10	285	223	449	7.1
55-26-101	do	164	7- 1-60	16	--	71	19	13	283	14	18	.6	11	302	255	520	6.9
55-27-201	El Paso Nat. Gas Co.	485	5-24-60	12	--	47	22	15	248	12	14	.4	5.3	250	208	444	6.9
55-44-7	L. B. Wardlaw	263	4-20-55	15	--	70	15	12	260	6.7	20	.8	14	306	236	501	7.9
55-58-5	F. H. Whitehead	360	8-16-39	--	--	30	26	22	183	16	45	--	>20	229	181	--	--
70-02-2	D. Harrison	266	8-10-39	--	--	--	--	--	232	> 10	10	--	>20	210	--	--	--
Do.	do	230	do	--	--	53	25	> 5	256	> 10	9	.5	>20	217	235	--	--
70-03-3	Whitehead & Wardlaw	370	7-26-54	15	--	63	16	7.8 --	254	6.4	13	--	8.2	266	223	456	7.5
70-09-1	E. K. Fawcett	Spring	6-20-39	--	--	73	14	4	268	> 10	13	.4	>20	244	239	--	--
70-10-501	Robert Miers	320	3-14-61	--	--	--	--	--	217	--	12	--	--	247	197	412	7.2
70-12-9	E. T. Rucker	380	2-20-39	--	--	180	8	13	232	15	41	--	86	386	305	--	--
70-18-4	-- Markwood	600	9- 5-39	--	--	54	12	11	232	> 10	9	.2	>20	204	182	--	--
70-20-4	J. H. Harding	320	4-15-54	13	--	57	13	5.0 .6	222	5.1	10	.2	7.8	233	196	405	7.8

Table M4.--Representative chemical analyses of water from the Edwards-Trinity aquifer in Region II, middle Rio Grande Basin--Continued

Well	Owner	Depth of well (ft.)	Date of collection	Silica (SiO_2)	Iron (Fe)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium and potassium (Na + K)	Bicar-bonate (HCO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Dis-solved solids	Total hardness as $CaCO_3$	Specific conduct-ance (micromhos at 25°C.)	pH
70-25-8	G. C. Pool	220	7-26-39	--	--	104	24	9	287	101	24	2.5	>20	406	360	--	--
70-33-7	W. S. Stephenson	520	4- 6-39	--	--	630	27	40	183	1,531	19	--	>20	2,337	1,686	--	--
70-33-9	City of Del Rio	Spring	6- 4-56	13	0.01	74	6.5	9.3	251	5.5	10	.2	6.9	256	211	434	7.3
70-35-1	B. Lewis	19	4- 3-39	--	--	--	--	--	299	25	30	--	>20	327	--	--	--
70-35-5	R. A. Weathersby	350	4-20-38	--	--	63	22	2.2	254	26	12	--	.3	251	248	--	--
70-35-8	Cupples	--	1-27-48	--	--	208	32	12	236	448	12	--	.0	906	650	1,160	--
70-37-2	J. D. Harwood	--	4-13-38	--	--	86	2.2	11	254	11	13	0	11	259	224	--	--
70-43-7	F. W. Herbst	17	7-31-39	--	--	68	7	21	207	12	11	--	60	281	200	--	--
70-44-2	J. F. Beidler	756	1-27-48	--	--	64	20	44	262	98	15	--	.0	406	242	627	--
70-45-5	U. S. Army	Spring	11- 2-45	11	--	66	6.8	24	255	6.7	14	.6	4.8	262	192	404	--
70-52-2	Gaebler Bros.	1,605	4-15-38	--	--	676	67	>5	230	1,680	10	2.3	0	2,550	--	--	--
71-11-2	Fermin Aguirre	800	4-18-39	--	--	80	20	2	262	41	20	--	>20	292	282	--	--
71-16-4	Tom Bright	550	8-29-39	--	--	64	6	4	214	> 10	11	.1	>20	191	183	--	--
71-22-5	Mrs. E. P. Bell	Spring	4-20-39	--	--	79	10	29	226	15	73	--	>20	317	241	--	--
71-23-8	Mrs. F. E. Bell	Spring	5-25-39	--	--	26	7	76	256	14	25	.6	>20	274	95	--	--
71-24-6	R. Gillis	Spring	7-18-39	--	--	65	12	8	244	> 10	11	.2	>20	231	213	--	--
71-31-7	J. F. Grant	Spring	4-12-39	--	--	73	12	2	244	22	10	.4	>20	240	233	--	--
71-32-2	R. Gillis	--	7-24-39	--	--	108	15	20	293	48	59	--	>20	394	329	--	--
71-40-2	F. Cochran	650	8- 1-39	--	--	74	10	11	262	11	16	.4	>20	251	226	--	--

of Howards Creek is shown on Plate M2.) East of Howards Creek the dissolved-solids concentrations normally range from about 200 to 400 ppm with higher concentrations occurring locally (Plate M10).

Utilization and Development

Annual withdrawals by wells from the Edwards-Trinity aquifer in Region II total approximately 22,000 acre-feet. Table M5 shows the estimated annual pumpage from the Edwards-Trinity aquifer in Region II for each major drainage subdivision.

Irrigation pumpage accounts for about 14,000 acre-feet or 64 percent of the total annual withdrawals from the aquifer. Irrigation development is concentrated primarily in major drainage subdivisions 53, 55, 60, and 64 (Plate M2). The combined annual pumpage for irrigation in these four subdivisions is about 12,000 acre-feet, which is 85 percent of the total pumpage for irrigation from the aquifer in Region II.

In the region the Edwards-Trinity aquifer supplies the requirements of many cities and towns including Brackettville, Del Rio, McCamey, Ozona, Rankin, and Sonora. Annual withdrawals for municipal needs are about 7,700 acre-feet, accounting for 35 percent of the total pumpage for all purposes (Table M5). Del Rio and Brackettville obtain their water supplies from San Felipe and Las Moras Springs, respectively. Withdrawals from San Felipe Springs account for approximately 65 percent of the total Edwards-Trinity municipal pumpage in Region II (Table M5).

Approximately 1 percent, or 160 acre-feet, of the total annual pumpage from the Edwards-Trinity aquifer in Region II is withdrawn for industrial purposes (Table M5). Most of the industrial pumpage from the aquifer is used by the petroleum industry.

Numerous domestic and livestock wells in the region produce water from the Edwards-Trinity aquifer. Pumpage for these purposes is probably small in comparison to total withdrawals from the aquifer.

Well construction in the Edwards-Trinity aquifer depends largely upon the part of the aquifer in which the well is completed. Wells completed in the limestone part of the aquifer are commonly uncased except for a few feet of surface casing. Wells completed in the "Trinity sand" normally are cased throughout or at least in the sand section.

Ground Water Available for Development

The determination of ground water available for development from the Edwards-Trinity aquifer is based on the average annual discharge from seeps and springs into the drainage system of the region. On the basis of flow measurements of the Pecos River, Rio Grande, Devils River and their tributaries it is estimated that on the order of 600,000 to 700,000 acre-feet of water annually is discharged naturally from the aquifer. The amount of discharge by seeps and springs that can be intercepted by well development is probably on the order of 400,000 acre-feet perennially. Before this quantity of water can be obtained extensive test drilling will probably be required to locate the areas where fractures and solution cavities are best developed in the aquifer. The largest

Table M5.--Annual ground-water pumpage from aquifers in Region II, middle Rio Grande Basin [1]

(Pumpage expressed in acre-feet [2])

Subdivision	53	55	57	59	60	61	62	63	64	65	66	67	Total
Cenozoic Alluvium Aquifer													
Municipal	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial	--	--	--	--	--	--	--	--	--	--	--	--	--
Irrigation	5,476	1,326	--	408	--	--	--	--	--	--	--	167	7,377
Total	5,476	1,326	--	408	--	--	--	--	--	--	--	167	7,377
Edwards-Trinity Aquifer													
Municipal	811	--	--	--	3	656	944	2	--	39	5,040	175	7,670
Industrial	24	--	136	--	--	2	--	--	--	--	--	--	162
Irrigation	4,612	1,530	--	204	2,941	774	--	--	2,844	--	668	668	14,241
Total	5,447	1,530	136	204	2,944	1,432	944	2	2,844	39	5,708	843	22,073
Other Aquifers [3]													
Municipal	--	--	--	--	--	--	--	--	--	--	--	--	--
Industrial	--	--	--	--	--	--	--	--	--	--	--	--	--
Irrigation	--	--	--	--	--	--	--	--	--	--	167	2,505	2,672
Total	--	--	--	--	--	--	--	--	--	--	167	2,505	2,672

See footnotes at end of table.

Table M5.--Annual ground-water pumpage from aquifers in Region II, middle Rio Grande Basin 1/--Continued

Subdivision	53	55	57	59	60	61	62	63	64	65	66	67	Total
Summary of Pumpage in Region II													
Municipal	811	--	--	--	3	656	944	2	--	39	5,040	175	7,670
Industrial	24	--	136	--	--	2	--	--	--	--	--	--	162
Irrigation	10,088	2,856	--	612	2,941	774	--	--	2,844	--	835	3,340	24,290
Total	10,923	2,856	136	612	2,944	1,432	944	2	2,844	39	5,875	3,515	32,122

1/ Municipal and industrial pumpage reported for 1960; Irrigation pumpage based on 1958 data.
2/ Figures are approximate, because some of the pumpage is estimated, and should not be considered accurate to more than two significant figures.
3/ Includes the Austin Group.

yields can be obtained from the major springs and other areas where cavernous conditions exist. However, large-scale development of the aquifer would significantly reduce the base flow of the streams in the region.

Other Aquifers

Austin Group

The Austin Group crops out in a broad northeast-trending belt across southern Kinney and northwestern Maverick Counties in the southeastern part of Region II (Plate M2). The Austin Group consists of a white to gray, massive, marly limestone, and ranges in thickness from 0 to 1,100 feet in the region.

Ground water in the Austin Group occurs under water-table conditions in numerous fractures and solution cavities which vary greatly in size and extent. Wells producing from the Austin Group in Region II are located in Kinney County (Plate M2). In this area 17 wells, drawing all or part of their water from the Austin, produce sufficient quantities for irrigation. One well located southwest of Brackettville discharges 2,000 gpm with a specific capacity of 0.71 gpm per foot of drawdown. Two wells in the same locality discharge 1,200 and 1,250 gpm with specific capacities of 92 and 96 gpm per foot drawdown, respectively (Bennett and Sayre, 1962, p. 44).

Bennett and Sayre (1962, p. 97) reported that dissolved solids in 19 samples of water from the Austin in Kinney County ranged from 351 to 956 ppm and averaged 498 ppm. Hardness in 11 samples ranged from 282 to 608 ppm and averaged 416 ppm.

Irrigation wells in Region II annually produce on the order of 2,700 acre-feet of water from the Austin Group (Table M5).

The Austin Group is quite variable in its water-bearing characteristics, but it is believed that water suitable for domestic and livestock use may be obtained in sufficient quantities on and near the outcrop. Larger quantities may be available locally.

Region III

The aquifers in Region III are of limited extent, produce relatively small quantities of water, and are believed to have limited potential within the middle Rio Grande Basin. Consequently, all of the aquifers of Region III are classified as "other aquifers."

Other Aquifers

Austin Group

The Austin Group crops out in a northeast-trending belt across southern Kinney and northwestern Maverick Counties of Region II (Plate M2). Except for a small segment of outcrop in the extreme northern part of the region, the Austin Group occurs in subsurface throughout Region III. As described previously, the Austin consists of a white to gray, massive, marly limestone which ranges up to 1,200 feet in thickness.

The water in the Austin apparently occurs in fractures and solution cavities which vary greatly in size and number from place to place. The water-bearing character of the aquifer is not known but is probably quite variable in Region III. The limited data available suggest that the Austin Group is capable of supplying water in sufficient quantity and acceptable quality for domestic and livestock purposes on and near the outcrop in the region.

Navarro and Taylor Groups

The Navarro and Taylor Groups, consisting of the Upson Clay, San Miguel, Olmos, and Escondido Formations, crop out in a rather extensive area in Maverick County and a small area in Kinney County (Plate M3). The Upson Clay overlies the Austin Chalk and consists of dark greenish-gray shale and shaly sand. The San Miguel Formation overlies the Upson Clay and consists of dark fossiliferous sandy and shaly limestone with interbedded clay. The Olmos Formation consists primarily of clay and shale with some thin seams of sand and coal. The Escondido Formation, the uppermost formation of the Navarro Group, consists of beds of clay, sandy clay, sandstone, and limestone. The thickness of the combined Navarro and Taylor Groups ranges from zero at the updip limit of the outcrop to 2,200 feet in the subsurface.

The water-bearing characteristics of the Navarro and Taylor Groups in Region III are not well known. In general, the Navarro and Taylor Groups are a poor source of ground water but small supplies suitable for domestic and livestock use may be obtained locally on and near the outcrop. The Navarro and Taylor Groups are limited in their development potential.

Carrizo Formation and Wilcox Group

The Carrizo Formation and Wilcox Group crop out in a north-trending belt across southeastern Maverick, northwestern Webb, and western Dimmit counties in Region III (Plate M3). The Wilcox Group in this region consists chiefly of thin-bedded sandstone and shaly sandstone with interbedded shale and clay. Minor amounts of lignite occur locally within the Wilcox in Region III. The thickness of the Wilcox Group in Region III ranges from zero at the updip limit of the outcrop to about 850 feet in the subsurface. The Carrizo Formation overlies the Wilcox Group and consists predominately of fine- to medium-grained massive sand. Thin shale streaks occur within the sand but they are of limited extent and make up only a minor part of the formation. The Carrizo Formation in Region III is about 250 feet thick in the subsurface. The Carrizo Formation and Wilcox Group dip generally eastward at about 60 feet per mile.

The sands of the Wilcox Group are capable of yielding rather highly mineralized water in sufficient quantities for domestic and livestock purposes on or near the outcrop. The development potential of these sands is believed to be limited.

Only domestic and livestock wells are presently developed in the Carrizo Formation in Region III, and its total potential in the region is not known. However, in the Winter Garden district of Dimmit County in the adjacent Nueces River Basin the Carrizo yields large quantities of water for irrigation purposes. The mineral content of water in sands of the Carrizo Formation generally increases downdip. However, water suitable for most purposes can probably be obtained from the Carrizo Formation on the outcrop and within 5 to 10 miles downdip from the outcrop.

Cook Mountain Formation

The Cook Mountain Formation crops out in a north-trending belt, 8 to 12 miles in width, across the southeastern part of Region III in Webb County (Plate M3). The formation in Region III consists of sand, sandstone, clay, marl, and thin limestone. The beds of sand and sandstone are fine- to medium-grained and constitute more than 50 percent of the formation. The thickness of the Cook Mountain Formation ranges up to more than 1,100 feet in the subsurface. The dip of the formation in Region III is about 80 feet per mile.

The Cook Mountain Formation is capable of yielding water in sufficient quantity for domestic and livestock purposes as well as small industrial and municipal supplies. The quality of the water, however, is quite variable and mineral concentrations are generally high. Presently, three industrial wells and one public-supply well screen the Cook Mountain Formation in the vicinity of Laredo. It is reported that the total pumpage from these major wells is on the order of 40 acre-feet per year.

Summary of Ground-Water Pumpage and Availability

On the order of 575,000 acre-feet of ground water is presently being pumped annually from the aquifers of the middle Rio Grande Basin for irrigation, municipal, and industrial purposes. Most of this pumpage, about 543,000 acre-feet, occurs in Region I where it is used primarily for irrigation. About 32,000 acre-feet is pumped from the aquifers in Region II where it is also used primarily for irrigation. Only about 40 acre-feet is pumped in Region III for all purposes. Of the total pumpage in the middle Rio Grande Basin, approximately 93 percent is used for irrigation, 4 percent for industrial purposes, and 3 percent for municipal use. Pumpage from the aquifers of the middle Rio Grande Basin is shown in Table M6.

On the order of 50 to 60 million acre-feet is available from storage in the Cenozoic alluvium of Region I. This estimate is based on a saturated volume of 947 million acre-feet in the alluvium, a specific yield of about 10 percent, and on the assumption that not more than two-thirds of the total volume of the water available in storage can be economically recovered.

The perennial quantity of water estimated to be available from the Edwards-Trinity aquifer in Region II is on the order of 400,000 acre-feet. Some additional water is available for development from the aquifer in Region I; however, data are insufficient to estimate the quantity available.

It is believed that additional quantities of water could be developed from the three secondary aquifers--Santa Rosa, Rustler, and Capitan Reef complex and associated limestones--but the quantity available is not known. Additional small quantities may be developed in the several "other" aquifers but their potential is believed to be small.

Table M6.--Annual ground-water pumpage from aquifers in the middle Rio Grande Basin 1/

(Pumpage expressed in acre-feet 2/)

Aquifer 3/	Municipal	Industrial	Irrigation	Total
REGION I				
Cenozoic Alluvium (P)	3,360	14,259	360,654	378,273
Edwards-Trinity (P)	1,411	987	117,107	119,505
Santa Rosa (S)	4,727	2,039	16,050	22,816
Rustler (S)	0	1,012	8,021	9,033
Capitan reef complex and associated limestones (S)	0	5,000	7,600	12,600
Others 4/	969	0	0	969
Subtotal	10,467	23,297	509,432	543,196
REGION II				
Cenozoic Alluvium (P)	0	0	7,377	7,377
Edwards-Trinity (P)	7,670	162	14,241	22,073
Others 5/	0	0	2,672	2,672
Subtotal	7,670	162	24,290	32,122
REGION III				
Others 6/	0	38	0	38
Subtotal	0	38	0	38
TOTAL	18,137	23,497	533,722	575,356

1/ Municipal and industrial pumpage reported for 1960; irrigation pumpage based on 1958 data.

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

3/ "P" indicates primary aquifer; "S" indicates secondary aquifer.

4/ Tertiary volcanic rocks.

5/ Austin Group.

6/ Cook Mountain Formation.

RECOMMENDATIONS FOR FUTURE STUDIES

The present reconnaissance study is general in nature and does not provide sufficient information for detailed water planning or for the planning of individual water supplies.

Detailed ground-water investigations should be undertaken on each of the primary aquifers and secondary aquifers to better define their geologic and hydrologic characteristics and the chemical quality of the water. These detailed aquifer studies should not be limited to the middle Rio Grande Basin but should include the entire aquifer throughout its extent. Studies should be made on some of the "other" aquifers where data suggest additional supplies might be developed.

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

The present water-level observation program in most of the middle Rio Grande Basin is inadequate and should be expanded as soon as possible. Additional observation wells should be located in all the primary and secondary aquifers throughout the middle Rio Grande Basin and especially in areas of intense pumpage in order that the effects of development may be determined.

Continuing studies are needed to collect, compile, and periodically analyze records of pumpage, water levels, and chemical quality. Additional work is needed in the collection of water-use data to improve the quality of data received, and the program should be expanded to include irrigation pumpage. Data from the continuing water-use and water-level programs will provide a means for determining the effects of present and future pumpage.

A continuing observation program of the chemical quality of water in the primary and secondary aquifers should be established to determine changes in the chemical quality that may affect the quantity of fresh ground water available for development. Wells should be sampled periodically throughout the extent of the aquifers with special attention given to areas of heavy withdrawals and in the vicinity of oil-field activities.

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RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE LOWER RIO GRANDE BASIN, TEXAS

By

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

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLES

ILLUSTRATIONS

Figures

TABLE OF CONTENTS (Cont'd.)

Plates
[all plates in pocket]

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE LOWER RIO GRANDE BASIN, TEXAS

ABSTRACT

The lower Rio Grande Basin, located in the extreme southern part of Texas, contains 3,320 square miles and covers all of Zapata County and parts of Webb, Jim Hogg, Starr, Hidalgo, and Cameron Counties.

The alluvium bordering the Rio Grande is the primary aquifer in the basin. The alluvium is tapped by 84 irrigation wells in the basin and the estimated pumpage in 1961 was about 1,100 acre-feet or 1,000,000 gallons per day. The Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, are secondary aquifers. They yield water for livestock watering, domestic use, and for drilling oil wells. Ground water suitable for domestic use or livestock watering is not available over much of the northern and western parts of the lower Rio Grande Basin. The ground-water resources of the lower Rio Grande Basin are small.

Further studies, including the quantity and chemical quality of ground water, pumpage, and the fluctuation of water levels in the alluvium, and the relation between the Rio Grande and the ground-water reservoir in the alluvium, are recommended.

RECONNAISSANCE INVESTIGATION OF THE GROUND-WATER RESOURCES OF THE LOWER RIO GRANDE BASIN, TEXAS

INTRODUCTION

Purpose and Scope

This investigation was made as part of a cooperative project between the Texas Board of Water Engineers (changed to Texas Water Commission, 1962) and the U. S. Geological Survey and entitled, "Reconnaissance ground-water investigations in Texas." The project was initiated to implement a directive of the Legislature in the Texas Water Planning Act of 1957 (Senate Bill 1, First Called Session of the 55th Legislature), which created a Water Planning Division of the Texas Board of Water Engineers and directed that the Board submit a statewide report of the water resources of the State and make recommendations to the Legislature for the maximum development of the water resources. A report, submitted by the Texas Board of Water Engineers in December 1958 in response to this directive, entitled "Texas Water Resources Planning at the End of the Year 1958, A Progress Report to the Fifty-sixth Legislature," states (Texas Board of Water Engineers, 1958, p. 78), "...Initial planning for development of the State's water resources will require that reconnaissance ground-water studies to be made in much of the State because time is not available to complete the recommended detailed investigations. Studies of this type will be chiefly to determine the order of magnitude of the ground-water supplies potentially available from the principal water-bearing formations."

The cooperative project of reconnaissance ground-water investigations was planned by major river basins and the studies of the basins were to have their principal emphasis on the following items (Texas Board of Water Engineers, 1958, p. 78):

1. Inventory of large wells and springs.

2. Compilation of readily available logs of wells and preparation of generalized cross sections and maps showing subsurface lithology.

3. Inventory of major pumpage.

4. Pumping tests of principal water-bearing formations.

5. Measurement of water levels in selected wells.

6. Determination of areas of recharge and discharge.

7. Compilation of existing chemical analyses of water and sampling of selected wells and springs for additional analyses.

8. Correlation and generalized analysis of all data to determine the order of magnitude of supplies available from each major formation in the area and the general effects of future pumping.

9. Preparation of generalized reports on principal ground-water resources of each river basin.

Description of Area

The lower Rio Grande Basin is in the extreme southern part of Texas and is that part of the drainage basin extending from the Gulf of Mexico to about 15 miles south of Laredo in Webb County (Figure L1). The lower Rio Grande Basin lies between latitude 25°50' and 27°37'N and longitude 97°09' and 99°30'W. It contains 3,320 square miles and includes all of Zapata County and parts of Jim Hogg, Webb, Starr, Hidalgo, and Cameron Counties.

The lower Rio Grande Basin was divided into five major subdivisions by the Water Planning Division of the Texas Board of Water Engineers. The locations of the major subdivisions are shown on Plates L1 and L2.

The lower Rio Grande Basin, which is in the West Gulf Coastal Plain, is elongate in shape with the long axis trending in a generally southeasterly direction. The part of the basin in Hidalgo and Cameron Counties is 100 miles long and averages 0.8 mile in width, and is part of the flood plain and delta of the Rio Grande. The rest of the basin in Starr, Zapata, and Webb Counties is about 105 miles long and averages 32 miles in width, and is largely brush covered. The valley of the Rio Grande is a relatively narrow flood plain or narrow terraces generally less than 4 miles in width. The part of the area furthest from the Rio Grande is rolling. Nearer the Rio Grande, the surface is rougher, with the local relief as much as 125 feet, and is crossed by the valleys of numerous intermittent streams tributary to the Rio Grande and trending in a south or southwesterly direction. The altitude of the basin ranges from sea level at the mouth of the Rio Grande to nearly 950 feet above sea level in southeastern Webb County.

According to the classification of Thornthwaite (1952, p. 32), the climate of the lower Rio Grande Basin is semiarid. The classification is based on precipitation and potential evapotranspiration. Rainfall ranges from nearly 28 inches in the southeastern part of the basin to less than 20 inches in the northwestern part (Figure L2).

The average annual evaporation from a free water surface is about 58 inches at Weslaco in south-central Hidalgo County about 5 miles north of the basin area and about 115 inches at Laredo. The average evaporation at Weslaco and Laredo exceeds the precipitation for every month of the year (Figure L3).

The population of the area is estimated to be 21,000, of which about 13,000 is urban. According to the 1960 census, the largest municipalities are Mirando City, 720; Zapata, 2,031; Rio Grande City, 5,835; Roma-Los Saenz, 1,496; and Grulla, 1,436.

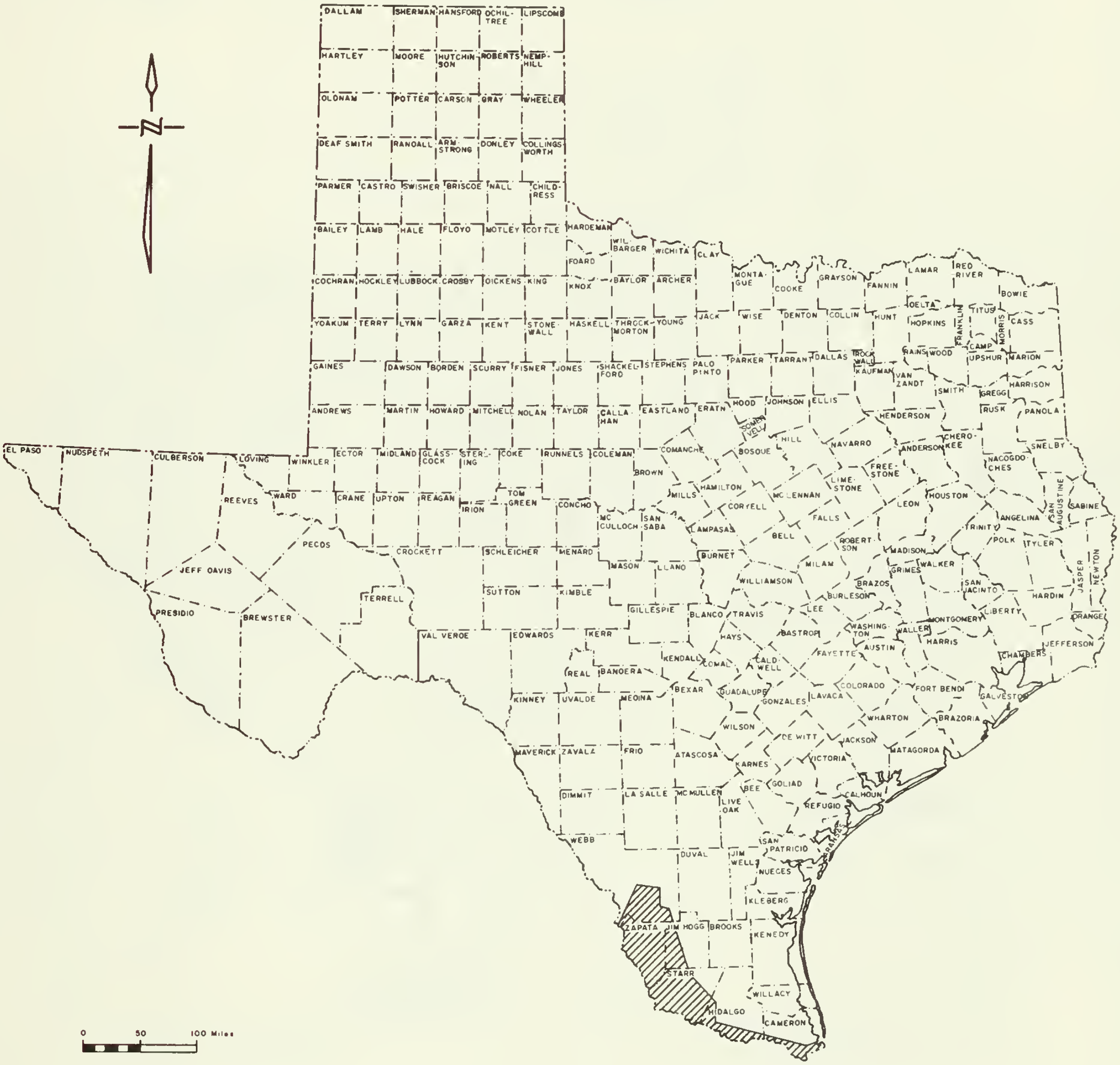

Figure L1

Map of Texas Showing the Location of the Lower Rio Grande Basin

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

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Figure L2
Map of Texas Showing Mean Annual Precipitation, in Inches, Based on the Period 1931-55
(After map prepared by U.S. Weather Bureau)

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

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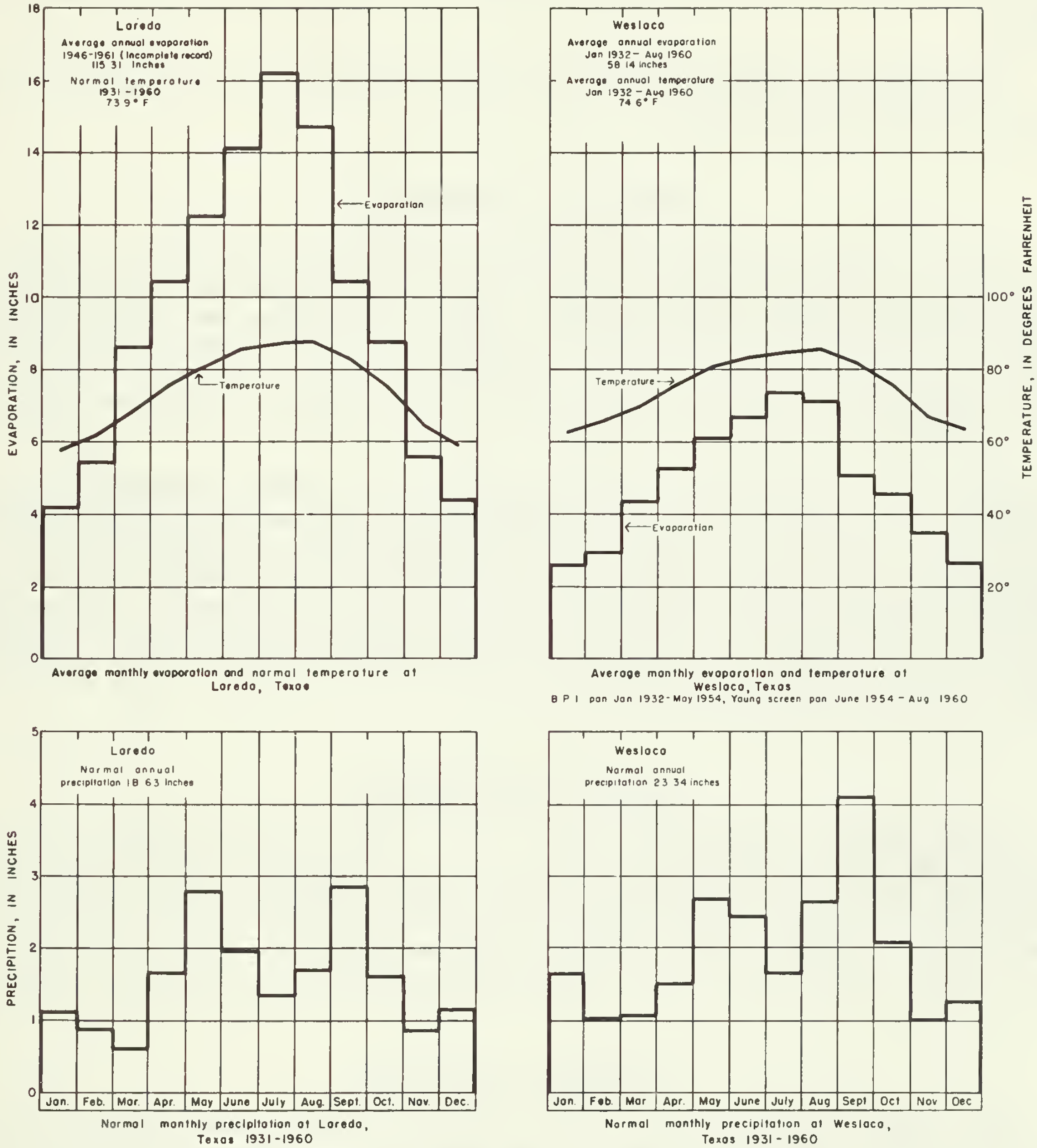

Figure L3

Precipitation, Evaporation, and Temperature at Laredo and Weslaco

(Data from Bloodgood, Patterson, and Smith, 1954, the Texas Water Commission, and the U.S. Weather Bureau)

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

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The area is devoted principally to the raising of livestock, consisting mostly of cattle but also some sheep and goats. Forage crops and grain sorghums are the principal crops in the area of dryland farming; vegetables and cotton are the principal crops irrigated in the alluvial land bordering the Rio Grande.

The principal minerals of the area are oil and gas. Other minerals are sand and gravel and pumicite.

Methods of Investigation

Data on wells and chemical analyses for the part of the basin in Cameron, Hidalgo, and part of Starr County were taken from the reports of previous investigations, particularly Baker and Dale (1961). During the period May through October 1961, wells were inventoried and samples of water were collected for chemical analyses in Starr, Zapata, and Webb Counties. Municipal and industrial pumpage data were furnished by well owners, whereas irrigation pumpage was estimated.

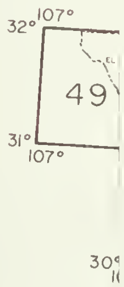
The base of the fresh to slightly saline water and the aggregate saturated thickness of the sand beds were determined from water-well data and from electric logs of oil and gas tests for the reconnaissance investigation of the ground-water resources of the Gulf Coast region (Wood and others, 1963). The water-bearing characteristics of the geologic units were based on the results of pumping tests of water wells, most of which were in the area north and east of the lower Rio Grande Basin, and were made during the investigation by Rose (1954) and Baker and Dale (1961).

Previous Investigations

Investigators of the ground water in the lower Rio Grande Basin and the parts of the basin each report covered are: Taylor (1907), all; Lonsdale and Day (1933), Webb County; Lonsdale and Nye (1941), Hidalgo County; Dale (1952), Starr County; Dale and George (1954), Cameron County; Rose (1954), Hidalgo and Cameron Counties; Wood (1956), Hidalgo and Cameron Counties and eastern part of Starr County; and Baker and Dale (1961), Starr, Hidalgo, and Cameron Counties.

Well-Numbering System

The numbers assigned to wells and springs in this report conform to the statewide system used by the Texas Water Commission. The system is based on the division of Texas into 1-degree quadrangles bounded by lines of latitude and longitude. Each 1-degree quadrangle is divided into 64 smaller quadrangles, $7\frac{1}{2}$ minutes on a side, each of which is further divided into 9 quadrangles, $2\frac{1}{2}$ minutes on a side. Each of the 89 1-degree quadrangles in the State has been assigned a 2-digit number for identification (Figure L4). The $7\frac{1}{2}$-minute quadrangles are given 2-digit numbers consecutively from left to right beginning in the upper left-hand corner of the 1-degree quadrangle, and the $2\frac{1}{2}$-minute quadrangles within each $7\frac{1}{2}$-minute quadrangle are similarly numbered with 1-digit numbers. Each well inventoried in each $2\frac{1}{2}$-minute quadrangle is assigned a 2-digit number. The well number is determined as follows: From left to right, the first 2 numbers identify the 1-degree quadrangle, the next 2 numbers identify the $7\frac{1}{2}$-minute quadrangle, the fifth number identifies the $2\frac{1}{2}$-minute quadrangle, and the last 2 numbers designate the well in the $2\frac{1}{2}$-minute quadrangle.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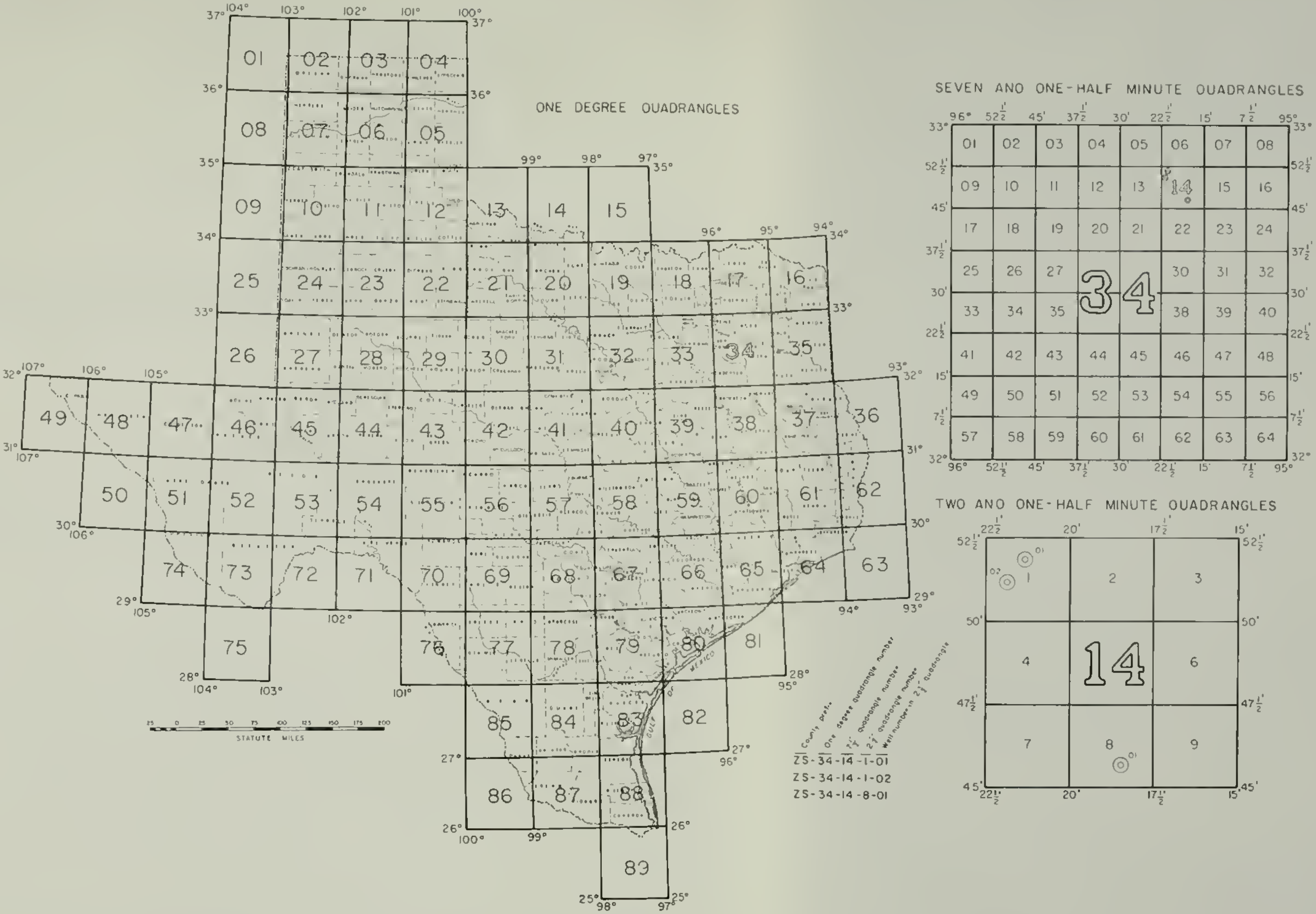


Figure L4

Map of Texas Showing the Well-Numbering System Used by the Texas Water Commission

U S Geological Survey in cooperation with the Texas Water Commission

In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for the six counties that are all or partly in the lower Rio Grande Basin are as follows:

County	Prefix	County	Prefix
Cameron	BY	Starr	XK
Hidalgo	LU	Webb	YZ
Jim Hogg	PU	Zapata	ZW

Acknowledgments

The cooperation of the many well owners, well drillers, and government officials, who so generously supplied information upon which this report is based, is gratefully acknowledged.

GEOLOGY

General Conditions

The geologic units that crop out in the lower Rio Grande Basin were deposited during the Tertiary and Quaternary Periods and range in age from Eocene to Recent. The outcrop areas of the geologic units are shown in Plate L1, and the principal characteristics and the water-bearing properties of the geologic units are given in Table L1.

In this report, small yields are less than 100 gpm (gallons per minute), moderate yields are from 100 to 1,000 gpm, and large yields are more than 1,000 gpm. Fresh water contains less than 1,000 ppm (parts per million) dissolved solids, and slightly saline water contains 1,000 to 3,000 ppm dissolved solids.

The geologic units of Tertiary age crop out in major subdivisions RG-71, RG-72, RG-74, and RG-75 as general northward-trending bands, the units decreasing in age eastward (Plate L1). They occur as sheetlike layers extending many miles northward along the strike of the units and eastward from the outcrop areas. The units, which range in thickness from a few hundred to a few thousand feet, thicken eastward; they dip in a general easterly direction at an angle greater than the slope of the land surface. In profile, the Tertiary units occur as truncated wedges that dip eastward, each wedge having a slightly greater dip than the overlying wedge.

The Tertiary sediments near the outcrop areas were deposited in a continental environment, but downdip they pass through a transitional phase to deposits of marine origin. The Tertiary deposits grade laterally and vertically from one type of material to another, and, as a consequence, the contacts between some of the units were determined arbitrarily.

The Tertiary units in the lower Rio Grande Basin have been folded and faulted in some places. These structural features are important in the occurrence of oil and gas, but apparently are not important in the occurrence of ground water in the basin.

Table L1.--Geologic units and their water-bearing properties, lower Rio Grande Basin

System	Series	Unit	Thickness (feet)	Occurrence and character of material	Water-bearing properties
Quaternary	Recent and Pleistocene	Alluvium	0- 300+	Terrace, flood-plain, and delta deposits of the Rio Grande consisting of unconsolidated gravel, sand, silt, and clay. Gravel mostly in lower part.	Yields moderate to large quantities of fresh to slightly saline water in the southern parts of major subdivisions RG-74 and RG-75, and in RG-76 in Hidalgo County and the western half of Cameron County.
		unconformity			
	Pleistocene	Beaumont Clay	0- 300(?)	Not exposed in basin. In subsurface in eastern part of major subdivision RG-76. Consists of clay with some lenses of sand and gravel.	The Beaumont Clay in conjunction with the overlying alluvium and the underlying Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, may be a source of small to moderate quantities of fresh to slightly saline water in major subdivision RG-76 in eastern Hidalgo County and western Cameron County.
		unconformity			
		Lissie Formation	0- 400(?)	Not well exposed in basin. In subsurface consists of unconsolidated sand and gravel interbedded with silt and clay.	The Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, is a source of small to moderate quantities of fresh to slightly saline water in the northeastern part of major subdivisions RG-71 and RG-72, the eastern part of RG-74, and all except the southwestern part of RG-75. In the southeastern part of RG-75 and in RG-76 in Hidalgo County moderate to large quantities of water may be obtained from the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, in conjunction with the Beaumont Clay and the alluvium.
		unconformity			
Tertiary(?)	Pliocene(?)	Willis Sand	--	Has not been differentiated on the surface or in the subsurface in the basin. Consists of sand, gravel, silt, and clay.	
		unconformity			
Tertiary	Pliocene	Goliad Sand	0- 100(?)	Lime-cemented sand and gravel and unconsolidated sand and gravel interbedded with clay; caliche is present near the land surface.	
		unconformity			
	Miocene(?)	Lagarto Clay	(?)	Not exposed in basin. In the subsurface it probably consists largely of clay and sandy clay.	The Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, locally yields small to moderate quantities of fresh to slightly saline water in the eastern parts of major subdivisions RG-71 and RG-72, and in the northeastern parts of RG-74 and RG-75.
		unconformity			
	Miocene	Oakville Sandstone	(?)	Not exposed in basin. In the subsurface it consists of sand and sandstone with clay, silt, and some volcanic ash.	
		unconformity			
	Miocene(?)	Catahoula Tuff	0- 500(?)	Volcanic ash, tuffaceous sandstone, bentonitic clay, clay, and lenses of sandstone.	
		unconformity			
	Oligocene(?)	Frio Clay	0- 500	Clay, interbedded with some sandy clay or bentonitic clay.	Generally not a source of water.
	Eocene	Jackson Group	0-2,000(?)	Clay, sandy clay, silt, with some beds of sandstone and volcanic ash, and limestone concretions.	Yields small quantities of fresh to slightly saline water in western Starr County, south-central Zapata County, and in localized areas elsewhere.
		Claiborne Group	0-4,500(?)	Varicolored clay interbedded with sand and sandstone, and some beds of limestone.	Yields small quantities of fresh to slightly saline water in southwestern Zapata County and in localized areas elsewhere.

Alluvium of Quaternary age crops out near the Rio Grande.

Geologic Units and Their Water-Bearing Properties

Tertiary System

Claiborne Group

The Claiborne Group of Eocene age crops out in the western part of the lower Rio Grande Basin in a northward-trending belt having an average width of about 10 miles. It consists, from oldest to youngest, of the Mount Selman Formation, Sparta Sand, and Cook Mountain Formation, undifferentiated, and the Yegua Formation. The Claiborne Group was not differentiated in this investigation because the contacts between some formations are uncertain. Furthermore, these formations are not important as sources of ground water in the basin.

The Claiborne Group consists largely of varicolored clay interbedded with layers of varicolored fine-grained sand and sandstone and some thin beds of limestone. The Claiborne dips eastward at about 450 feet per mile and has an estimated thickness of 4,500 feet. The group yields small amounts of fresh to slightly saline water for motels, domestic use, and livestock watering in southwestern Zapata County and in localized areas elsewhere.

Jackson Group

The Jackson Group of Eocene age, undifferentiated, crops out in the lower Rio Grande Basin in a northward-trending belt having an average width of about 10 miles in the southern part and about 18 miles in the northern part. The Jackson Group consists of interbedded clay, sandy clay, and silt, with some beds of sandstone and volcanic ash. Limestone concretions are common. The group dips about 200 feet per mile in an easterly direction in the southern part of the outcrop area, but the dip is less in the northern part. The thickness probably ranges from about 1,500 feet in the northern part of the outcrop area to about 2,000 feet in the southern part. The group yields small amounts of fresh to slightly saline water for domestic use and livestock watering in western Starr County, south-central Zapata County, and in localized areas elsewhere.

Frio Clay

The Frio Clay of Oligocene(?) age crops out in a northward-trending belt having an average width of about 3 miles (Plate L1). The Frio consists of clay with some beds of sandy clay or bentonitic clay. The thickness is about 500 feet. The Frio Clay generally is not a source of water.

Catahoula Tuff

In the lower Rio Grande Basin, the outcrop of the Catahoula Tuff of Miocene(?) age ranges in width from zero near central Starr County, where it has been completely overlapped by the Goliad Sand of Pliocene age, to about 9 miles. The Catahoula consists of volcanic ash, tuffaceous sandstone, bentonitic clay, clay, and lenses of sandstone. The dip is in a general easterly direction. The thickness along the outcrop area ranges from zero to about 500 feet. The Catahoula Tuff, in conjunction with the Oakville Sandstone and Lagarto Clay, locally yields small to moderate amounts of fresh to slightly saline water in the eastern parts of major subdivisions RG-71 and RG-72 and in the northeastern parts of RG-74 and RG-75. The water is suitable for small industrial and public supplies and for domestic use and livestock watering.

Oakville Sandstone

The Oakville Sandstone of Miocene age does not crop out in the lower Rio Grande Basin; however, it probably occurs in the subsurface with the beveled edge covered by younger formations. The Oakville consists of sand and sandstone interbedded with clay, silt, and some beds of volcanic ash. The thickness is not known because of the difficulty in picking formation contacts on the logs of wells. The Oakville Sandstone in association with the Catahoula Tuff and the Lagarto Clay, locally yields small to moderate amounts of fresh to slightly saline water that is used for small industrial and public supplies and for domestic use and livestock watering.

Lagarto Clay

The Lagarto Clay of Miocene(?) age is not exposed in the lower Rio Grande Basin; however, it may be present in the subsurface in southeastern Starr County and southern Hidalgo County. The character of the material is not definitely known, but the Lagarto Clay consists largely of clay and sandy clay. The thickness of the Lagarto is not known. The Lagarto Clay, in conjunction with the Catahoula Tuff and Oakville Sandstone, locally yields small to moderate amounts of fresh to slightly saline water that is used for small industrial and public supplies and for domestic use and livestock watering.

Goliad Sand

The Goliad Sand of Pliocene age crops out in a belt ranging in width from about 23 miles in Starr County to a mile in Webb County. It consists of lime-cemented sand and gravel and unconsolidated sand and gravel interbedded with clay; caliche is present near the land surface. The thickness of the Goliad is not well known, but is estimated to be about 100 feet. The Goliad Sand yields small to moderate amounts of fresh to slightly saline water that is used for small industrial and public supplies and for domestic use and livestock watering. The Goliad, in conjunction with the Willis Sand, Lissie Formation, Beaumont Clay, and the alluvium, may yield moderate to large quantities of water locally in eastern Starr County and southern Hidalgo County.

Tertiary(?) System

Willis Sand

The Willis Sand of Pliocene(?) age has not been differentiated in the lower Rio Grande Basin, but it or its equivalent probably is present in the subsurface as part of the sand, gravel, silt, and clay section that is made up by the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated. The Willis Sand, in conjunction with the Goliad Sand and the Lissie Formation, is an important source of water northeast of the lower Rio Grande Basin. In the lower Rio Grande Basin, the Willis may yield water to wells that are screened in the alluvium and the underlying Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the Beaumont Clay.

Quaternary System

Lissie Formation

The Lissie Formation of Pleistocene age crops out in only a small isolated area in south-central Starr County, but it probably underlies the alluvium in southern Hidalgo County. The Lissie, which is estimated to be about 400 feet thick, consists of unconsolidated sand and gravel interbedded with silt and clay and some caliche. It may yield water to wells that are screened in the alluvium and the underlying Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the Beaumont Clay in southern Hidalgo County.

Beaumont Clay

The Beaumont Clay of Pleistocene age does not crop out in the lower Rio Grande Basin, but it underlies the Quaternary alluvium in southeastern Hidalgo County and southern Cameron County. The Beaumont consists largely of clay with some lenses of sand and gravel. The thickness of the Beaumont is estimated to be 300 feet. No wells are known to tap the Beaumont Clay in the basin; however, it may be a source of small to moderate amounts of water in conjunction with the alluvium and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, in major subdivision RG-76 in eastern Hidalgo County and western Cameron County.

Alluvium

The alluvium consists of terrace, flood-plain, and delta deposits of the Rio Grande. It crops out in small discontinuous areas adjacent to the Rio Grande in western Webb, Zapata, and Starr Counties, and as a narrow band adjacent to the river in southern Starr County and southwestern Hidalgo County; it is exposed over all the lower Rio Grande Basin east of Penitas. The alluvium consists of unconsolidated gravel, sand, silt, and clay; the beds of gravel are mostly in the lower part. The alluvium ranges in thickness from about 50 feet near Rio Grande City to more than 300 feet in the vicinity of Brownsville. It yields moderate to large amounts of fresh to slightly saline water in the southern parts of major subdivisions RG-74 and RG-75, and in RG-76 in Hidalgo County and the western half of Cameron County.

Aquifers

An aquifer is a formation, group of formations, or part of a formation that is water bearing (Meinzer, 1923b, p. 30). The amount and quality of water available from an aquifer at different places or from different aquifers has a very large range. For purposes of this report, aquifers are referred to as being primary or secondary, depending on whether they yield large amounts of water in relatively large areas (primary aquifers) or whether they yield either large amounts of water in relatively small areas or small amounts of water in relatively large areas (secondary aquifers).

The Claiborne and Jackson Groups are not important as sources of water. The Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, are classified as secondary aquifers. The alluvium is the only primary aquifer in the lower Rio Grande Basin. The Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the alluvium in the lower Rio Grande Basin occur in a relatively small area when compared with the area occupied by these units in the Gulf Coastal Plain.

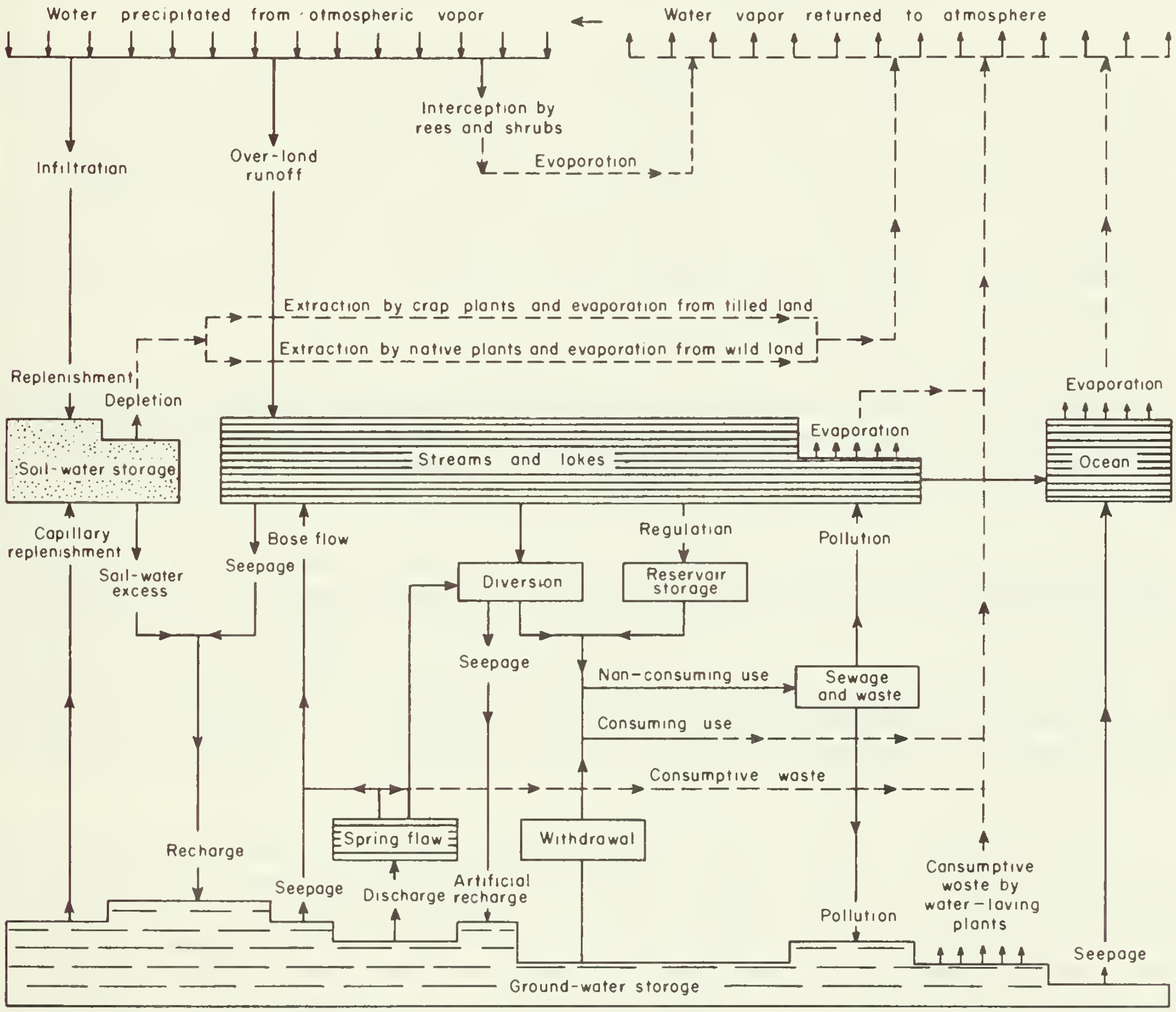
GENERAL HYDROLOGY

All the fresh water in the lower Rio Grande Basin is moving in the hydrologic cycle. A diagram of the hydrologic cycle is given in Figure L5. Some of the fresh water enters the basin as streamflow in the Rio Grande. A large amount of fresh water falls on the basin as precipitation, most of which leaves the basin by surface runoff in streams or by evaporation and transpiration. However, a part of the water that falls as precipitation moves downward through pore spaces and fractures in the rock to a zone in which the interstices are filled with water, thus becoming ground water. The water then moves laterally toward places of lower hydrostatic head, eventually to points of discharge. The rate of movement of water in aquifers is slow, being generally only a few feet to a few hundred feet per year.

If the water at the surface of the zone of saturation is not confined but is under atmospheric pressure only, it is under water-table conditions. If the water in an aquifer moves laterally beneath material less permeable than the aquifer, then the water becomes confined and is under artesian conditions. The water level in a well that is finished in an artesian aquifer will rise above the base of the confining material.

The recharge areas of the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the alluvium in the lower Rio Grande Basin are represented by the outcrop areas of these formations. In general, water-table conditions exist in the recharge areas, although locally, ground water in the lower part of the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the alluvium may be under artesian conditions. Ground water in the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, probably is under artesian conditions in most of the area downdip from the outcrop of the Catahoula.

Ground water is discharged naturally from the Catahoula Tuff, Oakville Sandstone, and the Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, by upward movement into overlying beds and by lateral movement into the alluvium. Under natural conditions, ground water is discharged from the alluvium by evaporation and transpiration



(Modified from Piper, 1953, p. 9)

Figure L5

The Hydrologic Cycle in the Lower Rio Grande Basin

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

100

and lateral movement to the northeast and east. The alluvium is in hydraulic connection with the Rio Grande, thus the river may be a gaining or losing stream depending on the difference in altitude of the stream level and the water table (Baker and Dale, 1961, p. 60).

Aquifers function as conduits in which the water moves from places of recharge to places of discharge. They function also as reservoirs in which the water is in transient storage.

The coefficient of transmissibility and the field coefficient of permeability govern the ability of an aquifer to transmit water. The coefficient of transmissibility is the number of gallons of water which will move in 1 day through a vertical strip of the aquifer 1 foot wide and having the height of the aquifer when the hydraulic gradient is unity. The field coefficient of permeability is the coefficient of transmissibility divided by the thickness of the aquifer and is the rate of flow in gallons per day through a cross section of 1 square foot under a unit hydraulic gradient at the prevailing temperature of ground water in the aquifer.

The specific capacity of a well is the rate of yield per unit of drawdown, and usually is expressed as gallons per minute per foot of drawdown. The specific capacity of a well tapping an aquifer is related to the transmissibility of the aquifer, but also to the method of well construction and the degree of development.

The coefficient of storage of an aquifer is the volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface.

The coefficients of transmissibility and storage of an aquifer generally are computed from pumping tests. A pumping test consists of measuring changes in water level in an aquifer at known times and distances from known changes in discharge rates from the aquifer.

Although pumping tests have not been made on wells in the lower Rio Grande Basin, the results of tests made in wells tapping the alluvium in Hidalgo and Cameron Counties in the area north of major subdivision RG-76 are useful as an indication of the hydraulic properties of the alluvium in the lower Rio Grande Basin. Coefficients of transmissibility ranging from 5,000 to 70,000 gpd per foot (gallons per day per foot) were reported by Rose (1954, p. 8). The specific capacities ranged from less than 17 to about 33 gpm per foot of drawdown. The wide range of the coefficients of transmissibility and specific capacities indicates the heterogeneous character of the material in the alluvium, although some of the wells were not open to the full thickness of alluvium and, therefore, would not exhibit the true characteristics of the formation.

The chemical quality of water depends on the dissolved minerals present and often determines its suitability for use. A general classification of water, according to dissolved-solids content, is as follows (Winslow and Kister, 1956, p. 5):

Description	Dissolved solids (ppm)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Water containing more than 1,000 ppm (parts per million) dissolved solids is undesirable for most ordinary uses; however, because most of the ground water in the lower Rio Grande Basin contains more than 1,000 ppm dissolved solids and the water, of necessity, is being used, sources of water containing up to 3,000 ppm dissolved solids are indicated in this report.

The U. S. Public Health Service (1962, p. 2152-2155) recommends that the following chemical substances should not be present in a drinking-water supply in excess of the listed concentrations:

Substance	Concentration (ppm)
Alkyl benzene sulfonate (ABS)	0.05
Chloride (Cl)	250
Fluoride (F)	*
Iron (Fe)	.3
Manganese (Mn)	.05
Nitrate (NO_3)	45
Sulfate (SO_4)	250
Dissolved solids	500

* The fluoride intake depends on the amount of water people drink, which varies with the air temperature, and on the fluoride concentration in the water. The concentration of natural fluoride in the drinking water should not exceed the upper limit given for the appropriate temperature range in the following table.

Annual average of maximum daily air temperatures (°F)	Recommended control limits of fluoride concentrations (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

According to the records of the U. S. Weather Bureau, the normal annual maximum temperature at Laredo is 85.0°F and at Brownsville 82.5°F.

Nitrate in drinking water may cause methemoglobinemia ("blue baby" disease). Maxcy (1950, p. 271) concludes that water containing nitrate in excess of 44 ppm should be regarded as unsafe for infant feeding.

Water containing sulfate much in excess of 250 ppm may have a laxative effect.

Hardness of water is important in water used for domestic and public supply or for industrial supplies. The classification of hardness as $CaCO_3$ in water is as follows:

Hardness range (ppm)	Classification
0 - 60	Soft
61 - 120	Moderately hard
121 - 180	Hard
More than 180	Very hard

The suitability of water for industrial use depends on the quality requirements of different industries and for different processes. The tolerances in chemical quality for industrial uses differ widely (Moore, 1940, p. 263, 271).

The chemical quality of water used for irrigation affects plants and the soil in which they grow. However, the suitability of water for irrigation depends not only on the chemical quality of the water but also on such factors as method of application, amount of water applied, soil texture, infiltration rate, farm management practices, climatic factors, and the tolerances of different crops for the dissolved minerals in the water. The U. S. Salinity Laboratory Staff (1954, p. 69) states, "The characteristics of an irrigation water that appear to be most important in determining its quality are:
(1) Total concentration of soluble salts; (2) relative proportion of sodium to other cations; (3) concentration of boron or other elements that may be toxic;

and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium."

The electrical conductivity (specific conductance) of a water is a good measure of the concentration of soluble salts in the water. The classification of waters for irrigation, based primarily on the salinity hazard as measured by the electrical conductivity of the water and the sodium hazard as measured by the sodium adsorption ratio (SAR), is shown in Figure L6. The absolute and relative proportion of sodium to calcium and magnesium determine the alkali hazard of irrigation water. The sodium adsorption ratio used to define the alkali hazard is defined by the following equation:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}},$$

where the concentrations of the ions are expressed in milliequivalents per liter. The alkali hazard can be obtained from Figure L6 by using the SAR and the specific conductance of the water.

An increase in the salinity of soils may be prevented to a certain extent by the application of excess water, thereby leaching the soil of the residual salts. Alkalinity may be controlled by adding calcium or magnesium to the soil or water to replace the exchangeable sodium and then leaching.

Boron is necessary to the normal growth of plants but it is toxic if in concentrations only slightly above optimum. The following limits of boron for irrigation water have been proposed (Scofield, 1936, p. 286).

Boron class	Grade	Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant crops (ppm)
1	Excellent	< 0.33	< 0.67	< 1.00
2	Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
3	Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
4	Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
5	Unsuitable	> 1.25	> 2.50	> 3.75

The quality of the water from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, in the lower Rio Grande Basin differs widely from place to place. Plate L1 shows where fresh to slightly saline water generally can be obtained from the aquifers; however, locally the water in these areas may contain dissolved solids considerably in excess of 3,000 ppm. The location of selected wells are shown on Plate L1 and chemical analyses of water from the wells are given in Table L2. The wide variation in the quality makes a characterization of the water as related to use difficult. However, in general, the water exceeds the recommended standards of the U. S. Public Health Service for drinking water and, according to the diagram for the classification of irrigation water (Figure L6), the water generally is not suitable for irrigation because of the high sodium hazard, salinity hazard, and boron content.

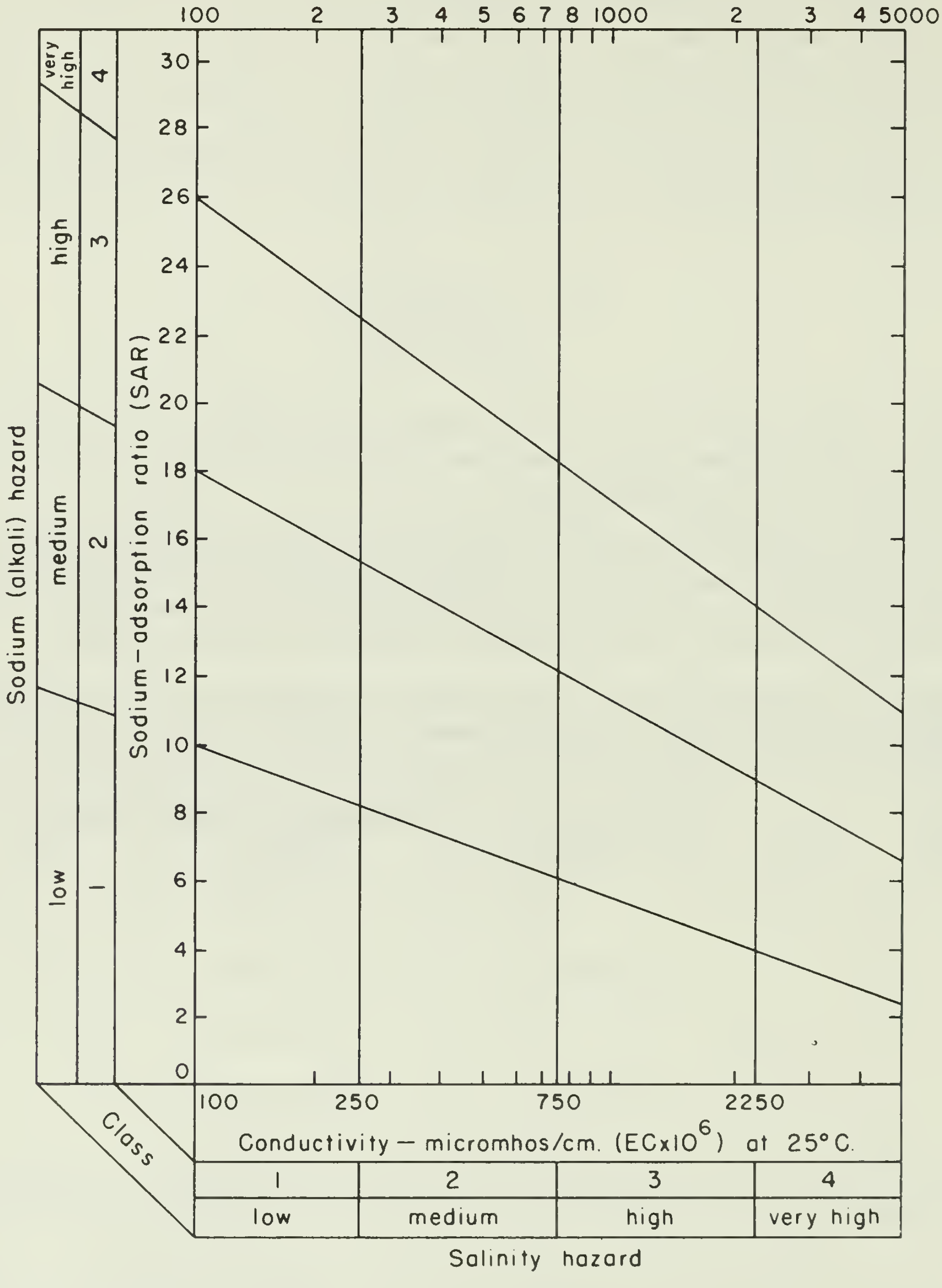


Figure L6

Diagram for the Classification of Irrigation Waters

(After United States Salinity Laboratory Staff, 1954, p. 80)

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

100

Table L2.--Chemical analyses of water from selected wells in the lower Rio Grande Basin

Analyses given are in parts per million except specific conductance, pH, percent sodium, and sodium adsorption ratio (SAR).

Water-bearing unit: Qa, Alluvium; Tcl, Claiborne Group; Tloc, Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated; Tf, Frio Clay; QTlwg, Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated; Tj, Jackson Group.

Well	Depth of well (ft)	Water-bearing unit	Silica (SiO_2)	Iron (Fe) (total)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3) a/	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$	Percent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C.)	pH
Major Subdivision RG-71																				
YZ-84-41-402	60	QTlwg	--	--	100	30	*191		262	109	314	1.2	17	--	891	373	53	4.3	--	--
802	400	Tloc	--	2.4	146	55	*247		300	134	518	.2	15	--	1,260	590	48	4.4	--	--
ZW-84-57-101	275	Tloc	29	.00	8.8	4.2	*362		332	162	272	--	3.2	--	1,000	40	95	25	1,730	8.2
Major Subdivision RG-72																				
YZ-84-33-701	42	QTlwg	--	--	80	26	*184		298	123	230	0.4	11	--	801	307	57	4.6	--	--
702	105	Tloc	--	2.1	286	81	*311		98	94	1,090	.4	.2	--	1,920	1,050	39	4.2	--	--
85-46-401	400	Tcl	13	--	5.5	.5	*1,190		646	364	1,200	2.5	1.0	--	3,090	16	99	129	5,210	8.4
ZW-85-45-901	143	Tcl	13	.64	131	64	*1,760		164	1,460	1,960	.2	4.5	--	5,470	590	87	32	8,380	7.5
86-15-604	210	Tcl	34	--	110	15	460	7.1	318	528	380	.3	1.0	1.6	1,690	336	74	11	2,630	7.5
902	230	Tcl	29	.44	104	17	*525		334	606	400	.5	1.5	--	1,850	330	78	13	2,890	7.5
16-401	237	Tcl	22	--	89	5.1	*310		110	262	392	--	1.2	--	1,140	243	73	8.6	1,960	7.3
402	180	Tcl	38	.28	129	17	*100		212	358	45	--	.0	--	831	392	36	2.2	1,130	7.5
705	214	Tcl	16	--	26	3.4	*421		176	414	295	.3	2.8	--	1,270	79	92	21	2,080	7.5
706	90	Tcl	45	.17	342	38	*263		190	920	332	--	1.5	--	2,030	1,010	36	3.6	2,800	7.1
23-302	210	Tcl	13	--	5.0	1.7	1,180	3.4	1,580	2.2	920	1.8	2.0	15	2,920	20	99	115	4,890	8.0
304	210	Tcl	15	--	2.0	.7	*607		582	148	490	.7	2.8	--	1,550	8	99	93	2,680	8.3
24-101	225	Tcl	15	--	5.5	1.1	*495		226	288	430	--	2.8	--	1,350	18	98	51	2,320	8.5
706	302	Tcl	23	.08	68	33	*879		268	1,160	560	--	.2	--	2,860	305	86	22	4,310	7.7
Major Subdivision RG-74																				
XK-86-24-801	305	Tj	22	--	51	19	*636		250	568	560	--	1.0	2.3	1,980	205	87	19	3,190	8.0

See footnotes at end of table.

Table L2.--Chemical analyses of water from selected wells in the lower Rio Grande Basin--Continued

Well	Depth of well (ft)	Water-bearing unit	Silica (SiO_2)	Iron (Fe) (total)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3) a/	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Boron (B)	Dis-solved solids	Hard-ness as $CaCO_3$	Per-cent so-dium	Sodium adsorp-tion ratio (SAR)	Specific conduct-ance (micromhos at 25°C.)	pH
XK-86-31-901	100	Tcl	10	--	102	31	*1,440		188	1,420	1,330	--	4.0	4.2	4,430	382	89	32	6,640	7.9
32-101	250	Tcl	24	--	702	48	*1,990		30	2,600	2,520	--	--	5.1	7,900	1,950	69	20	10,800	6.5
202	300	Tj	50	--	102	29	*761		224	797	720	--	.0	2.4	2,570	374	82	17	3,980	7.7
301	700	Tj	18	--	9.5	6.6	*1,840		1,740	78	1,800	--	.0	15	4,620	50	99	113	7,480	8.8
501	262	Tj	19	--	2.5	1.7	*795		426	496	620	--	1.5	--	2,140	13	99	96	3,540	8.2
605	350	Tj	26	--	9.0	9.7	*1,020		784	109	1,080	--	.0	3.5	2,640	62	97	56	4,550	8.4
906	250	Tj	16	--	128	36	*611		140	938	500	--	.5	2.1	2,300	468	74	12	3,450	7.5
40-201	300	Tj	--	--	--	--	--		289	500	384	--	3.9	--	--	b/ 150	--	--	--	--
202	400	Tj	--	--	--	--	--		756	0	2,310	--	9.8	--	--	b/ 57	--	--	--	--
601	300	Tj	--	--	--	--	--		776	6	4,780	--	3.5	--	--	b/ 165	--	--	--	--
87-09-904	170	Tloc	17	--	227	42	*2,040		156	685	3,080	--	--	4.9	6,170	739	86	33	10,100	7.7
10-703	112	QTlwg	117	--	43	21	*171		355	76	100	--	68	1.0	772	194	66	5.3	1,110	8.2
11-703	240	QTlwg	23	--	20	19	*542		422	277	476	--	1.2	3.0	1,570	128	90	21	2,540	7.8
18-601	224	QTlwg	88	--	158	36	*1,360		280	754	1,750	--	20	7.2	4,310	542	85	25	6,880	8.1
19-701	290	QTlwg	52	--	88	30	*385		238	277	470	--	42	1.4	1,460	343	71	9.0	2,410	7.8
25-601	200	Tf(?)	22	--	248	69	*1,920		336	914	2,730	--	5.0	3.8	6,080	902	82	28	9,820	7.2
26-902	275	QTlwg(?)	90	--	106	33	*541		274	1,120	125	--	12	1.9	2,160	400	75	12	2,890	8.3
27-502	290	QTlwg	88	0.29	452	108	*1,630		252	818	2,790	--	164	4.5	6,180	1,570	69	18	9,880	7.1
33-501	275	Tj	5.6	--	598	165	*9,290		93	2.6	15,800	--	--	13	25,900	2,170	90	87	38,400	7.1
34-303	204	QTlwg(?)	101	--	145	26	*937		308	821	945	--	81	6.6	3,210	469	81	19	4,860	8.3
902	80	QTlwg	--	--	175	36	*837		384	291	1,260	--	11	--	2,800	584	76	15	--	--
42-102	58	Qa	38	--	190	42	288	8.2	629	284	318	--	8.1	.90	1,490	646	49	4.9	2,350	7.1

See footnotes at end of table.

Table L2.--Chemical analyses of water from selected wells in the lower Rio Grande Basin--Continued

Well	Depth of well (ft)	Water-bearing unit	Silica (SiO_2)	Iron (Fe) (total)	Cal-cium (Ca)	Magne-sium (Mg)	Sodium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3) a/	Sul-fate (SO_4)	Chlo-ride (Cl)	Fluo-ride (F)	Ni-trate (NO_3)	Boron (B)	Dis-solved solids	Hard-ness as $CaCO_3$	Per-cent so-dium	Sodium adsorp-tion ratio (SAR)	Specific conduct-ance (micromhos at 25°C.)	pH
Major Subdivision RG-75																				
XK-87-28-103	200	QTlwg	78	--	60	9.9	*54		304	17	22	--	13	1.9	418	190	38	1.7	621	8.1
701	963	Tloc	26	--	213	25	*1,590		153	3,040	570	--	1.0	10	5,540	634	85	28	7,070	7.9
29-701	434	QTlwg(?)	20	--	105	37	*697		228	291	1,020	--	.0	3.0	2,290	414	79	15	4,040	8.2
35-504	182	QTlwg	39	--	278	80	*1,140		252	591	1,880	--	42	7.4	4,180	1,020	71	16	6,860	8.1
36-201	477	QTlwg(?)	3.6	--	82	25	*1,060		101	1,130	945	--	22	6.4	3,320	308	88	26	5,130	7.8
803	180	QTlwg	--	--	159	44	*340		336	118	625	--	45	--	1,500	578	56	6.2	--	--
42-307	54	Qa	33	--	240	57	268	--	298	565	402	0.8	9.4	.70	1,720	834	41	4.0	2,590	7.2
43-101	54	Qa(?)	--	--	122	35	*1,890		361	2,360	1,280	--	.8	--	5,870	448	90	39	--	--
407	85	Qa	44	--	244	52	230	--	332	500	370	--	4.2	.52	1,610	823	38	3.5	2,440	7.4
505	60	Qa(?)	--	--	524	152	*637		108	1,820	945	--	3.0	--	4,130	1,930	42	6.3	--	--
911	61	Qa	55	--	200	45	136	--	659	190	162	.4	.0	.00	1,110	684	30	2.3	1,740	7.2
44-502	95	QTlwg	--	--	111	32	*455		474	274	498	--	26	--	1,630	408	71	9.8	--	--
LU-87-37-401	280	QTlwg	--	--	134	40	*281		402	109	455	--	32	--	1,250	499	55	5.5	--	--
52-309	75	Qa	44	--	311	80	200	--	413	330	600	--	.0	.35	1,770	1,100	28	2.6	2,900	7.7
53-102	133	QTlwg	24	--	66	25	386	--	318	156	468	2.0	40	1.6	1,320	268	76	10	2,290	7.6
Major Subdivision RG-76																				
LU-87-54-407	116	Qa	42	--	198	40	128	--	548	170	205	--	5.4	0.22	1,060	658	30	2.2	1,720	7.6
63-501	119	Qa	38	--	242	53	97	7.9	387	218	340	0.4	5.9	.45	1,190	822	20	1.5	2,320	7.2
BY-88-58-608	187	Qa	47	--	112	38	96	--	480	136	75	--	.0	.09	752	436	32	2.0	1,170	7.6

a/ Includes the equivalent of any carbonate (CO_3) present.
b/ Hardness by soap method.
* Sodium and potassium calculated as sodium (Na).

The water from the alluvium in the lower Rio Grande Basin generally has a dissolved-solids content ranging from 1,000 to 2,000 ppm, is slightly alkaline, very hard, and the bicarbonate content ranges from 300 to 700 ppm. According to Figure L6, the water is low in sodium hazard and high to very high in salinity hazard. The boron is less than 1 ppm. In general, the water has been used successfully for irrigation; however, the soils need good drainage and may require special management for salinity control.

Fresh to slightly saline water is not available from the alluvium in the eastern fourth of major subdivision RG-76. Slightly saline water may be obtained from deposits underlying the alluvium in Hidalgo County and western Cameron County. Although no wells are known in RG-76 that tap the deposits underlying the alluvium, data from the adjoining coastal basin show that the water from the alluvium generally is of better quality than the water from underlying deposits.

OCCURRENCE AND AVAILABILITY OF GROUND WATER

For the purpose of this report, the occurrence, availability, and chemical quality of ground water in the lower Rio Grande Basin are discussed by the major subdivisions, which were delineated by the Water Planning Division of the Texas Water Commission (Plates L1 and L2).

Major Subdivision RG-71

Major subdivision RG-71, which covers an area of about 790 square miles, includes parts of Webb, Zapata, and Jim Hogg Counties (Plate L1). The climate is semiarid and the rainfall averages about 20 inches per year.

Small to moderate amounts of fresh to slightly saline water are available from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, except in a narrow strip along the west edge of the Catahoula outcrop, and from the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, in the northeast corner of the subdivision (Plate L1). The Jackson Group and the Frio Clay are not known to yield water to wells in RG-71.

The base of the fresh to slightly saline water ranges from just below sea level to about 600 feet above sea level in the northeastern part of the subdivision and from about sea level to nearly 1,200 feet below sea level in the southeastern part (Plate L2). The aggregate thickness of the sands containing fresh to slightly saline water in RG-71 is less than 200 feet except for a small area on the basin boundary.

Major Subdivision RG-72

Major Subdivision RG-72 contains 1,295 square miles and includes parts of Webb, Zapata, Jim Hogg, and Starr Counties (Plates L1 and L2). The climate is semiarid and the average annual precipitation is slightly less than 20 inches.

Small to moderate amounts of fresh to slightly saline water are available from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, in RG-72, except in a narrow belt along the west edge of the outcrop of the

Catahoula, and from the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated (Plate L1). Small amounts of fresh to slightly saline water are available also from the Claiborne and Jackson Groups east of Falcon Reservoir (Plates L1 and L2). Actually, the area east of Falcon Reservoir that contains fresh to slightly saline water may be larger because the boundary is based on the available data which, in many places, do not extend outside the delineated area on Plate L1.

The base of the fresh to slightly saline water in the Claiborne Group in RG-72 near Falcon Reservoir is as much as 350 feet below the land surface. The aggregate thickness of the sands containing fresh to slightly saline water in the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, is less than 200 feet. Section A-A' shows the approximate base of the fresh to slightly saline water from the southwestern part of major subdivision RG-72 to the vicinity of Brownsville (Figure L7).

Major Subdivision RG-74

Major subdivision RG-74 contains 730 square miles in Zapata, Starr, and Jim Hogg Counties (Plate L1). The climate is semiarid and the average annual precipitation is less than 20 inches.

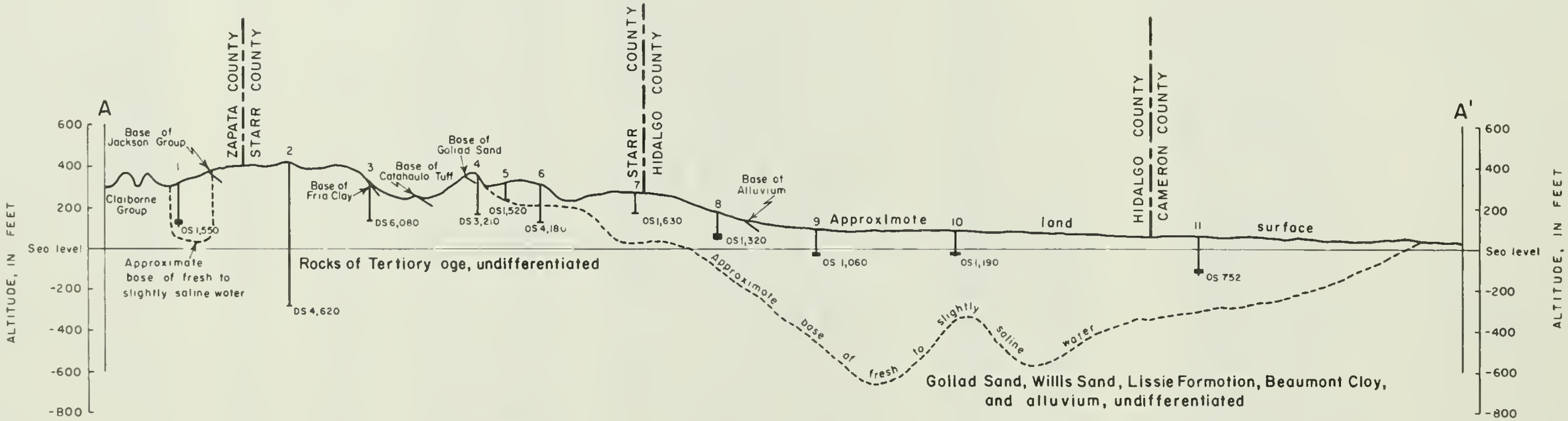
Small to moderate amounts of fresh to slightly saline water are available from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, in the northeastern and eastern parts of the subdivision, where it underlies the Goliad Sand (Plate L1). Fresh to slightly saline water occurs in the Goliad in a belt of irregular width along the northeastern edge of the subdivision. In the outcrop of the Catahoula and in a considerable part of the outcrop of the Goliad Sand, wells yield water that contains more than 3,000 ppm dissolved solids. Moderate to large amounts of fresh to slightly saline water are available from the alluvium adjacent to the Rio Grande and small amounts are available from the Jackson Group east and southeast of Falcon Reservoir (Plate L1).

The base of the fresh to slightly saline water in the northeastern part of RG-74 ranges from about 1,400 feet below sea level to 200 feet above sea level. The aggregate thickness of sands containing fresh to slightly saline water in RG-74 is less than 200 feet, except in small areas along the northeastern boundary of the basin.

Major Subdivision RG-75

Major subdivision RG-75 contains about 425 square miles in Starr and Hidalgo Counties (Plate L1). The climate is semiarid and the average annual precipitation is about 20 inches.

Small to moderate amounts of fresh to slightly saline water may be obtained from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, in a small area along the east side of RG-75, and from the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, over most of the subdivision except in the outcrop of the Goliad Sand northeast of Rio Grande City (Plate L1). Moderate to large amounts of water may be obtained also from the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, where it is



EXPLANATION

DS – Dissolved solids, in parts per million

Screen setting shown thus where known

5 0 0 20 Miles

Location of section shown on Plate L1

Figure L7

Section A-A', Lower Rio Grande Basin

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

overlain by alluvium. Moderate to large amounts of fresh to slightly saline water may be obtained from the alluvium adjacent to the Rio Grande.

The base of fresh to slightly saline water is more than 400 feet below sea level along the northeast boundary of RG-75, about 200 feet above sea level in the central part, and nearly at sea level in the southwestern part (Plate L2). The aggregate thickness of the sands containing fresh to slightly saline water in RG-75 is less than 200 feet except near the north boundary in Starr County.

Major Subdivision RG-76

Major subdivision RG-76 consists of 80 square miles in Hidalgo and Cameron Counties (Plates L1 and L2). The precipitation ranges from about 28 inches a year in the eastern part of RG-76 to about 20 inches a year in the western part.

In that part of major subdivision RG-76 in Hidalgo County and western Cameron County, moderate to large quantities of fresh to slightly saline water are obtained from wells that tap the alluvium. The Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, and the Beaumont Clay, which underlie the alluvium, yield water to wells in the adjacent coastal area but have not been tapped in RG-76.

The base of fresh to slightly saline water is about at sea level at Brownsville, but it is more than 600 feet below sea level in an area south of McAllen and Weslaco; it is about 200 feet below sea level near Penitas (Plate L2 and Figure L7). The aggregate thickness of the sands containing fresh to slightly saline water is probably more than 200 feet in eastern Hidalgo County, but it is less than 200 feet elsewhere.

UTILIZATION OF GROUND WATER

In the lower Rio Grande Basin, water from the Claiborne Group, the Jackson Group, and the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, is used mainly for domestic supply and livestock watering, but also for oil-well drilling and for supply of oil camps. Wells near the Rio Grande obtain water from the alluvium for domestic and livestock, industrial, and for irrigation supplies.

Most of the water pumped from the alluvium in 1961 was for irrigation. Of the 85 major wells that tap the alluvium, 84 were drilled for irrigation. However, only 23 of the irrigation wells, all of which were in RG-76, were used in 1961. The reported yields of the irrigation wells ranged from about 900 to 2,500 gpm. In 1961, the pumpage of ground water for irrigation in RG-76 was about 1,100 acre-feet or about 1,000,000 gpd.

Pumpage in other major subdivisions for all purposes was small.

GROUND WATER AVAILABLE FOR DEVELOPMENT

Additional amounts of fresh to slightly saline water for domestic and livestock supplies can be obtained from the Claiborne and Jackson Groups in the south-central part of major subdivision RG-72 and the western part of RG-74, in the area of fresh to slightly saline water shown in Plate L1. Whether this area is more extensive than shown could not be determined from the available data.

Small to moderate amounts of fresh to slightly saline water can be obtained from the Catahoula Tuff, Oakville Sandstone, and Lagarto Clay, undifferentiated, and the Goliad Sand, Willis Sand, and Lissie Formation, undifferentiated, in the areas shown on Plate L2. The total quantity available from these aquifers is unknown, but the potential for additional development is relatively small.

The potential for additional development from the alluvium is fairly large when compared to the other aquifers in the basin. Water from the alluvium is used largely for irrigation, and the potential yield from the alluvium probably is adequate to irrigate all of the area of the basin underlain by alluvium that was not irrigated from the Rio Grande in 1961. The potential yield of the alluvium in the basin depends on the amount of water recharged by the infiltration of precipitation and by seepage from the Rio Grande and the amount of water withdrawn from the alluvium in the area north of the basin.

PROBLEMS AND RECOMMENDATIONS

The most serious problem in the lower Rio Grande Basin is the lack of water of suitable chemical quality for domestic use and livestock watering. Problems and recommendations cannot be considered and made for the basin alone because the aquifers extend to the east and north beyond the boundary of the basin. The alluvium is the principal aquifer in the lower Rio Grande Basin, but most of the aquifer as well as the pumpage from the alluvium is in the area that adjoins the eastern part of the basin.

Ground-water problems in the alluvium are largely of two types. During extended periods of subnormal precipitation, a large amount of water may be pumped from the alluvium. Water levels may be lowered and water of inferior quality may move upward from below or move laterally from the north. During periods of normal or above-normal precipitation, water levels may be near the land surface and drainage problems may develop. These problems are related to the climate, the availability of water from the Rio Grande, both for direct use for irrigation and for natural recharge into the alluvium, and the rate and duration of pumping of ground water.

Available information is not sufficient for evaluating the hydrology and the perennial yield of the alluvium. In order to fill important gaps in the information, a continuing program of ground-water investigation covering all the delta of the Rio Grande should be instigated to (1) collect geologic information, (2) collect information regarding the amount and distribution of pumping, (3) measure water levels periodically in a network of selected wells tapping the alluvium and obtain altitudes of the wells by instrumental leveling so that the slope of the water surface can be determined, (4) collect samples of water for chemical analyses from selected wells and resample periodically, and (5) test pump wells tapping the alluvium near the Rio Grande to determine the nature and extent of the hydraulic connection between the river and the alluvium.

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Year	Water-Supply Paper no.	Year	Water-Supply Paper no.	Year	Water-Supply Paper no.
1935	777	1942	947	1949	1159
1936	817	1943	989	1950	1168
1937	840	1944	1019	1951	1194
1938	845	1945	1026	1952	1224
1939	886	1946	1074	1953	1268
1940	909	1947	1099	1954	1324
1941	939	1948	1129	1955	1407