195

GROUND-WATER REPORT 6

Geology and Ground-Water Conditions in Southern Lea County, New Mexico

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Abstract

Southern Lea County is at the southeastern corner of New Mexico. Most of the area is in the Pecos Valley section of the Great Plains physiographic province; it also includes the southern margin of the Llano Estacado. There are no perennial streams and no throughgoing surface drainage.

Rocks of Quaternary, Tertiary, and Triassic age are exposed and contain the principal aquifers. The most important aquifer is the Ogallala formation, which underlies the Llano Estacado and forms outliers south of it. In large parts of southern Lea County, however, the Ogallala has been removed by erosion and in the low-lying areas Quaternary alluvium, derived principally from the Ogallala formation, has been deposited and is the main aquifer. The two aquifers are continuous in the eastern part of the area. Below the Cenozoic rocks are sandstones and shales of the Dockum group of Late Triassic age, from which small quantities of water are obtained. No usable ground water is obtained from rocks older than the Triassic, but highly saline water is produced along with oil from Paleozoic rocks.

In 1954 about 6,000 acre-feet of ground water were used. Most of this quantity was needed for irrigation and for gasoline plants, in about equal amounts. Economic growth from a rapidly developing petroleum industry has brought about a demand for water for industrial and public supplies that is expected to continue. Development of adequate supplies is hindered by restricted occurrence and low transmissibility of the sediments. Because of the low recharge rate, most of the water pumped is being removed from storage.

The chemical quality of the ground water from the principal aquifers is generally fair to good. Production of large quantities of oil-field brine (3,700 acre-feet in 1955) has created a waste-disposal problem of major importance. Most of the brine has been discharged into surface pits. Leakage from the pits has caused contamination of the shallow water in some areas and unless other disposal methods are used, the problem will spread.

Introduction

LOCATION AND AREA

The area covered by this report comprises about 1,950 square miles of the southern part of Lea County, in the southeastern corner of New Mexico. Figure 1 shows the area covered by this report and areas covered by earlier ground-water reports published by the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources Division. Southern Lea County is bordered on the east and south by Texas, and on the west by Eddy County; the irregular northern limit of the area follows a low scarp, Mescalero Ridge, which forms the southern edge of the Llano Estacado, or High Plains. In order to show the geologic and hydrologic relations at the northern edge of the study area, several of the maps show a portion of northern Lea County also and these relations are discussed in the text. The southern Lea County area includes the incorporated towns of Eunice and Jal and the three villages of Maljamar, Monument, and Oil Center. The abandoned villages of Lea, Nadine, Halfway, Pearl, and Ochoa are recognized place names in the area and are used for convenience.

HISTORY AND SCOPE OF INVESTIGATION

This study is part of a long-range program of ground-water investigations in New Mexico by the U.S. Geological Survey, in cooperation with the State Bureau of Mines and Mineral Resources Division of the New Mexico Institute of Mining and Technology, and with the New Mexico State Engineer. It was proposed for the purpose of evaluating the water resources of a critically water-deficient area. The need for water by the oil and gas industry, which is the backbone of the area's economy, is one of the main factors determining the limits to which the economy can expand.

The investigation was begun in January 1953, and fieldwork by the senior author was carried on from that date until July 1954 and for short periods in 1955. The fieldwork consisted primarily of an inventory of the water wells in the area, and of the collection of drillers' logs and elevations of seismic shotholes. A map of the surface geology was prepared by the senior author, using photomosaics prepared by the Soil Conservation Service as a base. The west-central part of the map of the project area was revised by the junior author. Because extensive areas are covered by sand dunes, geologic mapping was necessarily interpretative and based primarily on the geomorphology of the area rather than on direct observation. The depth to water in wells was measured where practicable, and a representative number of water samples was taken for analysis by the Quality of Water Branch of the U.S. Geological Survey

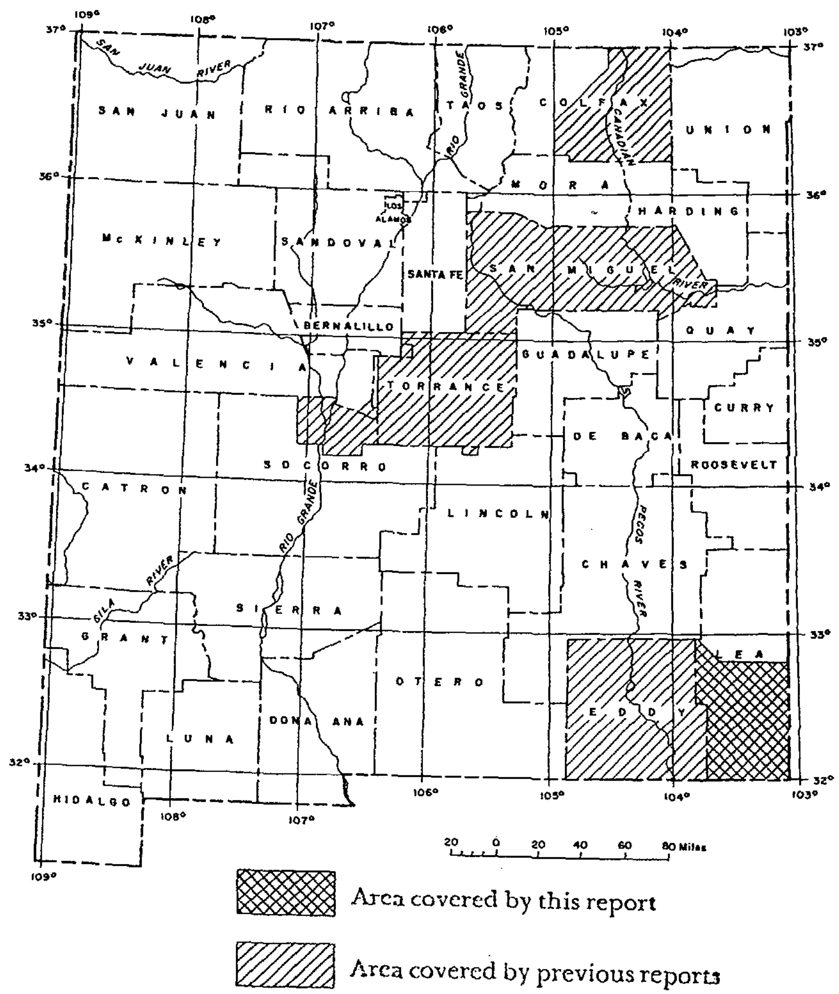

Figure 1

AREAS IN NEW MEXICO DESCRIBED IN GROUND-WATER REPORTS OF NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY, STATE BUREAU OF MINES AND MINERAL RESOURCES DIVISION

to determine the quality of water produced from the various stratigraphic units. Several samples of oil-field waters were also analyzed.

Most of the data on wells in the area and samples for chemical analyses were collected in 1953, 1954, and 1955. No attempt has been made to obtain data on wells drilled in the area since that time; however, as a result of several other investigations in the area, data have been produced which serve to fill gaps in coverage. Chemical analyses of samples collected in September 1958 by R. L. Borton and S. E. Galloway of the New Mexico State Engineer Office have been included in Table 8. Data on wells in the northwestern and south-central parts of the county were obtained during a 1-week reconnaissance by the junior author in December 1958. Additional information resulted from work on behalf of the U.S. Atomic Energy Commission in the southwestern corner of the county in the spring of 1959.

The investigation was under the general supervision of A. N. Sayre, Chief, Ground Water Branch, U.S. Geological Survey and under the direct supervision of C. S. Conover, then District Engineer in charge of ground-water investigations by the Geological Survey in New Mexico. Preparation of the final draft of the report was under the general supervision of P. E. LaMoreaux, who succeeded Dr. Sayre as Chief of the Ground Water Branch, and under the direct supervision of W. E. Hale, District Engineer, in charge of ground-water studies in New Mexico after July 1957.

PREVIOUS INVESTIGATIONS AND ACKNOWLEDGMENTS

Hoots (1925) presented a sketchy geologic map that included southern Lea County. The first satisfactory presentation of the surface geology of the area was published in N. H. Darton's *Geologic map of New Mexico* (1928a). Darton (1928b) described the geology of of the area in *Red beds and associated formations in New Mexico.* Since that time an extensive literature on the subsurface geology of the area has grown as a result of the quest for oil. Very little of this work has been concerned with the post-Paleozoic formations, which are the only ones of significance with respect to ground-water supply. In fact, it has become standard practice to log oil tests (both sample logs and electrical logs) only below the top of the Paleozoic rocks. In most oil-well logs it was found that the post-Paleozoic section is described in the most cursory fashion.

Hydrologic investigations prior to this study consisted only of periodic water-level measurements of observation wells near Pearl and Monument, and a short special study made by C. V. Theis (1954) near Eunice.

Two chemical analyses included in Table 8 were made by private concerns and were generously donated by the owners of the wells from which the samples were taken. The writers are especially indebted to the numerous geophysical exploration companies and oil companies who released data of a confidential nature, without which the study would not have been possible.

All photographs, except Figure 8, were made by H. O. Reeder, of the Geological Survey. Figure 8 is included by courtesy of the Soil Conservation Service.

WELL-NUMBERING SYSTEM

The system of numbering wells in this report is based on the common subdivisions in sectionized land. The well number, in addition to designating the well, locates it to the nearest 10-acre tract in the land net (fig. 2).

The well number consists of four parts separated by periods. The first part is the township number, the second part is the range number, and the third part is the section number. Since all the township blocks within Lea County are south of the base line and east of the principal meridian, the letters indicating direction are omitted as are the "T." and "R.," which are indicated by their position in the number. Hence, the number 20.35.31 is assigned to any well located in sec. 31, T. 20 S., R. 35 E.

The fourth part of the number consists of three digits which denote the particular 10-acre tract within the section in which the well is located. Figure 2 also shows the method of numbering the tracts within a section. For this purpose the section is divided into four quarters,

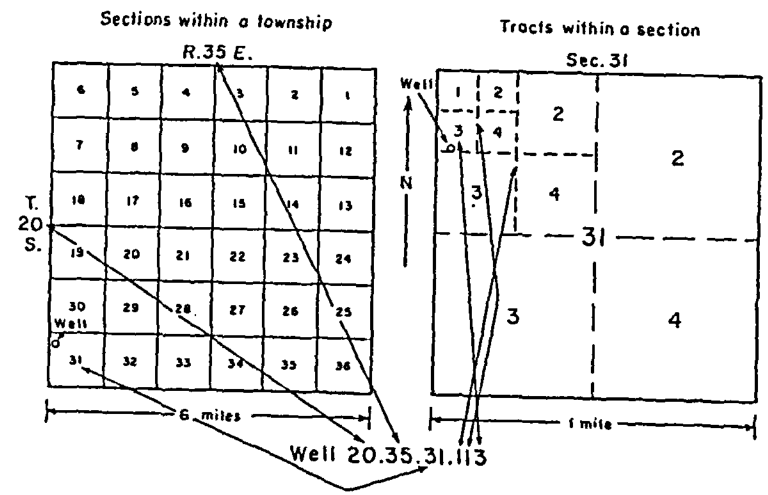

Figure 2

SYSTEM OF NUMBERING WELLS IN NEW MEXICO

numbered 1, 2, 3, and 4, in the normal reading order, for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth part gives the quarter section, which is a tract of 160 acres. Each quarter is subdivided in the same manner so that the first and second digit together define the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts and the third digit denotes the 10-acre tract. Thus well 20.35.31.113 in Lea County is located in the SW¼ of the NW¼ of the NW¼ of section 31, T. 20 S., R. 35 E. Letters a, b, c, . . . are added to the last part of the location number to designate the second, third, fourth, and succeeding wells in the same 10-acre tract. Normally subdivisions of a section are described beginning with the smallest subdivision (e.g., SW¼ of the NW¼ of the NW¼); in the well-location number the description is from the largest subdivision of a section to the smallest.

If a well cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth part of the well number is omitted.

The township and range system is not used in Texas and hence the well-numbering system is modified for the few wells which are included in this report. For wells in Texas, the township and range designation (the first two parts of the well number) is replaced by a block number, for example, A-12. Those blocks that begin with the designation "A" are public school land blocks which are 5 miles square and which are subdivided into 1-mile square sections numbered consecutively 1 to 25 in the same manner as are the New Mexico townships. Public-school-land block C-22 in Winkler County is of such shape that relative locations within it cannot be designated by any numerical system based on existing survey subdivisions. The next to last part indicates a 1-mile square section (except in block C-22), but the number of sections to a block and the sizes of blocks vary. The last part of the well number is determined in the same manner as described above.

Tables 6 and 7, giving records of wells in the southern Lea County area and adjacent counties in Texas, list the wells in numerical order according to the above numbering systems.

Geography

TOPOGRAPHY AND DRAINAGE

Southern Lea County is in the Pecos Valley section of the Great Plains physiographic province. Although Fenneman (1931, 1946) drew the boundary line between the High Plains section and the Pecos Valley section southward through the middle of southern Lea County, the boundary more appropriately follows the drainage divide east of Monument Draw. South of T. 21 S., this divide is in Texas. Mescalero Ridge marks the edge of the Llano Estacado part of the High Plains section on the north. The Llano Estacado part of the High Plains is an isolated mesa that covers a large part of western Texas and eastern New Mexico. It is believed that the name refers to the palisade-like escarpment that surrounds the plain. The name may also refer to the custom of early travelers in the region of driving stakes into the ground as reference points in the absence of prominent landmarks. There is no integrated drainage in southern Lea County, hence there is no through-going drainage to the Pecos River, which is west and south of the area. All stream courses are ephemeral and only one, Monument Draw, has significant length; it traverses the eastern part of the area from north to south for approximately 35 miles and extends into Texas.

The primary contrast between the Llano Estacado and the Pecos Valley section is the abrupt change in topographic texture. The Llano Estacado is a depositional surface of low relief which slopes almost uniformly southeastward, whereas the Pecos Valley section is a very irregular erosional surface which slopes toward the Pecos River, generally westward in the northwestern part and generally southward in the southern part of the area. The topography of the Pecos Valley section is further complicated by areas of interior drainage which are apparently the result of deep-seated collapse due to solution, and by vast areas of both stabilized and drifting dune sand. Sand covers perhaps 80 percent of southern Lea County.

The total relief of the area is about 1,300 feet. The altitude ranges from about 4,200 feet above mean sea level at the base of Mescalero Ridge at the northwestern corner of the area to about 2,900 feet near the southeastern corner of the area. Local relief is generally no more than a few tens of feet.

Figure 3 is a physiographic map of southern Lea County showing geographic subdivisions and major geographic features. The area names are derived from local usage or published maps. In a few places names have been given arbitrarily to areas for convenience of discussion.

Mescalero Ridge and High Plains

The most prominent topographic feature of southern Lea County is Mescalero Ridge, which marks the southwestern limit of the High

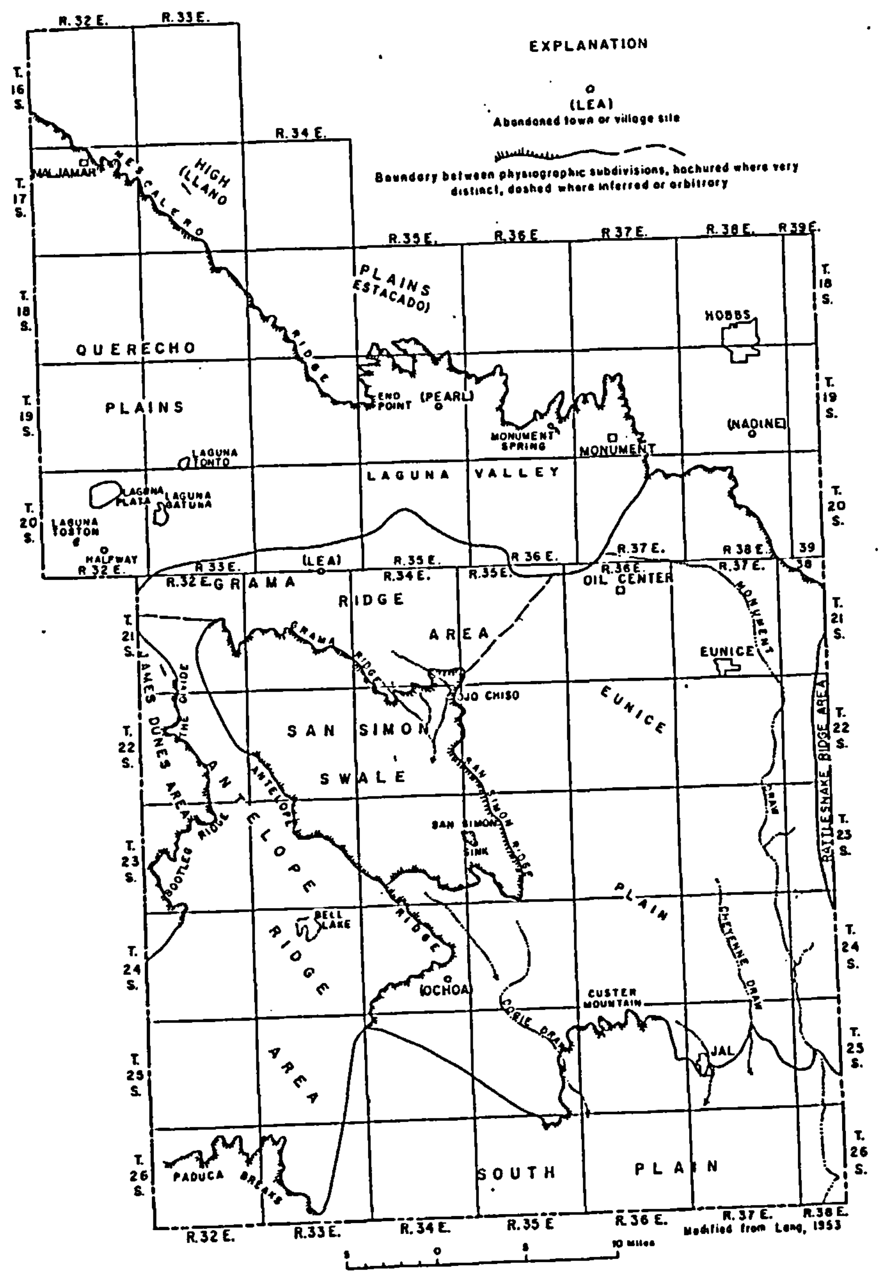

Figure 3

PHYSIOGRAPHIC SUBDIVISIONS OF SOUTHERN LEA COUNTY, N. MEX.

Plains in New Mexico (fig. 3). The so-called ridge, a nearly perpendicular cliff, faces west to southwest. The cliff is capped by a thick layer of resistant caliche, locally called caprock, which underlies the High Plains.

At the northwestern corner of the area, Mescalero Ridge trends southeasterly and rises sharply about 150 feet above the area immediately adjacent to the southwest. The trend is relatively straight for a distance of about 24 miles. The escarpment has neither large reentrants nor deep gullies, and the sharp relief is maintained throughout this distance.

In the northwestern part of T. 19 S., R. 35 E., the ridge curves sharply to the east. The relief is more subdued here, and the scarp has been dissected by large reentrants, which cut back into it as much as 4 or 5 miles (fig. 3). The scarp, owing in part to a heavy cover of dune sand, is barely discernible in the eastern part of Lea County in Tps. 20 and 21 S. In T. 21 S., the ridge extends from Lea County southeast into northern Andrews County, Texas. The subdued relief of the scarp beyond where it turns eastward is caused by erosion resulting from runoff. That runoff is channeled toward the scarp by the southeasterly trending nonintegrated drainage system of the Llano Estacado, whereas farther west on the High Plains rainfall is channeled away from the scarp.

The High Plains surface is uniformly flat and slopes about 17 feet per mile between 15 degrees and 20 degrees south of east. Most of the rainfall runoff is caught in shallow depressions, locally called buffalo wallows, where it remains until it seeps into the ground or evaporates. These depressions range in size from a few feet to more than a quarter of a mile in diameter and from a few inches to about 20 feet in depth. They are scattered in a random fashion, but some are connected by a poorly defined drainage pattern resulting from original irregularities in the surface.

The shallow depressions and small sand dunes are the only significant relief features on the Llano Estacado. Otherwise it is a flat, gently sloping plain, treeless, and marred only by slight undulations and covered with short prairie grass.

Querecho Plains and Laguna Valley

Immediately southwest and south of Mescalero Ridge is a vast sand dune area covering approximately 400 square miles. The western portion of this sand area, called Querecho Plains (fig. 3), extends westward from the scarp to Nimeim Ridge, about 6 miles west of the Lea–Eddy County line. The continuation of this sandy area eastward is known as Laguna Valley (fig. 3). On the south this area is bordered by an area of higher elevation extending from about Halfway to Oil Center. West of about R. 35 E. the land slopes to the west. The eastern part of Laguna Valley (east of R. 35 E.) slopes to the east. Querecho Plains and Laguna Valley are covered almost entirely by dune sand which is stable or semi-stable over most of the area, but which locally drifts. The surface is very irregu-

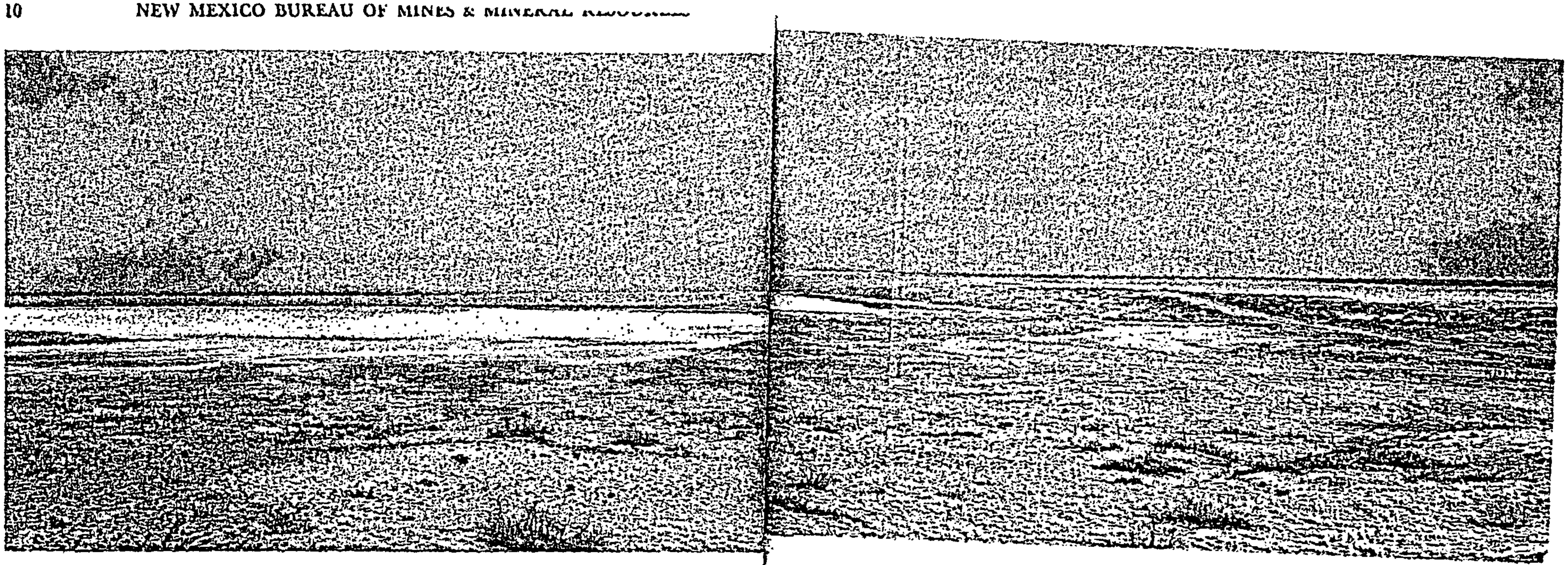

Figure 4

VIEW OF LAGUNA GATUNA LOOKING EASTWARD

(SE¼ SEC. 18, T. 20 S., R. 33 E.)

White appearance is due to salt and gypsum crystals precipitated in the lakebed.

lar and has no drainage features except at the edges of several playas. The sand is generally underlain by Recent alluvium but in several places the sand forms topographic highs where it is underlain by a caliche surface. The thickness of the sand cover ranges from a few inches to a probable maximum of 20 feet.

The most prominent feature in the Querecho Plains is a group of four playas (fig. 3). The largest of these, Laguna Plata, covers about 2 square miles in the north-central part of T. 20 S., R. 32 E. The other three playas are Laguna Gatuna, about 1 square mile in area; Laguna Tonto, less than half a square mile in area; and Laguna Toston, less than a quarter of a square mile in area.

These playas or dry lakes are flat-bottomed and have irregular outlines. Their floors are underlain by fine sediments with a scattering of pebble gravel and precipitated salt and gypsum (fig. 4). The margins rise sharply and are dissected by numerous gullies. Each playa has a large accumulation of dune sand on its east side. Laguna Toston is completely filled and no longer receiving sediments; and the fill is, to a great extent, stabilized by a cover of vegetation.

Other features in the Querecho Plains and Laguna Valley include sandless areas in which the underlying surface is exposed. One such area, covering several square miles in the southeast part of T. 19 S., R. 33 E., is a grassy plain that is almost perfectly flat and underlain by fine alluvium. The evenness of the plain and the fine character of the alluvium suggest lake deposits.

GRAMA RIDGE AREA

Grama Ridge is a name given to a southwestward-facing scarp which borders the San Simon Swale on the northeast. This scarp is at the southern edge of a high area, herein called the Grama Ridge area (fig. 3), which is topographically higher than the Querecho Plains–Laguna Valley area to the north. The Grama Ridge area covers the northern parts of Rs. 32 and 33 E. and all of R. 34 E. in T. 21 S., and parts of adjacent townships.

The Grama Ridge area is characterized by a hard caliche surface whose topographic texture is similar to that of the High Plains. The surface is spotted with many shallow depressions. There is no integrated drainage, but the depressions are cut by well-incised gullies which trend southeastward and which give the area a distinctive surface grain. In some places the Grama Ridge area is covered by sand, notably on the north where dune sand overlaps from the Querecho Plains–Laguna Valley area. On the east the area continues into a sand-buried caliche surface that covers most of the east half of the southern Lea County area.

The Grama Ridge area appears to be an outlier of the High Plains.

The slope and texture of its surface and the composition of the underlying material indicate that it was once part of the Llano Estacado. Furthermore, the slope and altitude of Grama Ridge agree with those of the High Plains.

Eunice Plain

For purposes of this report the term Eunice Plain is used to refer to the eastern part of the area, which has no other specific geographic designation. It is bounded on the north by the Llano Estacado and on the southwest by San Simon Ridge and Antelope Ridge. The westward extension of the Eunice Plain is the Grama Ridge area. On the south the Eunice Plain is bounded by an irregular, low, south-facing scarp which is most prominent at Custer Mountain (fig. 3), where it attains a height of about 60 feet. East and west of Custer Mountain the scarp is less pronounced. To the west it is buried under a mantle of dune sand. To the east it becomes more subdued and irregular, owing to dune-sand cover and to dissection by numerous gullies and draws. Monument Draw traverses the east side of Eunice Plain from north to south. The Eunice Plain is the most highly developed part of the area, including within its limits the towns of Eunice, Jal, and Oil Center, and most of the industrial units and oil fields of the area.

The Eunice Plain is underlain by a hard caliche surface and is almost entirely covered by reddish-brown dune sand. In some places the underlying surface consists of alluvial sediments—most commonly calcareous silt in buried valleys or Quaternary lake basins. It has a general southeast slope toward Monument Draw. The underlying surface is exposed only locally, but it is reflected to some degree in many places by the overlying sand cover a few inches to several feet thick. The dune sand is stable over much of the area, but large areas of migrating sand cover the eastern half of T. 23 S., R. 35 E. and the southern part of T. 23 S., R. 38 E. Large accumulations of drifting sand are found along the west side of Monument Draw, and there are many other small local areas of drifting sand. In the areas of drifting sand, the dunes tend to be longitudinal and trend a little south of east. The sand cover is 2 to 5 feet thick over most of the area, but locally is as much as 20 or 30 feet thick, especially in the drift area. The larger drift areas form a discontinuous strip across the plain extending slightly south of east from the San Simon Ridge. These drift areas represent an encroachment of sand from the San Simon Swale area, which has a great accumulation of sand on its east side.

In areas of sand cover, the vegetation is dominantly shin oak with bear grass and bur-grass. The dominant vegetation elsewhere is grama grass, bur-grass, and mesquite.

Monument Draw

The only major drainage feature within southern Lea County is Monument Draw, which heads in the southwest part of T. 20 S., R. 37 E. In its upper reaches the draw trends a little south of east, but in the northern part of T. 21 S., R. 37 E. it turns and meanders southward to the State line. Because available maps do not show its continuation beyond that point, it is assumed that it fans out and terminates a few miles beyond where it crosses the State line.

The course of Monument Draw is almost perpendicular to the regional topography and drainage. The regional slope is to the southeast, and wherever drainage patterns have developed they are consequent to the slope. Monument Draw, however, cuts across the normal drainage at a sharp angle and conforms to the general trend only in its uppermost reaches. Farther east, in Texas, the regional slope is also east and southeast. In some places along its east side the draw has some well-developed tributary drainage areas several miles long.

Over much of its course Monument Draw is a well-defined, sharply incised cut about 30 feet deep, ranging from about 1,800 to about 2,000 feet wide; but there is no throughgoing drainage course. The draw is partly filled, primarily by dune sand and alluvium, and it is densely overgrown in many places with vegetation.

The sediments on the south side of the northern reach of Monument Draw are capped by the hard caliche surface of the Eunice Plain. Where the draw turns southward, it traverses a broad level area of lake deposits and becomes more shallow and subdued (fig. 5). At the southeast corner of T. 21 S., R. 37 E. the draw almost disappears under a blanket of dune sand. It reappears about 4 miles to the south and continues as a sharply incised feature until it leaves southern Lea County at the Texas State line.

Rattlesnake Ridge Area

East of Monument Draw the Eunice Plain rises toward a north-trending topographic high, known locally as Rattlesnake Ridge. Throughout most of its length the crest of this ridge closely parallels the State line. Nearly 2 miles east of the State line, in the latitude of Eunice, the crest of the ridge is about 125 feet higher than Monument Draw, and the land slopes westward toward Monument Draw 27 to 28 feet per mile. Rattlesnake Ridge restricts Monument Draw to its north-south trend and is regarded as the drainage divide between the Pecos River basin and the Colorado River basin, Texas (U.S. Weather Bureau, 1949). The ridge is apparently the reflection of a structural feature of Cenozoic origin. It is possibly a fault, but more probably it is a gentle flexure produced by differential compaction of the sediments to the west.

San Simon Swale

To the west of Eunice Plain is a large depression, covering roughly 100 square miles, known as the San Simon Swale. It is bounded on the northeast by Grama Ridge and San Simon Ridge, and on the southwest by areas of higher altitude. The southwestern boundary is less sharply

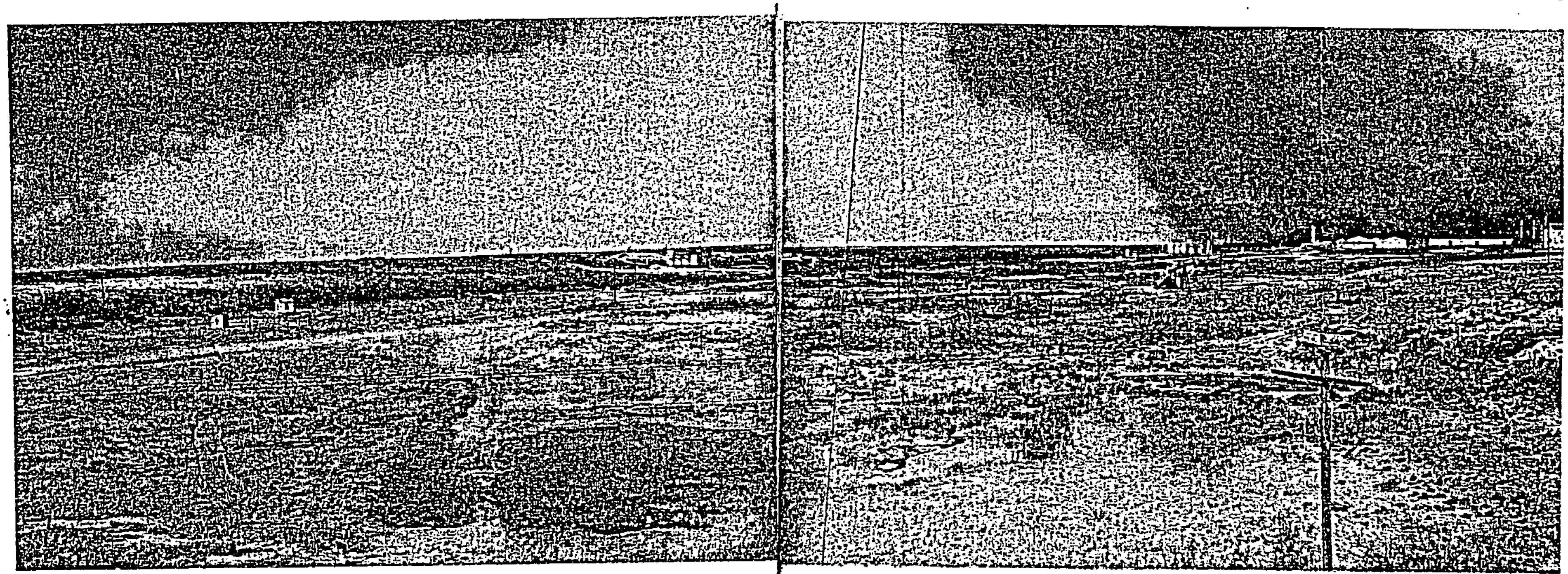

Figure 5

VIEW OF MONUMENT DRAW LOOKING NORTH-NORTHWEST FROM RAILROAD TRESTLE IN THE SW¼ SEC. 3, T. 21 S., R. 37 E., ABOUT 4½ MILES NORTH OF EUNICE, N. MEX.

Cross section of Figure 18 crosses area from white gable-roofed shed on left to the right of the carbon-black plant. Water in foreground is impounded rainfall.

defined than the northeastern boundary. The term *swale* is misleading in that it usually defines a marshy depression, whereas at the present time the San Simon Swale is entirely devoid of marshy areas. The swale is elongate southeastward and covers most of T. 22 S., Rs. 33 and 34 E. and T. 23 S., R. 34 E., and parts of adjacent townships. Most of it is covered by stabilized dune sand and no drainage pattern is apparent. At its southeast end a large area of drift sand is banked against the east side of the swale and is continuous with the area of drift sand on Eunice Plain. The lowest point within the swale is the San Simon Sink, in sec. 18, T. 23 S., R. 35 E., just west of the eastern escarpment of the swale. The sink is about 100 feet deep from its rim to the bottom and approximately half a square mile in area. Within the sink there is a secondary collapse about 25 to 30 feet deep (see fig. 6). The fill in the sink is mostly calcareous silt and fine sand. Active subsidence is reported to have taken place as recently as 25 or 30 years ago, when large annular fissures developed at the edge of the sink (see fig. 6, 7 and 8). These fissures are still evident and are still as deep as 5 feet in some places. The area immediately adjacent to the sink on the north, south, and west is a grassy plain underlain by sand and silt. Another sink, no longer active, is in sec. 33, T. 21 S., R. 33 E.

The San Simon Swale probably originated as the result of deep-seated collapse. The area may have subsided as a unit. More probably, however, the depression is the result of the removal of material by deflation and by fluvial erosion into large sinks of which the San Simon Sink may be the only one exposed, the others having been completely filled and hidden by the cover of dune sand. Assuming that the swale area was once completely covered by Tertiary sediments, about 2 cubic miles of material have been removed in Quaternary time. It is not probable that all of this material could have been deposited in sinks. A large part has been blown out of the sink, giving rise to the drift-sand areas to the east and southeast. At some time in the prehistoric past the swale may have been a perennial lake with outlets at its southeast end, and stream erosion may have lowered the level of the Eunice Plain in that area so as to form an extension of Antelope Ridge. However, there is no physical evidence to support such an interpretation, and the heavy dune-sand cover makes detailed investigation most difficult.

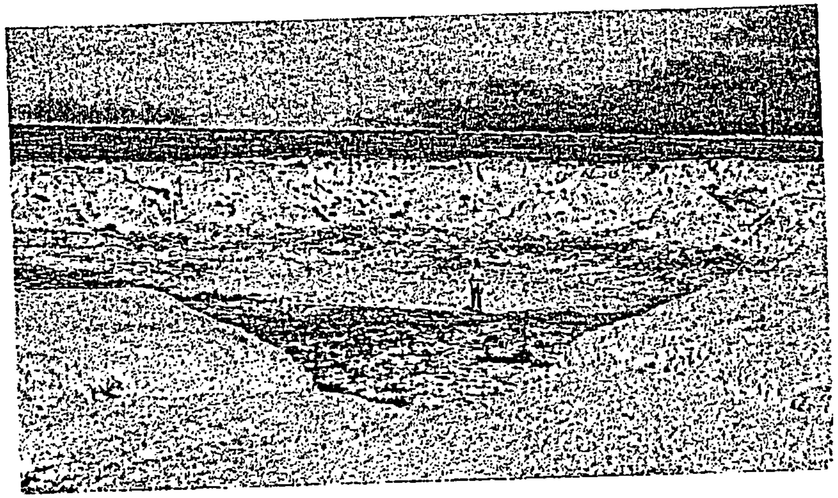

Figure 6

SECONDARY SINK WITHIN THE SAN SIMON SINK (SEC. 18, T. 23 S., R. 35 E.)

Surrounding sediments are Quaternary lacustrine deposits, dominantly sandy calcareous silt.

Figure 7

ANNULAR FISSURE DEVELOPED AT PERIPHERY OF SAN SIMON SINK BY SUDDEN COLLAPSE (SEC. 18, T. 23 S., R. 35 E.)

Fissure continues and curves to the right in the far background.

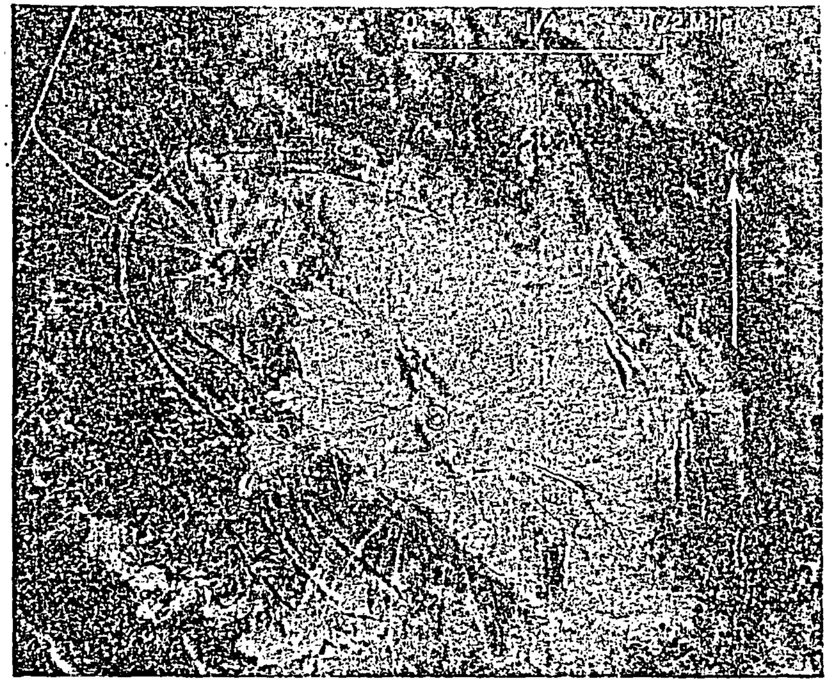

Figure 8

AERIAL PHOTO OF SAN SIMON SINK SHOWING ANNULAR FISSURES (SEC. 18, T. 23 S., R. 35 E.)

ANTELOPE RIDGE AREA

The area to the southwest and west of Antelope Ridge is here defined as the Antelope Ridge area. The northern part of the area is bounded on the west by the west-facing scarps of Bootleg Ridge and The Divide. The southern part of the area extends westward into Eddy County. The Paduca Breaks bound the area on the south in Lea County. The Antelope Ridge area has a relatively flat, sand-covered surface, underlain for the most part by a hard caliche surface similar to that of the Eunice Plain area. It is the least developed and most desolate part of southern Lea County. Toward the south the dune sand appears to be underlain by Quaternary fill and loamy soil, which apparently were deposited in a very large depression, probably similar to the San Simon Swale. As on the Eunice Plain it is almost impossible, because of the dune-sand cover, to delineate areas underlain by caliche from those underlain by alluvium. Two playa lakes are located in the Antelope Ridge area, Bell Lake (sec. 3, 4, 9, and 10, T. 24 S., R. 33 E.) and an unnamed depression at the southeast corner of sec. 24, T. 24 S., R. 33 E.

Antelope Ridge is an anomalous geomorphic feature. Through Tps. 22 and 23 S., R. 33 E. it forms the southwestern rim of the San Simon Swale. In T. 24 S., R. 34 E., it is higher than the Eunice Plain, which is in turn higher than the swale. Extrapolation of the land-surface contours from the High Plains across the Grama Ridge area would bring the High Plains contours into contact with contours of the same value on the northern part of Antelope Ridge. Therefore Antelope Ridge is probably another outlying remnant of the High Plains.

James Dunes Area

The James Dunes area in this report is that part of southern Lea County which lies below the west-facing scarps of Bootleg Ridge and The Divide (fig. 3); it is a topographically irregular area where dune sands rest directly on Triassic rocks. The area extends far to the west in Eddy County.

South Plain

The area south of Eunice Plain has no generally accepted local name and is here referred to as South Plain. The topography is very irregular and without integrated drainage. Several well-developed gullies head in the Eunice Plain area, but do not completely traverse the South Plain. The area is almost completely covered by a thick layer of sand.

At the southwest corner of the southern Lea County area a low, south-facing scarp is known locally as the Paduca Breaks. The area immediately to the south of the Breaks is a westward continuation of the South Plain.

CLIMATE

The climate of southern Lea County is characterized by low annual precipitation, low humidity, and high average annual temperature. Historically, the climate has ranged from dry subhumid to arid, although the majority of the time the climatic conditions can be classified as marginal between semiarid and arid (Thornthwaite, 1941). Precipitation is highly variable both areally and seasonally, although the maximum precipitation usually is recorded during the summer months. Temperature maxima are usually recorded during June and the weather station at Jal frequently records the highest temperature of the year for the State. The area is situated at the southwest edge of the Great Plains dust-bowl area and is subject to severe windstorms, which sometimes last a week or more.

The mean annual precipitation in southern Lea County ranges from 15.68 inches per year at Hobbs in the northern part to 12.63 inches at Jal in the southern part of the area.

Figure 9 shows the average distribution of precipitation over the area during the period 1949–55 based on data from the U.S. Weather Bureau.

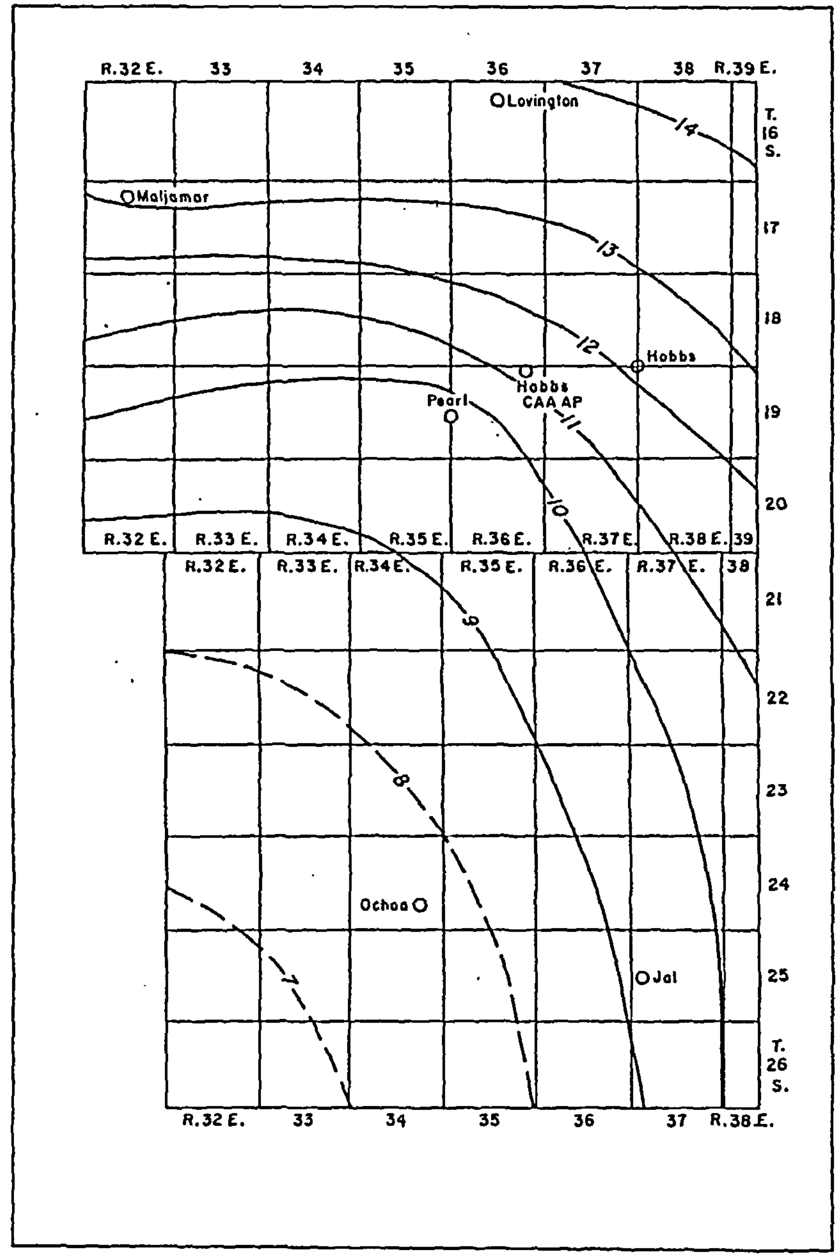

Figure 9

Average annual rainfall in southern Lea County, N. Mex., 1949–55

Lines show equal average annual precipitation in inches.

The map is not intended as an accurate description of conditions. The short period of record used to compile the map does not provide sufficient data for such purposes. Additional stations or longer record would modify the pattern slightly. Nevertheless, the general characteristics of the area's precipitation and the increase in aridity toward the southwest are evident. The greater part of the precipitation is in the form of sudden showers of limited duration and areal extent; regional rainfalls of longer than 24 hours duration are rare and probably average less than two a year. Figure 10 illustrates the degree of variation of annual precipitation from place to place.

Figure 11 shows monthly precipitation at Pearl for the years 1950–53 and illustrates the erratic seasonal distribution of precipitation. This graph should not be considered representative of the area as a whole, but it serves to show the general characteristics of the area. During the 4-year period maximum precipitation occurred in 3 different months, as early as May, in 1951, and as late as October, in 1953.

During the late 1940's and early 1950's the area was subject to drought. While the deficiencies are not large, in a semiarid to arid climate they are sufficient to affect the vegetation of the area adversely.

Measurements of evaporation are not available for the area. However, an examination of the evaporation records of the weather stations at Portales, New Mexico; Red Bluff Dam, Texas; and Grandfalls, Texas, indicates that the total annual evaporation is about 100 inches. Portales is about 125 miles north of Eunice; Red Bluff Dam is 60 miles southwest of Eunice; and Grandfalls is 130 miles south-southeast of Eunice. Statistical analysis by the U.S. Weather Bureau (undated) shows that the monthly evaporation opportunity is probably distributed in inches as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3	4	8	11	12	14	13	12	9	7	4	3

These figures represent the probable evaporation in inches as recorded in a standard class "A" land-type pan of the U.S. Weather Bureau. Evaporation from a larger free-water surface, such as that of a pond or lake, would be about 70 percent of the recorded figure (Harding, 1942, p. 75). Furthermore, the water loss from body of standing water would depend on total rainfall. Hence, if an enclosed pond, such as a brine-disposal pit, were subject to 70 inches of evaporation and received 10 inches of rainfall during the period of a year, the net water loss would be 60 inches. A pond which has a surface area of 100 feet by 100 feet would, therefore, be capable of losing about 50,000 cubic feet or 1.15 acre-feet of water by evaporation in 1 year.

The average annual temperature of the area is about 62°F, ranging only 3.8°F from Maljamar (60.4°F) in the north to Jal (64.2°F) in the

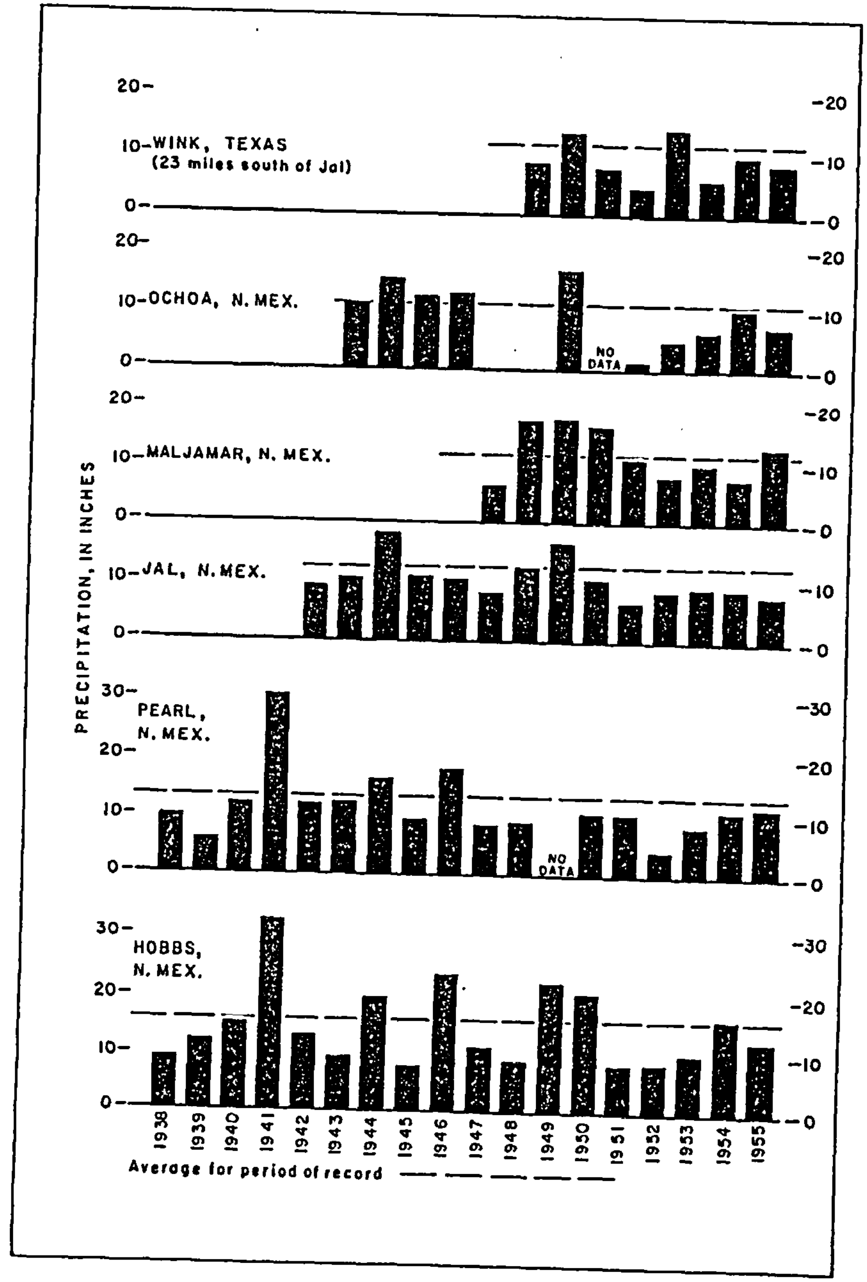

Figure 10

ANNUAL PRECIPITATION IN AND NEAR SOUTHERN LEA COUNTY, N. MEX., 1938–55

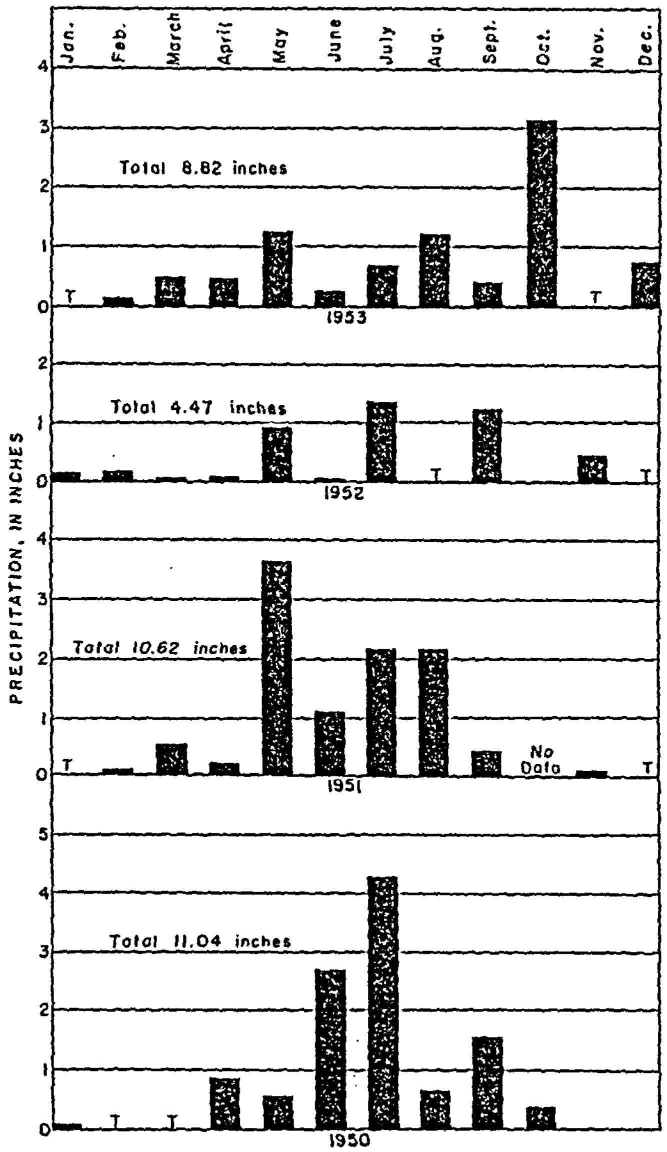

Figure 11
MONTHLY PRECIPITATION AT PEARL, N. MEX., 1950–53

south. The average annual temperatures recorded at U.S. Weather Bureau stations within and near the southern Lea County area during the period 1949–55 are shown on Table 1.

The average monthly temperature ranges from a high of about 81°F at Jal during the summer to a low of about 42°F at Maljamar in winter. The extreme recorded temperatures during the period 1949–55 were more than 100°F for the highest and just a few degrees above zero for the lowest. The average period of time between last and first freezing temperatures is 208 days, and the range is from 180 to 246 days. Figure 12 shows the seasonal variation in temperature as recorded at Jal and Pearl, New Mexico, during the year 1953.

TABLE 1. AVERAGE ANNUAL TEMPERATURE AT STATIONS IN SOUTHERN LEA COUNTY, N. MEX., 1952–55

Station	Altitude (ft)	Average annual temperatures (°F) 1949	1950	1951	1952	1953	1954	1955	Average (°F) 1949–55
Maljamar	4,153	59.2	61.4	60.4	59.6	60.7*	62.0	59.8	60.4
Pearl	3,800	60.2	62.2	61.8*	61.4	62.7	62.6	62.2	61.9
Hobbs CAA AP	3,655	59.7	61.5	60.9	60.8	62.2	62.5	60.8	61.2
Hobbs	3,615	60.6	61.8	62.0	61.9	63.1	63.6	61.9	62.1
Jal	3,150	61.6	64.4*	64.4	63.6*	65.1	66.3*	64.2*	64.2
Wink (Texas) CAA AP	2,785	64.0	66.2	65.4	64.3	66.1			

* Includes estimated average temperature for one month of missing record.

Windstorms occur throughout the year, but are of greatest frequency and intensity during the spring. Wind velocities reach magnitudes sufficient to damage structures, and frequently gusts are powerful enough to move rock particles of pebble size. On one occasion, after a windstorm in March 1953, the senior author found pebbles lodged on the fender of a car about 3½ feet above the ground. The largest pebble weighed 0.7 gram and was about 40 cubic millimeters in volume. In the southern part of the area sand dunes encroach on roads and the Texas Pacific Railroad tracks during storms, and unpaved roads in parts of the area become badly rutted by the wind action.

POPULATION

Until the 1880's this area was occupied by the Comanche Indians, who subsisted principally on the great herds of buffalo (American bison) which roamed over most of the Great Plains. Between 1880 and 1890, buffalo hunts destroyed the herds. After 1890 several ranches were established, and the 1900 census reported a total population of 128 in Precinct 5, Eddy County, of which Lea County was then only a part. During the first decade of this century land was made available for homesteading, and by 1910 Precinct 5 had a population of 967. In 1917 Lea County was formed from parts of Eddy and Chaves Counties, and

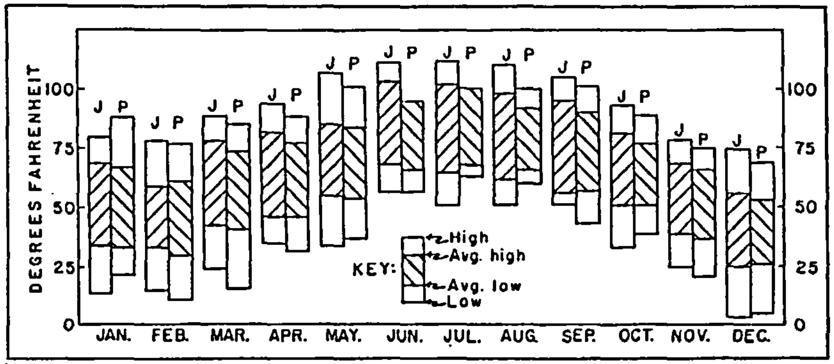

Figure 12
TEMPERATURE RANGES AT JAL AND PEARL, N. MEX., 1953
Data for Pearl in June and July are partly missing.
J—Jal; P—Pearl.

the 1920 census is the first which gives particular data for the area covered by this report. The population changes are shown in the table below:

CENSUS YEAR	POPULATION IN SOUTHERN PART OF LEA COUNTY	POPULATION OF INCORPORATED TOWNS	
		Eunice	Jal
1920	911	—	—
1930	1,299*	—	404
1940	4,884*	1,227	1,157
1950	7,787*	2,352	2,047

* Includes population of incorporated towns.

In 1953 the populations of both Eunice and Jal were estimated at more than 3,000 each.

The sudden growth between 1930 and 1940, and its continuance, is a result of the development of the oil industry in an area which had theretofore been exclusively used for cattle raising. Lea County has grown in population from 6,144 in 1930 to 30,717 in 1950, and the percentage living in the southern part has increased from 21 percent in 1930 to 25 percent in 1950. It is probable that this trend will continue in coming years with further expansion of the oil industry.

ECONOMY

Southern Lea County has undergone very rapid economic changes during its development. With the passing of the buffalo, between 1880 and 1890, came the advent of commercial stock raising and the development of a few ranches. During the first decade of the present century the area was opened to homesteading, and numerous small ranches and communities came into being. Nadine, Ochoa, and Pearl, which today are mere place names, were once centers of population which could boast 100 or more inhabitants.

The first oil well in Lea County, drilled in 1926 at Maljamer, gushed in a new economic era and the development of a continually expanding oil and gas industry. By the end of 1945 the southern Lea County area had yielded 258,555,485 barrels of oil and the production for that year was 21,986,778 barrels. In 1955 production was about 10,000,000 barrels more than it was in 1945. More than half of the total oil production of the area was produced between 1945 and 1955. Through 1955, the cumulative production of oil and gas was 559,065,920 barrels of oil and 3,612,288,095 thousand cubic feet of gas. The production for the most recent years is summarized in Table 2.

All the currently producing fields are along the edge of the Delaware basin (fig. 13) on relatively shallow structures. In 1954 a successful discovery well was drilled in the deeper part of the basin near Bell Lake by the Continental Oil Co., and it appears that expansion of the oil and gas industry in the southern Lea County area may continue for a considerable period of time.

Nine gasoline plants are located within the area. Table 2 gives a brief summary of their production during the years 1952–55. During World War II the critical need for carbon black, for use in the manufacture of synthetic rubber, led to the construction of four carbon black plants in the southern Lea County area. All of the carbon black plants are located along the Texas Pacific Railroad near Eunice. The carbon black is produced by burning natural gas under oxygen-deficient conditions. Production by the carbon black plants is summarized in Table 2.

TABLE 2. SUMMARY OF INDUSTRIAL PRODUCTION IN SOUTHERN LEA COUNTY, N. MEX., 1952–55*

	1952	1953	1954	1955
GAS PROCESSING				
Gas received into plants (M cu ft)	219,897,940	234,093,793	232,240,380	263,448,919
Gasoline produced (bbl)	3,105,409	3,323,503	3,407,551	3,392,166
Butane produced (bbl)	1,182,163	1,303,395	1,263,929	1,421,795
Propane produced (bbl)	826,440	1,008,150	1,327,919	1,409,515
CARBON BLACK				
Gas used (M cu ft)	49,960,785	50,949,295	47,283,812	49,178,558
Carbon produced (lbs)	102,612,649	99,432,260	90,434,096	92,194,707
OIL AND GAS				
Oil (bbl)	31,548,763	33,110,136	31,652,980	32,354,648
Gas (M cu ft)	272,692,184	275,090,981	287,701,197	305,047,423
Operating oil wells	3,576	3,693	3,899	4,165

* Based on data from the New Mexico Oil Conservation Commission Annual Reports.

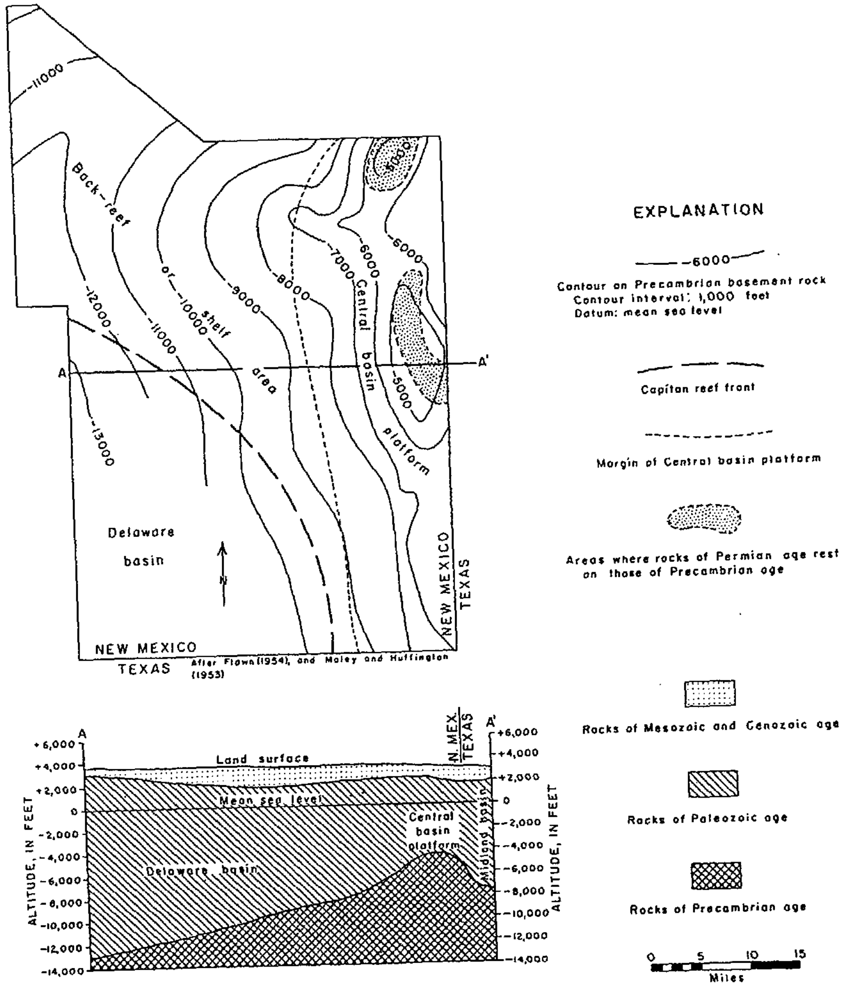

Figure 13

STRUCTURE MAP AND CROSS SECTION OF THE DELAWARE BASIN AND CENTRAL BASIN PLATFORM, LEA COUNTY, N. MEX.

The remainder of the economy of the area is critically dependent on the oil and gas industry. Oil-well drilling, oil exploration, oil-industry services such as equipment sales and well servicing, provide the larger part of the income of the area.

Stock raising, which once dominated the economy of the area, is now of only secondary importance. The drought of the early 1950's cut the herds to relatively small sizes. The records of the New Mexico State Tax Commission show that the cattle population of Lea County during the years 1952, 1953, and 1954 was 46,503, 41,064, and 37,374, respectively, a decline of nearly 20 percent during the 3-year period. It is estimated that the reported figures represent about 70 percent of the total cattle population in Lea County and that about a third of the cattle are to be found in the southern Lea County area. Hence, the cattle population for the southern Lea County area during the 3-year period was about 22,000, 20,000, and 18,000.

Geology

Southern Lea County includes a part of a large subsurface structural feature known as the Permian basin, which underlies southeastern New Mexico and a large part of western Texas. Exploration for oil has revealed a highly complex subsurface geology which involves rocks ranging from Precambrian and early Paleozoic to Permian in age. Paleozoic and Precambrian rocks have little significance in questions relating to potable and industrially usable ground waters except, incidentally, as the source of the highly mineralized water produced with oil. The oldest rocks exposed in the area are Triassic in age. Cretaceous rocks have been uncovered in a gravel pit near Eunice, but the unit is apparently of very limited extent. The only other rocks to be seen at the surface are Tertiary and Quaternary in age. Only the Mesozoic and younger rocks yield potable water (see table 3). Rock exposures are notably poor; nowhere in the area is there a complete section of the Triassic or Cretaceous rocks, and large areas are covered by drift sand.

Plate 1 shows the distribution of geologic units exposed in southern Lea County. The contacts on the map are generalized and their location is, to some extent, approximate, except for the contact between the Ogallala formation and the Quaternary alluvium at the base of Mescalero Ridge. Because of the poor exposures, some contacts necessarily have been drawn on the basis of topographic breaks indicated on various unpublished topographic maps.

The following description of the stratigraphy of the area is rather brief, and the numerous controversial questions regarding correlation and structure are not discussed. The description is based primarily on a résumé prepared under the direction of R. E. King (King et al., 1942).

STRATIGRAPHY

Southern Lea County includes parts of the Delaware basin, the back-reef or shelf area, and the Central basin platform of the Permian basin (fig. 13). The southwestern part of the county overlies the Delaware basin and the eastern part overlies the Central basin platform. Between the two areas is the back-reef or shelf area. These general areas are defined on the basis of differing sedimentary depositional environments that existed during Permian time. The boundary between the basin and shelf areas is fairly sharp, being marked by a complex of reef deposits; the boundary between the shelf area and the platform is transitional. The total thickness of the Paleozoic and younger rocks in these provinces ranges from about 8,000 feet in the Central basin platform to more than 17,000 feet in the deepest part of the basin.

Precambrian Rocks

The Precambrian rocks that underlie southern Lea County have been penetrated only in deep oil-test wells. According to Flawn (1954a, 1954b), the known depth to the Precambrian basement rocks ranges in southern Lea County from 7,600 feet on the east side to 16,800 feet on the west side. The Precambrian consists primarily of granitic igneous rocks which apparently intruded older igneous and metamorphosed sedimentary rocks over a vast area in western Texas and eastern New Mexico during middle Precambrian time.

Paleozoic Rocks

A thick section of Paleozoic sedimentary rocks overlies the Precambrian basement rocks. The Lower Ordovician is represented by the Ellenburger group, which is a light-colored cherty, crystalline dolomite. The Middle Ordovician is represented by the Simpson group, which conformably overlies the Ellenburger with a sharp lithologic break. It is 880 feet to 1,850 feet thick and consists of three main limestone units that alternate with green shales and thin layers of sandstone and limestone. The Upper Ordovician Montoya dolomite is a cherty limestone, which is about 250 feet thick on the Central basin platform.

Rocks of Silurian age are represented on the Central basin platform by a coarse-grained crystalline glauconitic limestone 180 to 200 feet thick, correlative with the Middle Silurian Fusselman dolomite and overlain by 180 feet of green, gray, and black shales interbedded with dense limestone.

Rocks of Devonian age consist of interbedded calcareous chert and siliceous limestone, which reach a known maximum thickness of 980 feet. The siliceous section is believed to be Late Devonian but may be Early Mississippian in age. Rocks of definite Mississippian age are absent from the area covered by this report.

Rocks of Pennsylvanian age are separated from the older rocks by an erosional unconformity. On the Central basin platform the rocks of Pennsylvanian age overlie the Simpson group of Middle Ordovician age; elsewhere they overlie rocks of Devonian age. Here their thickness ranges from 1,650 to 2,700 feet and the Pennsylvanian is divisible into two units. The bottom unit is shale, and the top unit is limestone, gray shale, and conglomeratic red shale. In the Delaware basin the rocks of Pennsylvanian age are dark shales and limestones.

The rocks of Permian age of the area were deposited on an irregular surface formed by Late Pennsylvanian folding. The basins subsided more rapidly than the Central basin platform and hence continued to accept sediments at times when there was little or no deposition on the platform. The Permian rocks are divided into four series: Wolfcamp, Leonard, Guadalupe, and Ochoa.

TABLE 3. STRATIGRAPHIC UNITS IN SOUTHERN LEA COUNTY, N. MEX.

Era	System	Geologic age	Geologic unit	Thickness (ft)	General character	Water-bearing properties
Cenozoic	Quaternary	Recent and Pleistocene	*Sand*	0–30±	Dune sand, unconsolidated stabilized to drifting, semiconsolidated at depth; fine- to medium-grained.	Above the zone of saturation, hence, does not yield water to wells. Aids recharge to underlying formations by permitting rapid infiltration of rainwater.
			Alluvium	0–400±	Channel and lake deposits; alternating thickbedded calcareous silt, fine sand, and clay; thickest in San Simon Swale; less than 100 feet thick in most places.	Saturated and highly permeable in places in east end of Laguna Valley. Forms continuous aquifer with Ogallala formation. Wells usually yield less than 30 gpm. Locally above the water table.
Cenozoic	Tertiary	Pliocene	Ogallala	0–300±	Semiconsolidated fine-grained calcareous sand capped with thick layer of caliche; contains some clay, silt, and gravel.	Major water-bearing formation of the area. Unsaturated in many localities, such as north side of Grama Ridge, west side of Eunice Plain, Antelope Ridge area, and Rattlesnake Ridge. Greatest saturated thickness along east side of Eunice Plain, west of Monument Draw, where wells yield up to 30 gpm. Highest yields, up to 700 gpm, obtained from wells along south edge of Eunice Plain, east of Jal.
Mesozoic	Cretaceous		Undifferentiated	35±	Small isolated and buried residual blocks of limestone, about 3 miles east of Eunice.	Possibly small isolated bodies of water locally.
Mesozoic	Triassic	Dockum group	Chinle formation	0–1,270±	Claystone, red and green; minor fine-grained sandstones and siltstones; underlies all of eastern part of southern Lea County area; thins westward; absent in extreme west.	Yields small quantities of water from sandstone beds. Yields are rarely over 10 gpm. Water has high sulfate content.
			Santa Rosa sandstone	140–300±	Sandstone, chiefly red but locally white, gray, or greenish-gray; fine- to coarse-grained; exposed in extreme west; underlies Cenozoic rocks in western part of area, and is present at depth in eastern part.	Yields small quantities of water over most of the area. Some wells are reported to yield as much as 100 gpm. Water has high sulfate content.
Paleozoic	Permian or Triassic		Undifferentiated	90–400+	Siltstone, red, shale, and sandstone; present at depth under all of southern Lea County.	No wells are known to be bottomed in the red beds. Probably can yield very small quantities of high-sulfate water.
Paleozoic	Ordovician through Permian			6,500–17,000±	Thick basin deposits ranging in character from evaporites to coarse clastics; thinnest on the east side of the area over the Central basin platform, thickest toward the southwest.	No presently usable water supply available from these rocks. Source of highly mineralized oil-field waters.
Precambrian					Granite, granodioritic and other igneous and metamorphic rocks; complex structure.	Not hydrologically significant.

The basal Permian, the Wolfcamp series, is absent in the structurally higher parts of the Central basin platform; but where present in the structurally lower parts, it is chiefly limestone. At its base there is a variable thickness of as much as 440 feet of red and green shales and conglomerate. In the Delaware basin the Wolfcamp consists of dark shale and brown sandstone.

Above the Wolfcamp is the Leonard series, which consists mainly of the Bone Spring limestone. In the basin area it is black calcareous shale interbedded with black limestone and is as much as 3,000 feet thick. Toward the basin margins and in the shelf and platform areas, the Leonard is represented by the Abo and Yeso formations, which have a diverse lithology. The Yeso overlies the Abo and grades vertically into the Glorieta sandstone.

In the subsurface on the Central basin platform the San Andres limestone, which overlies the Glorieta, is composed of dolomite beds with subordinate limestone members and is as thick as 1,460 feet. It is divided into an upper light-colored, noncherty part, and a lower dark cherty part. The San Andres limestone is, in some areas, of Leonard age, and is correlative with the upper part of the Bone Spring limestone. In other areas it is of Guadalupe age and is correlative with the Cherry Canyon formation of the Delaware basin.

In the Delaware basin the Guadalupe series is represented by the Delaware Mountain group, which is subdivided into three formations, which are (oldest to youngest): Brushy Canyon, Cherry Canyon, and Bell Canyon. The Delaware Mountain group consists of fine-grained sandstone with thin layers of black shale and argillaceous limestone. Toward the margin of the basin the upper two formations grade into the Capitan and Goat Seep reef facies, which fringe the basin. The lower Brushy Canyon formation is absent in the shelf and platform areas and the Cherry Canyon and Bell Canyon formations are represented by the Whitehorse group, which rests unconformably on the San Andres limestone and extends to the top of the Guadalupe series. The Whitehorse group grades shelfward from gray, coarsely crystalline reef limestones and dolomites into buff to tan well-bedded dolomite interbedded with fine-grained sandstones and thence into alternating anhydrite, dolomite, and sandstone. The Whitehorse group consists of five formations which are (oldest to youngest): the Grayburg, Queen, Seven Rivers, Yates, and Tansill. The group ranges in thickness from 880 feet to more than 1,500 feet.

The Ochoa series consists chiefly of evaporite deposits that were formed during recurrent retreats of a shallow sea. The lowermost formation of the series is the Castile formation, which is chiefly anhydrite but contains some halite beds. It rests unconformably on the Delaware Mountain group in the Delaware basin but does not extend beyond the basin margin. The Castile formation ranges in thickness from zero to about 1,800 feet. Overlying the Castile formation is the Salado formation, which extends across both the Delaware and Midland basins and across the Central basin platform. It ranges in thickness from zero to about 2,000 feet. In the back-reef and platform areas it rests unconformably on the Whitehorse group. The formation is mainly halite containing some anhydrite. The Rustler formation, which ranges in thickness from 90 to 360 feet and consists chiefly of anhydrite but includes red beds and salt, overlies the Salado. In some places it is separated from the Salado by a marked unconformity.

Permian or Triassic Rocks

Overlying the Rustler formation is a sequence of red beds to which several names have been applied. They consist of micaceous red siltstone, shale, and sandstone and are commonly cemented with gypsum. For the purpose of this report they are classed as Permian or Triassic red beds, undifferentiated.

According to Page and Adams (1940, p. 62) these red beds rest conformably on the Rustler formation and ". . . . A zone of coarse, frosted quartz grains is almost everywhere present in the lower 10 feet." These authors named the lower part of the red-beds interval the Dewey Lake, and this term has persisted in most of the literature on the subsurface geology of the area.

The upper part of the red-beds sequence has been referred to as the Tecovas formation and evidence has been cited (Page and Adams, 1940, p. 62) for an unconformity, which was the basis for separating rocks of Permian age from those of Triassic age. Inasmuch as the type section of the Tecovas formation is in Potter County, Texas, more than 200 miles from southern Lea County, this name seems inappropriate.

In the course of mapping the Nash Draw quadrangle, a few miles west of Lea County, Vine (1959) assigned all the red beds between the Rustler formation and the Santa Rosa sandstone to the Pierce Canyon red beds, and he considers the unit to be of Permian or Triassic age.

The present investigation has produced no information that will help resolve the problems of the age of these red beds. A description of drill cuttings from the unit is included in Table 4.

The hydrologic significance of these red beds is not completely understood; however, it is doubtful that any wells in southern Lea County produce water from them. The lower limit of potable ground water may be somewhere within the stratigraphic interval. Further, the red beds probably retard the interchange of water between the evaporite-bearing rocks of the Permian and the sandstone aquifers of the overlying Dockum group.

Mesozoic Rocks

The Mesozoic era is represented in the area only by Upper Triassic rocks of the Dockum group and by a small exposure of Cretaceous rocks near the eastern margin of the county. The contact between the Triassic

TABLE 4. LOG OF THE TRIASSIC SECTION, CONTINENTAL OIL CO. NO. 2 BELL LAKE UNIT
SE¼SW¼ SEC. 30, T. 23 S., R. 34 E.

Age	Formation and thickness (ft)	Depth (ft)	Thickness (ft)	Description
	Ogallala	0– 60	60	Caliche, white, sandy.
Tertiary	125	60– 125	65	Sandstone, tan, fine- to medium-grained, sub-rounded, calcareous.
		125– 210	85	Sandstone, fine, and siltstone, greenish-gray; slightly calcareous.
		210– 280	70	Siltstone and clay, red and green; some sandstone, green, fine-grained, calcareous.
Triassic	Chinle 325	280– 300	20	Sandstone, light-gray, fine- to very fine-grained, slightly calcareous; much pyrite with many small euhedral crystals.
		300– 450	150	Siltstone and clay, red and green; some sandstone, green, fine-grained, calcareous.
		450– 680	230	Sandstone, red, generally fine- to medium-grained but ranging from very fine to coarse, angular, friable; moderately calcareous with silica and ferric-oxide cement; some gravel, chert, and gypsum.
Triassic	Santa Rosa 310	680– 720	40	Clay and siltstone, red.
		720– 760	40	Sandstone, red, fine- to very fine-grained, friable, moderately calcareous; some siltstone and clay.
		760– 790	30	Siltstone, red, noncalcareous, micaceous, green streaks, and spots; some gypsum.
Triassic or		790– 800	10	Clay, red, silty, micaceous.
Permian,		800– 820	20	Siltstone, red, clayey, micaceous.
undiffer-entiated		820–1,000	180	Siltstone, red, noncalcareous, micaceous, green streaks, and spots; some gypsum.
	495	1,000–1,010	10	Clay, red, silty.
		1,010–1,255	245	Siltstone, red, noncalcareous, micaceous, green streaks and spots; some gypsum.
Permian	Rustler	1,255–1,270	15+	Anhydrite.

and Permian cannot be definitely determined because of their similar lithologies and a lack of fossils. Table 3 summarizes the geologic and hydrologic characteristics of the Mesozoic and younger formations found in the southern Lea County area.

Triassic

The Triassic rocks of the area consist chiefly of a sequence of red beds, the Dockum group, which are separated from the rocks of Late Permian or Triassic age by an erosional unconformity. The Dockum group is divisible into the Santa Rosa sandstone and the Chinle formation; however, the distinction cannot be made throughout the area because of lithologic similarities and poor exposures. The Santa Rosa is a fine- to coarse-grained sandstone, which ranges in thickness from about 140 feet to more than 300 feet; it contains minor shale layers. In some places the sand grains approach silt size; elsewhere the rock is conglomeratic. It is generally red, but it contains white, gray, and greenish-gray sands. The Santa Rosa is exposed in the face of Livingston Ridge in Eddy County (T. 21 S., R. 31 E.) and in the southwestern parts of T. 20 S., R. 32 E. Triassic rocks of the Dockum group, undifferentiated, are exposed in the face of The Divide and in the Paduca Breaks (see fig. 9).

The uppermost formation of the Dockum group is the Chinle, which ranges in thickness from zero to 1,270 feet. It is thickest in the eastern part of the area and entirely absent in the western part, where it has been removed by post-Mesozoic erosion. The Chinle is dominantly red and green claystone but also contains minor fine-grained sandstone and siltstone. The Chinle is exposed in the south-facing scarp of Custer Mountain, where it consists of badly weathered red claystone with green streaks and nodules. About 3 miles west of Custer Mountain about 40 feet of the Chinle is exposed in the sides of an isolated mesa (fig. 14). At that locality it consists of alternating beds of red and green claystone, ranging in thickness from 1 to 4 feet, and a 4-foot bed of greenish-gray, very fine-grained argillaceous sandstone which has thick cross-bedding and rounded claystone granules as much as 1 cm in size. The beds dip gently to the northeast.

About 2 miles southeast of Monument the Chinle formation is exposed in a large pit. Here, the rock consists of micaceous red clay containing green reduction spots. The clay was mined and ground for use as drilling mud for many years.

Because of lithologic similarities between the sandstones of Chinle and the Santa Rosa sandstone, some exposures have been mapped as Dockum group, undifferentiated. Inasmuch as the Triassic rocks in the western part of the county generally dip toward the east or southeast, the area shown as Dockum group in Tps. 21-24 S., R. 32 E. may be part of the Santa Rosa sandstone. The exposures are generally poor because of the extensive cover of drift sand, but an outcrop in the Paduca Breaks

Figure 14

ANGULAR UNCONFORMITY BETWEEN THE OGALLALA AND CHINLE FORMATIONS EXPOSED ON FLANK OF SMALL MESA IN THE SW¼ SEC. 12, T. 25 S., R. 35 E.

Solid line is approximate base of flat-lying Ogallala sediments which cap the mesa. Dashed line to left, drawn on top of an intraformational clay-pebble conglomerate, indicates the dip of the underlying Chinle formation.

in T. 26 S., R. 32 E. is coarse-grained, crossbedded sandstone and probably is the Santa Rosa.

The Triassic sediments display characteristics of rapid deposition and short distance of travel from their source. Few of the quartz grains of the sandstones are well rounded, and crystal faces are common. Numerous minor constituents are present, the most common being mica, which is present throughout the section. Gypsum is common as a secondary mineral. Cuttings of Triassic rocks taken from the Continental Oil Co. No. 2 Bell Lake Unit oil well were examined by the senior author and are described in Table 4. The interval between 760 feet and 1,255 feet has been assigned to Permian or Triassic red beds, undifferentiated. No clear-cut formational break was observed in the cuttings.

Jurassic

Rocks of Jurassic age have not been found in southern Lea County.

Cretaceous

Rocks of Cretaceous age were deposited in Lea County, but have been almost entirely removed by erosion. Only one exposure of Cretaceous rocks is known; it consists of large slump blocks of limestone that have been excavated in a gravel pit of the Lea County Concrete Co. east of Eunice in the SW¼ sec. 29, T. 21 S., R. 38 E. The limestone is white, light gray, or buff and is highly fossiliferous. Individual blocks are 3 to 5 feet thick and are as much as 20 feet long. Most of them are embedded in poorly consolidated sand and gravel, but a few rest directly on red beds of the Chinle formation.

In three other pits in the NE¼ sec. 29, semiconsolidated sands and gravels are exposed. They range in color from light gray or buff to dark brown, and in some places grains are bound by ferruginous cement. A section about 35 feet thick is exposed in one of the pits, but beds cannot be traced with certainty from one pit to another. This sequence is similar to the Paluxy sand of the upper part of the Trinity group, which crops out in Concho Bluff near Notrees, Tex., and at Shafter and Whalen Lakes, Andrews County, Tex. (Brand, 1933). The sand and gravel may be equivalent to the Paluxy, but they are barren of fossils and are also similar to the Ogallala formation.

Cretaceous rocks occur in the subsurface in T. 20 S., Rs. 38 and 39 E., but they are known only from drillers' logs of water wells and seismic shotholes.

CENOZOIC ROCKS

Tertiary

The Tertiary rocks are represented in the area by the Ogallala formation of Pliocene age. The Ogallala formation underlies the High Plains, the Grama Ridge, and Rattlesnake Ridge areas and most of Eunice Plain and Antelope Ridge areas. It is a heterogeneous complex of terrestrial sediments, which mantles an irregular erosion surface cut into the Triassic rocks. The Ogallala crops out along the face of Mescalero Ridge, and it caps Custer Mountain and small mesas to the west of Custer Mountain (see pl. 1 and fig. 14).

The Ogallala formation ranges in thickness from a few inches to about 300 feet. It is chiefly a calcareous, unconsolidated sand, but it contains clay, silt, and gravel. Some beds of well-consolidated, silica-cemented conglomeratic sandstone 1 to 3 feet thick also occur within the Ogallala. At Custer Mountain and on the mesas west of Custer Mountain, the Ogallala consists of a resistant cap of siliceous sandstone that is underlain by 4 or 5 feet of reddish-tan, friable, calcareous sandstone which becomes less calcareous and more conglomeratic toward its base. Where exposed along Mescalero Ridge, the Ogallala is generally a tan, friable, calcareous sandstone.

Figure 15 shows columnar sections based on logs of three holes drilled for the El Paso Natural Gas Co. northeast of Jal. The distance from hole 1 to hole 2 is 600 feet and from hole 2 to hole 3 is 800 feet. The rapid change in the section from one well to the other, which typifies the Ogallala, is the result of intertonguing, lensing, lithologic gra-

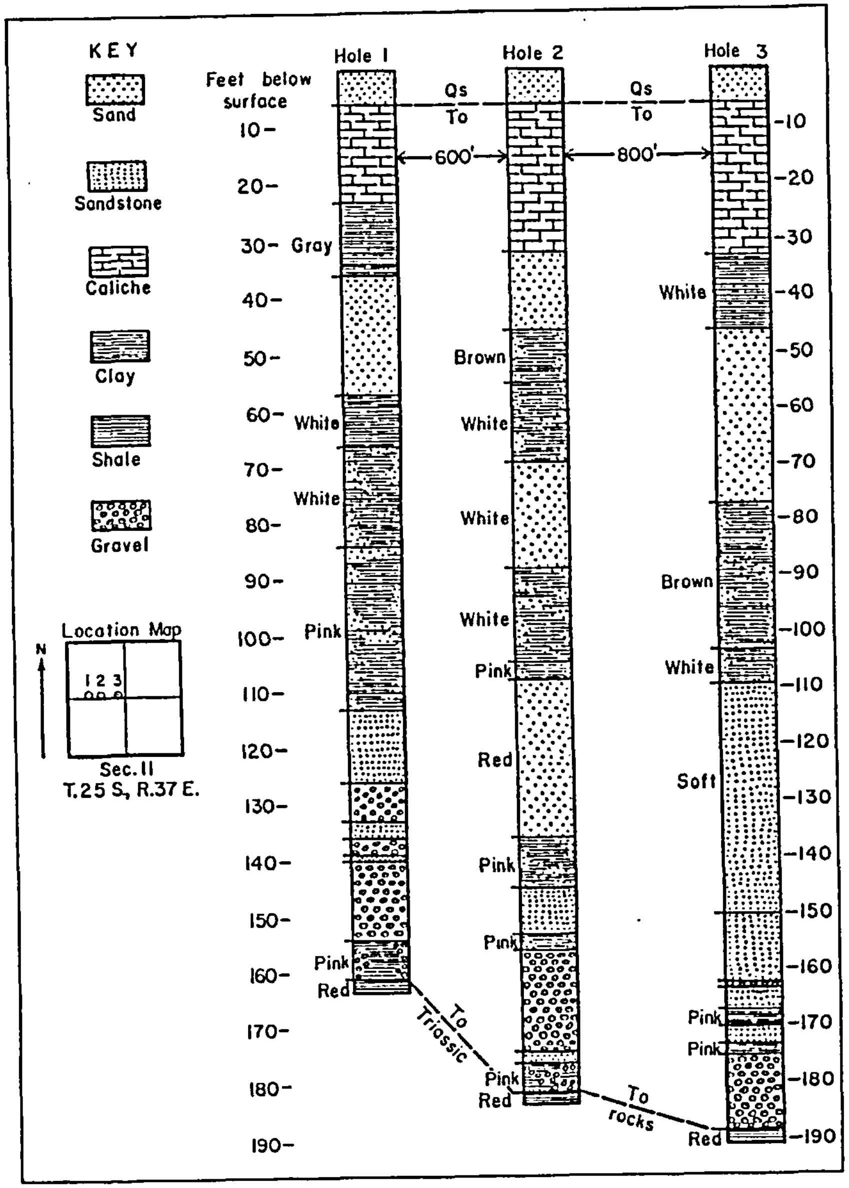

Figure 15

Columnar sections of the Ogallala formation northeast of Jal, N. Mex., based on logs reported for test holes drilled for the El Paso Natural Gas Co.

The rapid vertical and lateral lithologic changes are typical of the formation. Q—Quaternary dune sand; To—Ogallala formation.

dations, and pinching out of beds. There are no persistent marker beds anywhere in the formation, and in many places, correlation between logs of some holes only a short distance apart is impossible. The basal gravel encountered in the test holes is present in many places in the area, usually in buried stream courses on the pre-Ogallala erosion surface. During Ogallala time the conditions of deposition varied rapidly; the sorting power of the streams which deposited the formation fluctuated, and well-sorted sediments are interbedded with poorly sorted sediments. It is not uncommon to find beds of mixed clay and gravel, especially at the base of the Ogallala.

Fossils were found at only one locality in the Ogallala formation, in a sand pit on the east side of Monument Draw in the SE¼ sec. 3, T. 21 S., R. 37 E. These were calcified hackberry seeds, apparently of the variety *Celtis willistoni*, which are found in the Valentine beds in Brown County, Neb. (Elias, 1942).

The Ogallala on the Llano Estacado is capped by a layer of dense caliche, which ranges in thickness from a few feet to as much as 60 feet. At the surface the caliche is well indurated and is almost completely calcium carbonate. Below the surface it is less well indurated and with increasing depth it is softer and more porous, and grades into the underlying sands. The caliche was formed after the end of Ogallala deposition and is probably late Pliocene in age. It has been subject to erosion during Quaternary time and is probably the source of the calcareous silts which are common in younger deposits. The origin of the caliche is a question which has received considerable attention (Bretz and Horberg, 1949a). There is, however, no general agreement as to its mode of origin. The numerous theories concerning the origin of caliche include precipitation from lakes and streams, upward moving ground water, and downward percolating soil water, but no one theory is comprehensive enough to explain all the features observed.

Quaternary

Sediments of Quaternary age are present in southern Lea County in the form of alluvial deposits, probably of both Pleistocene and Recent age, and dune sands of Recent age. The alluvium was deposited in topographically low areas where the Ogallala formation had been stripped away. The dune sands mantle the older alluvium and the Ogallala formation over most of the area.

The older alluvium is exposed locally in small duneless patches, or in pits. It probably is the equivalent of the Gatuna formation of Robinson and Lang (1938). It underlies the areas of Querecho Plains, Laguna Valley, San Simon Swale, the South Plain, and several smaller areas (fig. 9). East of Eunice along Monument Draw and in the southeast corner of T. 19 S., R. 33 E., the alluvium forms extremely flat surfaces. In other areas the alluvium seems to have been deposited in channels that were cut into the Ogallala and later buried. The alluvium ranges

in thickness from a few inches to more than 400 feet (in the San Simon Sink), but it is generally less than 100 feet thick. At the surface it is generally a calcareous silt, probably derived from reworked caliche. The best exposure of the older alluvium is on the east side of San Simon Sink where a vertical section of about 30 feet can be seen (fig. 16). The section here is composed of poorly consolidated calcareous silt alternating with gray and white, well-sorted unconsolidated sands and some greenish-gray clays. The sand beds are as much as 3 to 4 feet thick. Figure 17A is a cumulative frequency curve showing the distribution of grain sizes in a sample of lacustrine sand of Quaternary age from the San Simon Sink. Over 73 percent of the sample falls within the 0.125 to 0.250 mm grain size interval, and the sorting coefficient (So) is 1.17 (Krumbein and Pettijohn, 1938, p. 230). The sand is composed almost entirely of subangular to subrounded quartz grains.

The alluvium is characterized by a profusion of gastropod shells, which are found at almost every locality where it is exposed. The gastropod shells range in size from microscopic to 1 cm in axial length. Pelecy-

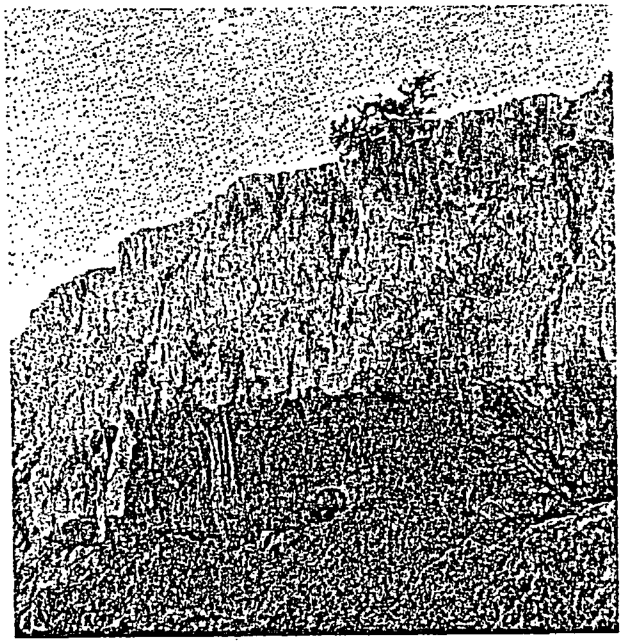

Figure 16

QUATERNARY ALLUVIUM ON EAST SIDE OF SAN SIMON SINK (SEC. 18, T. 23 S., R. 35 E.)

Light upper part is calcareous silt; lower, darker part is fine-grained, well-sorted sand.

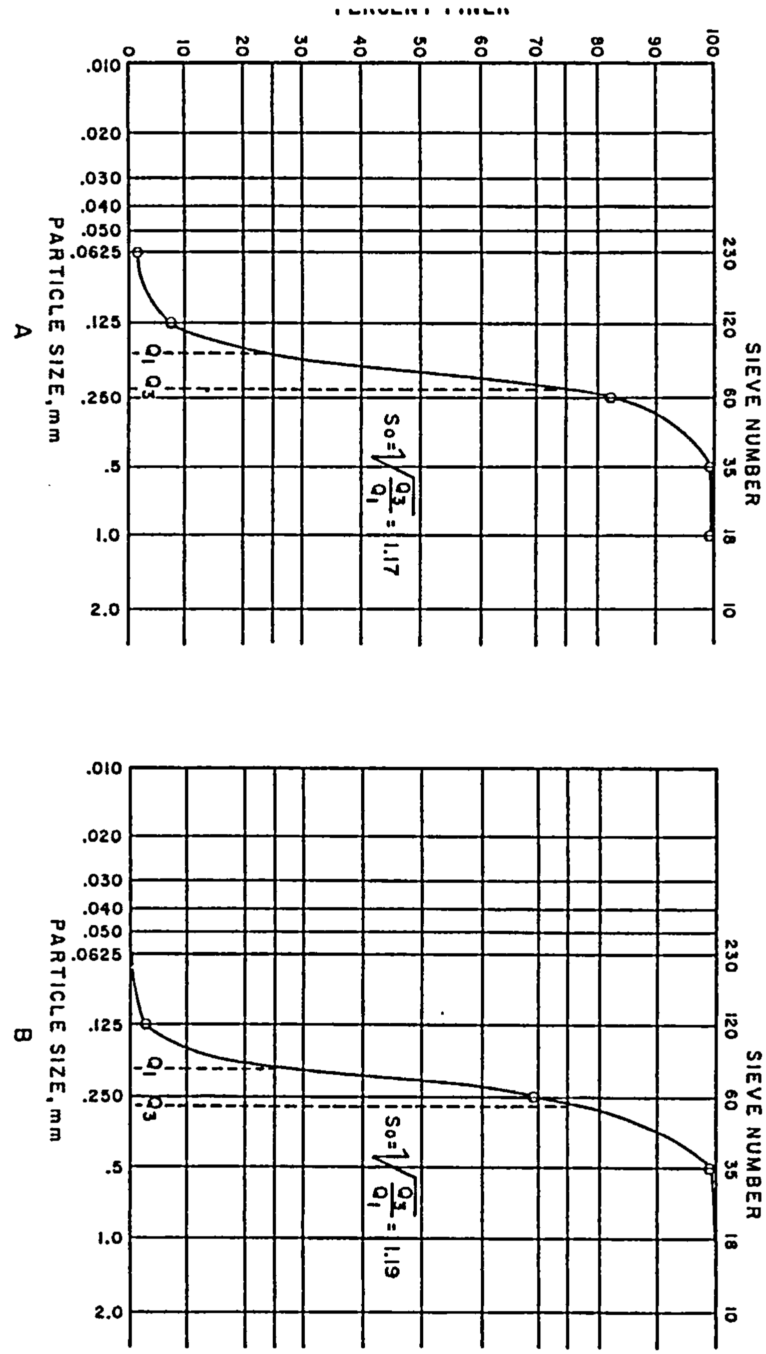

Figure 17

CUMULATIVE GRAIN-SIZE FREQUENCY CURVES OF QUATERNARY SANDS, SOUTHERN LEA COUNTY, N. MEX. (A) LACUSTRINE SAND, SAN SIMON SWALE; (B) DUNE SAND, SEC. 4, T. 23 S., R. 35 E.

pod shells, which would indicate an aqueous environment, were not observed in the Quaternary deposits south of the High Plains; however, one such shell about 4 mm wide was found in the Quaternary fill in a sink on the High Plains at the NE cor. sec. 5, T. 19 S., R. 37 E. It was found in association with gastropod shells.

The areas of little or no relief, even bedding, and the abundance of gastropod shells suggest that during early Quaternary time deposition was in shallow lakes that covered a large part of southern Lea County.

The most extensive Quaternary unit is the cover of red dune sand to which Darton (1928a) applied the name "Mescalero sands." The sand covers about 80 percent of southern Lea County, an extensive area on the east side of the Pecos Valley in Eddy County, and large areas in Texas. Probably much of it has been derived from the Permian and Triassic rocks of the Pecos Valley. The sand is generally fine- to medium-grained and uniformly reddish-brown, but near the base of Mescalero Ridge and in some parts of the San Simon Swale it is white. The difference in color probably indicates that this light-colored sand was derived from the Ogallala formation. The dunes are stable or semistable over most of the area but are actively drifting in some places. The thickness of the dunes ranges from a few inches to 30 feet, but generally the sand forms a veneer 5 to 10 feet thick. In areas where it is thickest, the lower part of the sand section is semiconsolidated. The cementing agent is probably iron oxide that has been leached from the upper part and reprecipitated below by downward percolating water. The semiconsolidated lower part of the Mescalero sands is observable in blow-outs where the unconsolidated upper portion has been removed by wind erosion.

Figure 17B is a grain-size frequency curve of a sample of dune sand collected in sec. 4, T. 23 S., R. 35 E., in the drifting dune area east of San Simon Swale. About 66 percent of the sample falls within the 0.125 to 0.250 mm grain-size interval, and the sorting coefficient is 1.19. The sorting characteristics of this sample and the shape of the cumulative curve are very much like those of the sample of lacustrine sand previously described, the only significant difference being that the dune sand is slightly coarser. The strong similarity between the two sands is probably the result of a common source.

STRUCTURE

The major structural features of southern Lea County are the Delaware basin and the Central basin platform in the subsurface (fig. 13), which are described and illustrated in the section on stratigraphy. The Triassic rocks of the area have a regional dip of less than 1 degree to the southeast; however, the dips are reversed in the vicinity of collapse depressions, and there are other variations in direction of dip (fig. 14). The only other structural features are major unconformities and collapse structures. The large structural features of the Permian basin are reflected

only indirectly in the Mesozoic and Cenozoic rocks, as there has been virtually no tectonic movement within the basin since the close of Permian time. The topographic high of Rattlesnake Ridge along the eastern side of the area is probably the result of subsidence or differential compaction of the greater thickness of sediments in the basin to the west. The San Simon Swale apparently is due to removal of salt by solution from underlying beds of Permian age. Maley and Huffington (1953) have shown that the evaporite deposits of the Castile and Salado formations are considerably thinner under the east side of the San Simon Swale than elsewhere in the area.

Permian and Triassic Unconformity

The contact between the Permian and Triassic is an erosional unconformity that slopes regionally to the southeast. The Rustler formation of the Ochoa series (Permian) is overlain by an irregular thickness of red beds of Permian or Triassic age that are present throughout the area. The Permian and Triassic unconformity is the lower limit of potable and industrially usable ground waters. The location of this boundary is, however, indefinite in most of the areas where it is underlain by red beds. The top of the Rustler formation should be regarded as the effective boundary below which no waters of presently useful quality can be found.

Red-Bed Erosion Surface

Plate 1 shows contours on parts of the buried erosion surface which underlies the rocks of Tertiary and Quaternary age of southern Lea County. This surface is highly irregular but has only moderate relief. It has undergone, depending on the locality, two or three episodes of erosion. Beneath it the Triassic rocks thicken regionally toward the southeast. The erosion surface truncates the southeastward dipping formations; thus, in the western part of the area the surface is cut into the Santa Rosa sandstone, and farther to the east it is cut into the Chinle formation. In a small area between Eunice and Hobbs the surface is cut into Cretaceous rocks that are not red beds, but the base of the Tertiary and Quaternary rocks is, for convenience, referred to as the red-beds surface.

Although data were sufficient to map the erosion surface in only part of the area, certain features of the surface are hydrologically important and give a clue to the configuration of the surface in other parts of the area. Closed depressions, such as those in T. 18 S., R. 32 E. and T. 25 S., R. 34 E. are common. Only those that are more than 50 feet deep are shown on the map; presumably there are many that are shallower than 50 feet. These features have probably formed by the collapse of the Triassic rocks into cavities in the underlying Permian salt beds or by gradual subsidence as the salt has been removed in solution by ground water. Distinctive shapes of the buried valleys, such as a tendency of

some to be wider near the heads of the valleys than farther downstream, particularly in the southwestern part of the county, strengthen the concept that the red-beds surface was formed at least in part by solution and collapse processes. Its karst-like features are much less pronounced in the areas where the Ogallala formation remains intact. This probably indicates that where the caliche caprock of the Ogallala formation has been broken as a result of subsidence or collapse, the underlying sand and gravel is more easily eroded.

The trend of valleys and ridges on the buried red-beds surface is generally east-west in the northwestern part of the area, and generally north-south in the southern and eastern parts of the area. The most prominent valley appears to head in the San Simon Swale, which may indicate that in early Tertiary time the Swale drained southward. The buried valley could, however, have formed by the coalescing of sinkholes; the deep sink within the valley lends credence to this possibility.

The red-beds surface apparently is depressed throughout the length of Monument Draw. Theis (1954) collected data on five wells drilled at what was then the Panhandle Carbon Co. plant. These data show clearly the depression of the Triassic surface beneath Monument Draw. Four of the five wells are shown on Figure 18; well 2 was several thousand feet north-northwest of well 1. Wells 3, 4, and 5, in the bottom of the draw, encountered red beds 46 to 54 feet lower than at well 1. The upper part of each log records an interval of white sand ranging in thickness from 16 to 35 feet. The lower parts of the sections are, however, quite different. On the plain the sand is overlain by caliche, but in the draw the caliche is absent, and the sand immediately underlies a thin soil cover. The absence of the caliche could be accounted for by preferential erosion. The white sand could be the same formation across the entire section, but it is more likely that the similarity of the sediments found in the draw to the flanking Ogallala sediments results from the fact that the Quaternary fill was derived from the Ogallala and has not been transported far from its origin.

Figure 18 shows the depression as an erosional feature. It might also be inferred from the similarity of the logs of the five holes that the linear depression is a slump feature; however, a collapse feature of such marked linearity is unusual. Regional subsidence, as is suggested elsewhere in this report, could account for the position of the draw parallel to Rattlesnake Ridge and the consequent southward trend of the stream. It seems probable that the draw was, at one time, a perennial stream which cut through the Ogallala and into the underlying red beds. As the climate of the region changed and the erosive power of the stream declined because of increased aridity, the channel was filled to its present level.

Another interesting and hydrologically important feature of the red-beds surface is the ridge that extends southeastward from the southwestern part of T. 16 S., R. 32 E., into T. 19 S., R. 35 E. The crest of the ridge forms the northeast boundary of a broad subsurface valley that drains

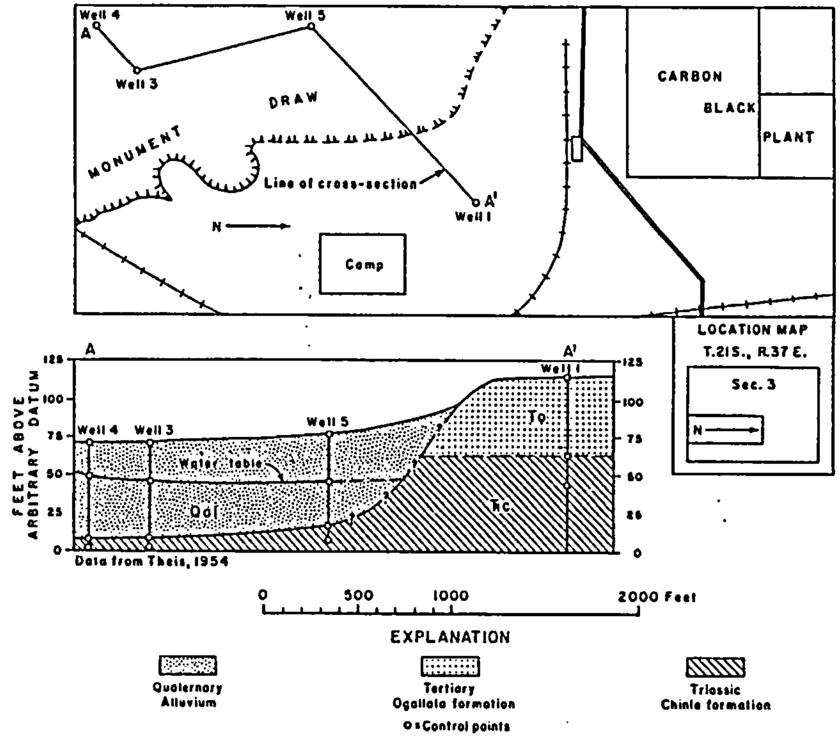

Figure 18

SECTION ACROSS NORTH SIDE OF MONUMENT DRAW, LEA COUNTY, N. MEX.

See also Figure 5.

toward, and perhaps beyond, T. 20 S., R. 32 E., and from which the Ogallala formation has been completely removed. Northeast of the ridge the Ogallala has been preserved intact. The character of the red-beds surface on the two sides of the ridge is markedly different. To the southwest the buried surface is marked by closed depressions, indicating the influence of solution and collapse. Beneath the relatively undisturbed Ogallala formation, the red-beds surface has many of the characteristics of a dendritic drainage pattern. This difference probably is controlled indirectly by differences in the lithologic composition of the underlying Permian rocks. The hydrologic consequences of this will be discussed in the section on ground-water occurrence.

The position of the buried ridge with respect to the surface drainage divide, Mescalero Ridge, is of considerable interest with regard to the Pleistocene and Recent geologic history of the area. Throughout much of its length, the buried ridge is half a mile to a mile southwest of Mescalero Ridge. This difference in position apparently indicates the

amount of retreat of Mescalero Ridge since the major cycle of Pleistocene erosion that removed the Ogallala formation from the Querecho Plains area.

Collapse Structures

A great thickness of Permian salt beds underlies the southern Lea County area. Some surface features were formed by the removal of salt by solution and consequent collapse of the overlying beds. These collapses are reflected at the surface by closed depressions, the largest of which is the San Simon Swale. Drillers for seismic exploration crews have reported drilling over 400 feet into the San Simon Sink without encountering red beds. Elsewhere in the swale the red beds are encountered at relatively shallow depth. It appears that the swale was formed initially by a very large collapse in the general area of the present sink. Subsequently, material eroded from the surrounding area was deposited in the sink area or removed by deflation. Quaternary alluvium surrounds the sink and is now being washed or blown into the sink, indicating that the present sink was at one time completely filled, but that renewed collapse or compaction has again made it an area of active deposition. Recent subsidence is reported by residents of the area. About 25 years ago the sink collapsed suddenly and annular fissures, which are still well incised, developed around its rim (fig. 7). Deposition in the sink is continuing at a rapid rate, estimated on the order of 1 foot every 5 years (fig. 19).

On the east side of T. 18 S., R. 32 E. the red-beds surface appears to have closed depressions (pl. 1) which may represent pre-Ogallala collapses that have no surficial expression because of complete burial. Several other depressions are indicated in the red-beds surface in other areas. Lagunas Plata, Gatuna, Toston and Tonto, at the south end of Querecho Plains, appear to be of similar origin to San Simon Swale, but of smaller size. Evidence for a collapse origin is found in Laguna Plata. On the north and northwest slopes of this lake, shale of the Dockum group, probably the Chinle formation, is exposed to a height of about 20 feet above the lake bed; yet, in two test holes drilled in the lakebed in exploring for potash (20.32.3.344 and 20.32.10.143) the red beds were encountered at depths of 20 and 41 feet respectively. Other depressions in eastern New Mexico have originated in the same way (Judson, 1950). The presence of major closed depressions in the red-beds surface in southern Lea County (pl. 1) suggest that such large sinks formed in pre-Ogallala time as well as more recently.

Two other depressions similar to those described above, Bell Lake in secs. 3, 4, 9, and 10, T. 24 S., R. 33 E., and an unnamed depression in sec. 24, T. 24 S., R. 33 E., may also be collapse depressions. These lakes are unique in that they have large accumulations of dunes that are made up entirely of gypsum sand. The source of the gypsum has not been determined definitely, but it probably was derived from ground water seeping upward into the lakebeds. There is no indication of upward

Figure 19

Sugarberry Tree in the bottom of San Simon Sink
(sec. 18, T. 23 S., R. 35 E.)

Lower limbs were once high enough that a horse and rider could pass beneath. Deposition in the sink has partly buried the tree. The absence of precipitates indicates a leaky bottom where seepage is too rapid for effective evaporation.

movement of ground water in the area at the present time, and the dunes have been stabilized by the action of rain water, which dissolves and recements the grains. Upward movement of water from the Permian and Triassic formations could bring about precipitation of gypsum in the lakes, with subsequent dune formation by wind action. However, the static water levels in wells finished in the Triassic are not nearly high enough at the present time to permit such a process. Although no data are available regarding the head in the Permian aquifers, it is unlikely that it is now sufficiently high to force water into the lakebeds.

The presence of these gypsum dunes can be taken to indicate two things: that the lakes are collapse depressions, the area of collapse providing the conduit for the upward movement of ground water; and that the head in the pre-Tertiary rocks at one time was much higher than now. These implications follow from the fact that there is no known source of gypsum near the surface in southern Lea County and that gypsum is found in significant quantities only in these dunes.

Origin of Undrained Depressions on the Llano Estacado

There has been much consideration given to the genesis of the so-called buffalo wallows on the Llano Estacado (see p. 14). An early theory ascribed their origin to the wallowing activity of the buffalo, with the

removal of material by adhesion to the hooves and fur of the buffalos, and by deflation. There is little evidence regarding the subsurface geology of these depressions, but the authors believe that the majority of them have formed through leaching of the caliche cap and calcareous cement of the sandstones of the Ogallala underlying the caliche, with subsequent removal of the loosened material by the wind.

Judson (1950), in an examination of several large depressions which have been dissected by the retreating scarp along the north edge of the Llano Estacado, south of San Jon, Quay County, N. Mex., found strong evidence to support the leaching theory of origin. The depressions examined showed no evidence of collapse in the deeper Mesozoic rocks. The Ogallala sands immediately underlying the depressions were identical in grain characteristics with the Ogallala sands underlying the caliche cap adjacent to the depressions; they differed from the latter only in that the carbonate cement had been leached out. Because the caliche that underlies the High Plains ranges in thickness from about 5 feet to possibly 30 feet and is chiefly calcium carbonate, which is relatively soluble, many of the present depressions can be attributed to leaching of the caliche layer. The depressions examined by Judson were broader and deeper than most of the depressions of the High Plains and had sand dunes on their lee sides; he attributed the deepening of these depressions largely to deflation. Most of the High Plains depressions, however, are more subdued in relief and do not commonly have dune sand accumulations on their lee sides.

White et al. (1946) reported having drilled hundreds of test holes in the depressions on the High Plains in Texas. Caliche was encountered in almost every hole but was absent in some. Beneath some of the depressions the caliche was hard and impermeable. The bottoms of most of the depressions are covered with silt deposits ranging from 2 to 10 feet in thickness.

If these depressions originated by collapse, caliche would be present under them in thicknesses comparable to the thickness underlying the surrounding plain. The fact that caliche is absent under some of the depressions implies that the depressions must have come about by removal of caliche rather than by deep-seated collapse. Since the caliche commonly is covered by several feet of silt, its removal probably was effected by leaching rather than by deflation. However, no definite statement can be made regarding the origin of individual depressions without knowledge of their subsurface structure, since some of the depressions may be reflections of deep-seated collapse.

GEOLOGIC HISTORY

The meager evidence concerning the Precambrian history of the southern Lea County area indicates a complex history of mountain building, metamorphism, and erosion. During most of the Paleozoic era

the area was the site of active deposition, but during Pennsylvanian time what is now the Central basin platform emerged to form a range of mountains. Erosion during this period removed a part of the sequence of older Paleozoic rocks. This area was emergent throughout most of Pennsylvanian time, but it was submerged long enough to receive a sequence of Late Pennsylvanian rocks. Deposition of Pennsylvanian rocks apparently continued without interruption in the Delaware basin section.

At the close of Pennsylvanian time the entire area subsided and the major features of the Permian basin took shape. The Central basin platform and the shelf area subsided more slowly than the Delaware basin; consequently they received a lesser thickness of sediments which were lithologically different because of different environmental conditions. King (1942, p. 537-538) summarizes the probable history of the area during Permian time:

> . . . the basins were centers of accumulation of clastic rocks—first black shales and later sandstones—and the total thickness of beds deposited in them was greater than elsewhere. Limestone tended to form over all the higher-standing areas. Landward, because of climatic conditions that favored evaporation, evaporites were laid down in the fringing seas. On the margins of these seas, redbeds were deposited that were derived from the bordering lands.
>
> In Wolfcamp time the seas spread over the whole of the West Texas region, but from Leonard time onward they became progressively more restricted, so that the belts of redbeds, evaporites, and limestones encroached farther toward the Delaware basin. One notable encroachment of evaporite took place in later Guadalupe time, when most of the area north and northeast of the Delaware basin was covered by it. Another took place in Ochoa time, when the Delaware basin itself was covered.
>
> The general and gradual retreat of the seas was complicated by several lesser fluctuations, which from time to time caused marked restrictions and readvances. The most notable of these were at the end of the Leonard time and the end of Guadalupe time, when the seas appear to have been nearly restricted to the Delaware basin. Following each restriction, the area of deposit and the seas gradually spread out again. . . .
>
> The final event of Permian time was the disappearance of evaporite-depositing waters from the West Texas region, and the spreading over it of the last formation of the Ochoa series, a thin sheet of redbeds. After this, deposition ceased in the area until later Triassic time.

The end of the Permian marks the end of the Paleozoic era and a major time break in the geologic column. During most of Triassic time the southern Lea County area was emergent and subject to erosion. In Late Triassic time it was the site of terrestrial deposition of the sediments of the Dockum group. In Jurassic time the area was once again subject to erosion. This is the first of three erosion cycles that have incised the Triassic rocks of the area. During Cretaceous time a large part of the western interior of North America was submerged and the West Texas–southeastern New Mexico area was the site of a large epicontinental sea

in which a thick sequence of Cretaceous rocks was deposited. The Mesozoic era came to a close with the Laramide revolution and the uplift of the Rocky Mountains. Concurrent with the upthrusting of the Rocky Mountains, the Late Cretaceous sea retreated and the exposed surface was subjected to intense erosion. In the area of southern Lea County the entire sequence of Cretaceous rocks was stripped off except for small remnants, and the Triassic rocks were subjected to a second cycle of erosion.

In Pliocene time terrestrial deposits of the Ogallala formation were laid down as a thick mantle which obliterated the irregular surface and replaced it with the even surface of the High Plains.

Subsequently, during Quaternary time, a new cycle of erosion set in and the Pecos River developed its broad valley to the west and south, stripping away much of the Ogallala formation and in places eroding the Triassic rocks a third time. Erosion by the Pecos and Canadian Rivers in New Mexico and by the Red, Brazos, Colorado, and other rivers in Texas isolated a large remnant of the Ogallala formation—the Llano Estacado. The early stages of the retreat of Mescalero Ridge to its present position probably resulted from erosion by streams tributary to the Pecos River to the west and south. In time the surface drainage to the east and north of the Pecos River was disrupted by the development of collapse depressions. Continued erosion of the Ogallala sediments partially filled the depressions. Some lakes were developed by the interruption of surface drainage, and these became sites for the deposition of the Quaternary lake deposits that underlie southern Lea County in some places. In the Querecho Plains, Laguna Valley, and South Plain, the Ogallala formation apparently was completely removed, except for a few isolated remnants, and Quaternary deposits derived from Ogallala were laid down on the Mesozoic rocks. Monument Draw in early Quaternary time was probably throughgoing and may have even been a perennial stream fed by water from the Ogallala formation of the High Plains. At present, there is no throughgoing flow except during extreme floods. The climate became more arid in later Quaternary time, and the detrital materials were reworked by wind, giving rise to the vast deposits of dune sand that now cover large parts of the area.

Ground Water

Ground water originates as rain or snow. Thus, it occupies a place in the *hydrologic cycle*, the mechanism by which energy from the sun maintains the circulation of water from the oceans to the skies to the land and back. A small part of the total precipitation in an area moves downward beyond the root zone of plants and below the zone from which it can be returned to the atmosphere as vapor. This water then goes into transient storage underground; if water saturates the rock, it is termed ground water and the rock is called an aquifer.

Most ground water in the upper part of the earth's crust returns, ultimately, to the atmosphere, completing the ground-water part of the hydrologic cycle. Areas in which water enters the ground-water reservoir are called recharge areas, and areas in which it returns to the atmosphere are called discharge areas. Recharge and discharge may take place naturally or artifically; pumping from wells is an example of artificial discharge.

Southern Lea County is important as a recharge area, but little natural discharge takes place there. The aquifer beneath the High Plains is recharged largely by infiltration from short drainage ways and from the temporary lakes that form in shallow depressions after heavy rains. A very small quantity of ground water discharges to the atmopshere at Monument Spring and at a few other springs, but most of the ground-water discharge in the area is by pumping from wells.

Under natural conditions recharge is in equilibrium with discharge. That is, over a long period of time the amount of water lost through natural discharge is equal to the amount gained by natural recharge. When water is removed by pumping, this additional discharge must be compensated for by a reduction in natural discharge, an increase in natural recharge, or removal of water from storage. Natural recharge can be increased only if the aquifer does not normally accept all of the water that is available to it. For example, if the water table is at the surface in the recharge area, runoff in excess of the amount that is moving through the aquifer is rejected as recharge. In such an area some of this rejected recharge can be induced into the aquifer by lowering the water table by pumping. If the water table is deep below the surface in the recharge area, the natural recharge cannot be increased by pumping because the aquifer already accepts all the water available to it.

In southern Lea County the water table is at or near the surface in only one or two small areas; thus, the recharge cannot be increased by lowering the water table. The principal areas of natural discharge of the aquifers of southern Lea County are many miles away from the areas of intensive pumping and the drawdown due to pumping moves so slowly that the effects of pumping are not offset by a reduction of natural

discharge. The net effect under present conditions is a depletion of storage.

In arid regions such as southern Lea County, where recharge is very low, large volumes of water may be available in storage in the aquifers, because it had been accumulating for many centuries. This abundance of water leads to the general impression that there is an inexhaustible supply of water available. The fact is, however, that water removed from storage in great quantities in such areas normally is replaced only very slowly and is lost as far as the present and immediately succeeding generations are concerned.

A typical value for the rate of recharge to water-table aquifers in the southern High Plains is about one-quarter to one-half inch of water per year (Theis, 1937). In an aquifer with a porosity (ratio of void space to total rock volume) of 20 percent, this would raise the water 1¼ to 2½ inches per year if there were no discharge whatever from the aquifer. In such an aquifer, a 3-foot decline in water level as a result of 1 year of intensive pumping represents the expenditure of a 29-year accumulation, again assuming no natural discharge.

PRINCIPLES OF OCCURRENCE

Ground water may be classified according to its mode of occurrence. Figure 20 shows the relationships of the different types of ground-water bodies. The zone above the water table which contains no water except that held by capillary action is called the zone of aeration or the vadose zone. The portion below the water table is called the zone of saturation.

Figure 20 illustrates water levels in wells drilled into the various types of aquifer. Well 1 penetrates a perched aquifer; the level of the water in the well coincides with the top surface of the aquifer, but it is above the main water table of the area. The water level in well 2, which penetrates the unconfined aquifer, is lower than that of well 1, and coincides with the main water table, the top of the zone of saturation. Well 3 penetrates a confined water body (artesian aquifer), the unconfined aquifer above having been cased off. The water level is above the top of the confined aquifer but lower than the main water table because the hydrostatic pressure is insufficient to raise the water any higher. The imaginary surface that is defined by the static water levels in tightly cased wells that penetrate an artesian aquifer is called a piezometric surface. Well 4 penetrates the area of recharge of the deeper aquifer, where it is unconfined. The water in this aquifer is under atmospheric pressure except for downdip beyond the point where the water table comes into contact with the overlying confining bed.

The interested reader is referred to standard textbooks and several government publications that discuss further details on the occurrence of ground water. All of the ground water in the Ogallala formation and the Quaternary sediments of southern Lea County is unconfined where

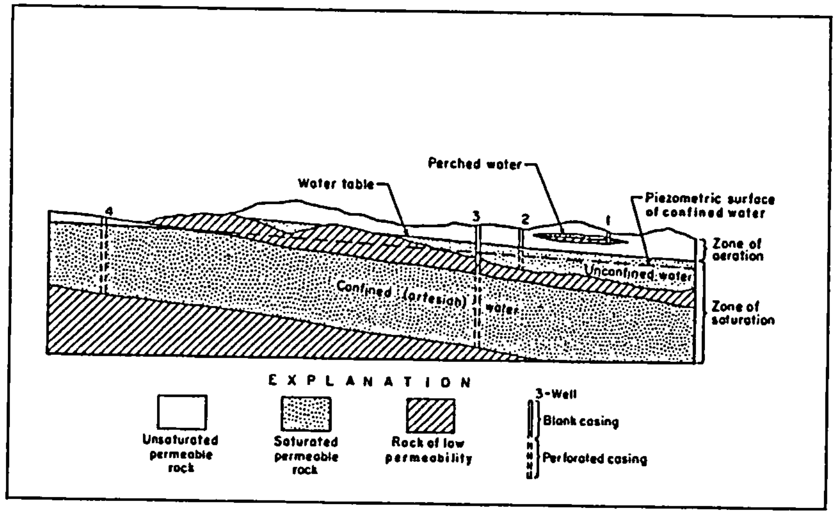

Figure 20

IDEALIZED CROSS SECTION SHOWING DIFFERENT MODES OF OCCURRENCE OF GROUND WATER

the underlying red beds are relatively impermeable. They form a lower confining layer, which prevents further downward movement. It is quite possible that the Ogallala formation and the Quaternary sediments of the southern Lea County area may contain perched aquifers within them since they both contain clay beds which could support such a water body. However, no wells are known to be finished in such a zone.

Most of the water derived from the Triassic formations in the southern Lea County area is confined water. As an example, well 24.37.10.123 drilled into the Triassic rocks encountered water at a depth of about 740 feet, and the static water level after completion of the well was only 120 feet below the surface.

EFFECTS OF PUMPING

When water is pumped from a well, the water table or piezometric surface in the vicinity of the well will be drawn down at a rate which normally decreases with time. The greater the rate of pumping the greater the decline of water level. The ability of a well to yield water can be roughly estimated by comparing this decline of the water level (drawdown) with the rate of pumping. The number of gallons of water yielded per minute per foot of drawdown in a well is called the specific capacity. The specific capacity of a well is variable with time and rate of discharge. It is not a unique characteristic, but nevertheless is a useful measure for the comparison of the performance of wells.

The depression of the water table, or of the piezometric surface around the well, caused by pumping is roughly conical in shape and is known as the cone of depression. When pumping is started, the water level in the well declines rapidly and the cone of depression begins to spread out from the wall. If the discharge rate is held constant, the rate of decline soon decreases. Theoretically, the cone of depression can expand to the limits of the aquifer, but the effect becomes less and less pronounced away from the well.

Two pumping wells that are close to each other and pumping from the same aquifer may develop cones of depression which will intersect and cause excessive drawdown in both wells. The result is that greater pumping lifts are required and more energy is expended in raising water to the surface than would otherwise be necessary.

Figure 21 illustrates the effect of well spacing on pumping lifts. The situation illustrated is for water-table conditions. The same relations, however, would apply under artesian conditions.

Ground-Water Maps

Water-table and piezometric-surface contour maps are used to picture the areal extent and movement of ground water. They are constructed by interpolating between control points consisting of water-level measurements made in wells that are considered representative of the aquifers. One practical difference between the two kinds of maps is that the water-table contour map shows the altitude at which water will be encountered by drilling in a locality; the piezometric-surface contour map indicates only the level to which water will rise in wells tapping the confined aquifer. The depth to the confined aquifer is not indicated by the shape of the piezometric surface. Both maps, however, indicate the direction of ground-water movement. Both surfaces slope from areas of recharge to areas of discharge, and the general direction of flow of ground water is at right angles to the contour lines.

Plate 2 illustrates the movement of ground water in southern Lea County. Two sets of contours are shown, water-table contours for the Ogallala formation and Quaternary alluvium, and contours on the piezometric surface of the confined water of the Triassic aquifers. The water-table contours are based mainly on a well canvass made in 1953 and 1954; however, data collected in previous years also have been used in compiling the map, making allowance for the differences in time of collection. Some data for the southwestern part of the county were collected in 1958 and 1959. The map also gives the well locations, depths to water, and depths of wells. In making the well canvass, water levels were measured wherever practicable, but depths to water reported by well owners or others have been used where it was not possible to measure the depth to water. Other pertinent details about the wells are shown in Table 6.

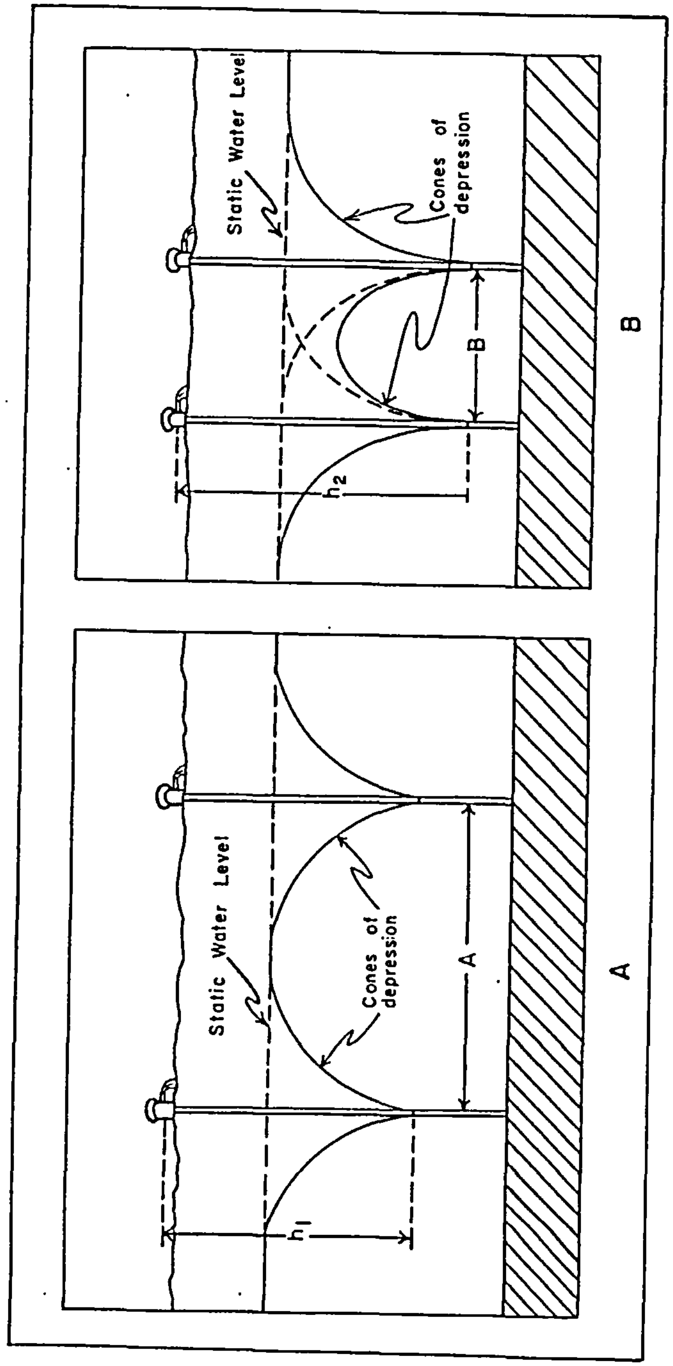

Figure 21

Effects of well spacing on pumping lifts

A.—Wells are far enough apart so that the cones of depression have negligible influence on each other.

B.—The same wells as in A except that they are close enough for the cones of depression to overlap significantly. Mutual interference has decreased area of each cone and a steeper hydraulic gradient is necessary to transmit the same amount of water to the wells. Increased pumping lifts result.

PRINCIPAL AQUIFERS

All the potable ground water used in southern Lea County is derived from three principal geologic units, the Dockum group, the Ogallala formation, and Quaternary alluvium. Potable ground water is not available below the Permian and Triassic unconformity but, because this boundary is not easily defined, the top of the Rustler anhydrite formation is regarded as the effective lower limit of potable ground water. Virtually all the water wells in the area bottom in Triassic or younger rocks. No potable water is known to be derived from the Permian rocks except possibly from well 21.33.2.231. The well is reported to be 1,150 feet deep and the water is potable. This is the deepest water well in southern Lea County area; it may have penetrated the undifferentiated Permian or Triassic red beds but no log is available, and it is not possible to identify the aquifer definitely.

A few wells derive water from several aquifers, but inasmuch as the shallow water in the Quaternary alluvium and the Ogallala formation is of better chemical quality than that from the rocks of Triassic age and since the younger rocks are more permeable, and hence permit greater well yields, most wells are completed in the shallowest zone that will produce the desired quantity of water.

Aquifers in Rocks of Triassic Age

There are several aquifers in the Triassic rocks. Water is obtained from both the Santa Rosa and the Chinle formations. No water is known to be derived from the undifferentiated Permian or Triassic red beds, except possibly from well 21.33.2.231. Triassic rocks underlie all of southern Lea County but are exposed only in minor outcrops. The lower part of the exposed Triassic section, the Santa Rosa sandstone, crops out in the north-trending scarps which are located a few miles to the west of the Lea–Eddy County line and in the south-facing scarps of Paduca Breaks. The overlying Chinle formation is exposed at Custer Mountain and in a large excavation about 2 miles southeast of Monument. The regional dip of the Triassic rocks appears to be less than 1 degree to the east and south. The recharge area of the Triassic rocks is in the western part of southern Lea County and the eastern part of Eddy County. Some recharge probably is derived also from the overlying Ogallala formation and the Quaternary alluvium where they overlie permeable beds of Triassic age in the subsurface.

The Santa Rosa sandstone is the principal aquifer in the western third of southern Lea County. The unit is recharged by precipitation on the sand dunes, both in Lea County and a few miles to the west in Eddy County; by precipitation and runoff directly on the outcrop; and probably by ground-water flow from the overlying Ogallala formation and alluvium. Recharge appears to be concentrated in three areas, as indicated by the configuration of the contours shown on Plate 2. The ground-water mound indicated by the 3,300-foot contour in T. 22 S., R. 32 E., which closes to the west in Eddy County, represents recharge on the outcrop and infiltration through the dune-sand cover. The ground water ridge in T. 21 S., R. 33 E. and the mound in T. 24 S., R. 33 E. are both beneath a cover of younger rocks and presumably they indicate recharge from the discontinuous aquifers in these rocks.

The water-table gradient in the Triassic rocks southwestward from Mescalero Ridge toward Lagunas Plata and Gatuna may result in part from water that moves downward from the Ogallala formation and into the Triassic rocks and in part from precipitation that infiltrates through the thin veneer of alluvium covering the Triassic rocks southwest of Mescalero Ridge.

Ground water in the Santa Rosa sandstone moves outward from these centers of recharge. In the southwestern part of the county the data are adequate to provide a firm indication of movement toward the south and southwest. In Tps. 19 and 20 S., Rs. 32 and 33 E., the contours indicate that water discharges from the Triassic rocks in the vicinity of the Lagunas. The water does not discharge to the atmosphere, because the lake surfaces are about 200 feet higher than the pressure surface of the Santa Rosa aquifer. It is tentatively concluded that the water in the Santa Rosa discharges downward into the Permian rocks, inasmuch as the lakes appear to be related to collapse activity and probably the vertical permeability has been greatly increased as a consequence of the rupturing of beds by collapse.

East and south of the centers of recharge the movement of ground water in the Santa Rosa sandstone is influenced greatly by the San Simon Swale. The pressure gradients are apparently toward the swale. This interpretation is consistent with the theory that the swale is of collapse origin and that a vertical conduit formed by the collapse provides a relatively permeable zone for the downward discharge of water. However, the Triassic section thickens eastward in Lea County, and it seems fairly certain that in the vicinity of the swale many of the wells finished in Triassic rocks obtain water from sandstone units in the Chinle formation.

Wells bottomed in the Triassic rocks generally have low yields, as the formations have a low permeability. The porosity of the Santa Rosa sandstone in well 23.34.31.340 is estimated to be about 13 percent, and the fine-grained character of the rock indicates that its permeability is very low. When initially drilled, this well yielded 75,600 gallons of water in 27 hours of pumping. The drawdown was about 300 feet at an average rate of pumping of 47 gpm. The specific capacity of the well is therefore about 0.14 gpm per foot of drawdown. Well 20.32.18.233 is also bottomed in the Santa Rosa sandstone; incomplete well-test data indicate that it has a specific capacity of less than 0.2 gpm per foot of drawdown.

Oil Center is the only community that obtains its public supply from Triassic rocks. The entire community of about 20 dwellings is

served by one well (21.36.9.222) which has a maximum sustained discharge rate of about 6 gpm. The well must be pumped almost continuously in order to meet the demand.

The well is 447 feet deep and apparently is bottomed in the Chinle formation, as the total Triassic section at this locality is probably over 1,000 feet thick.

Until July 1954, when a new water system was constructed, the City of Jal derived its public supply from five deep wells bottomed in Triassic rocks. Stratigraphically, these wells appear to be bottomed about 300 feet lower than the one at Oil Center; the aquifer may be the Santa Rosa sandstone. Average yield of these wells was about 25 to 30 gpm, and the total supply was inadequate to meet the growing need for water in recent years. Therefore, the well field was abandoned in favor of a more favorable supply from shallow wells located several miles east of town. One defect of the abandoned water supply system was that the wells were drilled too close to each other. The two most distant wells were only 1,500 feet apart. Consequently, there was excessive interference between the wells (fig. 21). Wider spacing would have provided more economical operation of the water system and a greater yield, although the increase in yield would not have been enough to provide for the town's need.

Water well No. 1 (26.37.7.331) at the Jal No. 1 Plant of the El Paso Natural Gas Co. is typical of wells which derive water from the Triassic formations. It is 476 feet deep and it penetrates four water-bearing intervals between 215 and 465 feet. The lowermost interval is 50 feet thick and may be in the Santa Rosa sandstone. The upper intervals range from 5 to 10 feet thick and are in the Chinle formation. This well yields about 100 gpm, which is about the maximum that can be expected from wells bottomed in the Triassic rocks.

Ogallala Formation and Quaternary Alluvium

The Ogallala formation mantles the High Plains immediately north of the southern Lea County area, where it ranges in thickness from 100 to 250 feet. The saturated thickness of the Ogallala formation on the High Plains ranges from 25 feet to 175 feet because of the very irregular Triassic erosion surface which underlies it. The recharge of the Ogallala on the High Plains is due entirely to precipitation, as the formation is topographically high and isolated. The Ogallala formation beneath the eastern part of Eunice plain is saturated also. However, the Triassic rocks project above the water table in the western part of the Ogallala outcrop area in southern Lea County, and there the Ogallala rocks are saturated only along valleys or in isolated depressions in the red-beds erosion surface.

Contours on the water table in the Ogallala formation and the Quaternary alluvium are shown on Plate 2. The boundaries of the aquifer are shown by heavy dashed lines, which encircle or delineate areas in which the red-beds erosion surface projects above the water table. They are generalized, and in some areas the location is only approximate. These high places in the red-beds surface exert important controls on the occurrence and movement of water in the Cenozoic rocks. The southeastward direction of movement of ground water beneath the Llano Estacado is to a great extent caused by the generally southeastward slope of the red-beds surface. Although recharge to the Ogallala apparently is distributed rather evenly, because of the even distribution of shallow depressions on the High Plains, the position of Mescalero Ridge relative to the buried red-beds ridge (pl. 1) may permit somewhat more concentrated recharge at the escarpment. The orographic effect of Mescalero ridge probably results in somewhat more concentrated rainfall along the ridge (pl. 1), and the alluvial fan deposits immediately southwest of the ridge probably are more permeable than the caliche covering of the high plains.

Some water apparently spills over the buried red-beds ridge and moves southwestward; however, on the basis of the limited data available, there does not seem to be a continuous saturated zone in the thin cover of alluvium in the Querecho Plains. This probably results partly from the fact that precipitation is significantly lower in the Querecho Plains and partly from the fact that the Santa Rosa sandstone, which underlies much of the area, is sufficiently permeable to accept most of the water that infiltrates through the alluvium.

Along the southern edge of the High Plains, from End Point to the area of Monument, the water leaves the Ogallala formation of the High Plains and enters the Quaternary fill which underlies the Laguna Valley area. The water which is not thus diverted to the Quaternary alluvium along the southern edge of the High Plains continues to move southeastward into Texas and eventually is intercepted by wells or discharges along the eastern border of the Llano Estacado.

The saturated thickness of the sediments in the Quaternary fill of the Laguna Valley area ranges from about 15 to 30 feet, and water levels are about 30 feet below the land surface. From End Point eastward, the movement of the water is to the southeast. In the Laguna Valley area, the water table is intersected by an impermeable barrier formed by a gentle rise of the red-beds surface to the south. This causes the water to be diverted eastward into T. 20 S., R. 37 E. and T. 20 S., R. 38 E. From the north end of Monument Draw southward, the ground water moves through both the Quaternary alluvium and through the large outliers of the Ogallala formation underlying the Eunice Plain area. The two formations are considered as one aquifer under the Eunice Plain. The sediments along Monument Draw and under the Eunice Plain to the west of the draw have an average saturated thickness of about 30 feet. The bulk of the water is derived by underground flow from the Laguna Valley area. Although there is some local recharge by precipitation and by underground flow of infiltrated rain water from the west side of the

Eunice Plain and from the Grama Ridge area, such recharge is probably negligible compared to the quantity received from Laguna Valley. Along the east side of the Eunice Plain, east of Monument Draw, the buried Triassic rocks form a north-trending barrier which is reflected topographically by Rattlesnake Ridge. Ground-water flow is diverted southward by this barrier. In the Rattlesnake Ridge area, the base of the Ogallala is above the water table except locally in depressions in the Triassic rocks. For that reason, the Ogallala is generally unsaturated. On the west side of Eunice Plain, along the San Simon Ridge and south of Grama Ridge, the sediments are either thinly saturated or dry.

Figure 18 illustrates the relation of ground water in the Tertiary–Quaternary aquifer to the red-beds surface. Two wells drilled on the plain north of Monument Draw encountered no water. Water levels in wells 3, 4, and 5 were 11 to 16 feet lower than the top of the red beds in well 1 in January 1945, when the test drilling was done.

Toward the south end of the Eunice Plain, in the area immediately north and east of Custer Mountain, the Triassic erosion surface is also above the water table so that southward movement of underground flow is diverted eastward.

The Quaternary fill in the San Simon Swale ranges from a few feet to over 400 feet in thickness. The thickest section is at the southeast end of the swale in the area of the San Simon Sink. The Quaternary cover is thinnest toward the west, and generally the sediments are unsaturated in that part of the area. The recharge in the area of the San Simon Sink is primarily through infiltration of runoff into the sink, but partly by underground flow from the sediments beneath the Grama Ridge area. The reentrant at the northeast end of the swale is the only area within the swale where water is known to occur at shallow depth in the Quaternary fill. The Quaternary sediments in the reentrant are much less than 100 feet thick, and water levels range from about 10 feet to 50 feet below land surface. Elsewhere in the swale, water levels are deeper than 400 feet below the surface. Water from great depth in most of the San Simon Swale is probably derived from the Triassic aquifers. However, in the area of the San Simon Sink, it is possible that the Quaternary fill may yield water from such depth.

The ground-water body in the alluvium of the San Simon Swale is apparently isolated from other Tertiary or Quaternary aquifers and probably is perched or semiperched. Ground water movement is probably from the edges of the swale toward the San Simon Sink area, and discharge is probably downward. The relatively high permeability of the sediments which underlie the sink area is demonstrated by the behavior of the stock tank (pond) which is located in the bottom of the sink. Mud, silt, and other debris served to seal the tank, until the tank was cleaned. Whereas, prior to cleaning, it was a perennial source of stock water, afterwards, because it could not effectively retain rainfall runoff, it was frequently dry.

The Ogallala formation is present in the Antelope Ridge and Grama Ridge areas in thicknesses ranging from a few feet to over 100 feet. Generally, it is unsaturated, but in a few places the basal few feet are saturated. Almost all the wells in this area derive their water from Triassic rocks. A few isolated wells, such as well 24.34.10.112, derive water from sediments filling isolated depressions or valleys in the Triassic erosion surface. Other wells, for example wells 24.33.10.113 and 24.33.24.444, derive water at shallow depth from the Quaternary fill in surface depressions.

The Ogallala has been mostly stripped away in the area that is here called the South Plain, and the principal aquifer is alluvium consisting mostly of fine sand with some silt and clay. The alluvium is more than 750 feet thick in sec. 19, T. 26 S., R. 36 E., as indicated in test wells drilled for the City of Jal as part of an extensive program of water development carried out in 1960.[1] The depths to water in wells 26.35.13.222 and 26.36.9.440, and in two municipal wells in secs. 18 and 19, T. 26 S., R. 36 E., indicate that as much as 550 feet of the fill is saturated in an area of about one square mile (pl. 2) and suggest that water in this aquifer may move toward the deepest part of the basin. Pumping tests indicate transmissibilities ranging from 16,000 to 23,000 gpd per foot. The pumping tests were made in wells that penetrated 335 to 340 feet of saturated sediment. Toward the eastern end of the South Plain approximately 20 feet of Quaternary sediments are saturated and receive recharge from the Eunice Plain.

Quaternary sediments in the Paduca Breaks area are too thin to be an effective aquifer, and the underlying Santa Rosa sandstone is sufficiently permeable to accept whatever recharge the area may receive..

USE OF GROUND WATER IN SOUTHERN LEA COUNTY

Ground water is the principal source of water supply in the southern Lea County area. Locally, runoff impounded in earthen tanks built in large arroyos, notably in the South Plain area, is used for stock watering, but this represents only a small percentage of the water used for this purpose. The principal uses of ground water in southern Lea County in the order of quantity consumed are irrigation, gasoline-plant operation, public supply, other industrial uses, stock, and rural domestic supply. Table 5 gives the estimated total consumption for the year 1954 by categories.

Significant increases in demand on the ground-water supplies of the southern Lea County area are certain to take place in two of the above

1. This and other information on T. 26 S., R. 36 E. and the adjacent area to the west was obtained from an unpublished report entitled "Proposed new ground water basin, southwest Jal area, Lea County, New Mexico," by E. L. Reed, transmitted to the State Engineer May 8, 1961. This work is summarized briefly here because it represents a substantial contribution to the knowledge of the hydrology of southern Lea County.

TABLE 5. GROUND-WATER USE, SOUTHERN LEA COUNTY, N. MEX., 1954

Use		Estimated amount (acre-feet)
Irrigation*		2,600
Gasoline plants		2,400
Public supplies		550
Eunice	275	
Jal	250	
Maljamar	9	
Monument	9	
Oil Center	7	
Other industrial uses		350
Gas stripping plants	150	
Oil-well drilling	130	
Shot-hole drilling	10	
Carbon-black plants	20	
Oil-pool repressuring†	30	
Oil-pool repressuring‡	10	
Stock		250
Rural domestic		200
Total		6,350

* 1952 data.
† Potable water.
‡ Treated water.

categories, public supplies and gasoline plants. It is unlikely that the irrigated acreage will increase significantly. Actually, there are areas near Pearl and Monument that have been withdrawn from cultivation and the conversion of two irrigation wells to municipal supply in T. 20 S., R. 38 E., has further reduced the cultivated acreage. The towns of Eunice and Jal grew steadily prior to 1955, and this trend is likely to continue for some time. Similarly, the oil and gas industry will continue to expand through further development of the shallow oil-bearing horizons and the discovery of new sources at greater depth in the Delaware basin. With the growth of the towns and additional gasoline-plant facilities, a yearly demand of 8,000 to 10,000 acre-feet is a distinct possibility.

Irrigation

Irrigation is practiced only on a small scale, but it is the largest category of water use in southern Lea County. Irrigation is carried on only at the northern fringe of the area, where underground flow from the Ogallala formation provides sufficient ground water for such purposes. The total acreage under cultivation in 1952 was estimated to be 1,320 acres, largely in alfalfa and cotton.

In 1952 there were two centers of irrigation farming in the area shown on Plate 2, only one of which is in southern Lea County as defined in this report. One was on the Llano Estacado in the vicinity of and southwest of Nadine. About 650 acres were irrigated in secs. 7 and 8, T. 20 S., R. 38 E., and about 590 acres in secs. 27, 34, and 35, T. 19 S., R. 38 E., The other area of irrigation farming was in T. 19 S., R. 35 E., in the vicinity of Pearl. The total irrigated acreage there was only 80 acres although several times this amount had been cultivated in previous years. On the basis of an estimated average use of 2 acre-feet per acre, the total pumpage in 1952 was estimated at about 2,640 acre-feet. In succeeding years the irrigated acreage has probably decreased, and the amount of water used for irrigation should have decreased also.

Gasoline Plants

In 1955 there were 11 gasoline plants in southern Lea County. Of these, eight obtained their water supplies locally within the area. The remaining three obtained water from wells on the High Plains. The plants which obtained their water supplies locally and their locations are as follows:

El Paso Natural Gas Co.	
Jal Plant 1	SE¼SE¼ sec. 1, T. 26 S., R. 36 E.
Jal Plant 2	NW¼NE¼ sec. 34, T. 24 S., R. 37 E.
Jal Plant 3	NE¼NE¼ sec. 33, T. 24 S., R. 37 E.
Jal Plant 4	NE¼ sec. 7, T. 24 S., R. 37 E.
Skelly Oil Co.	
Eunice Plant 1	NW¼SW¼ sec. 27, T. 22 S., R. 37 E.
Eunice Plant 2	SE¼NE¼ sec. 28, T. 21 S., R. 37 E.
Gulf Oil Corp.	
Eunice Plant	NE¼ sec. 3, T. 22 S., R. 37 E.
Phillips Petroleum Co.	
Eunice Plant	NE¼ sec. 5, T. 21 S., R. 37 E.

An additional gasoline plant, the Pure Oil Co. Dollarhide Plant, located in Texas about 1 mile east of the NE¼ sec. 9, T. 25 S., R. 38 E., obtains its water from three wells on the west side of Monument Draw east and northeast of Jal.

The function of a gasoline plant is to process natural gas and extract from it the primary distillates, gasoline, butane, and propane. The water used in a gasoline plant is in two separate systems, the cooling system and the boiler system (fig. 22). The cooling systems consume large amounts of water because evaporation is an essential part of the cooling process.

Because of the high proportion of water consumed by an evaporating tower, gasoline-plant water consumption varies seasonally over a wide range. Consumption in one plant ranged from a low of 154.6 barrels of water per million cubic feet of gas in December to a high of 215.4 per million in June. The plant with lowest water-use rate required 12.1

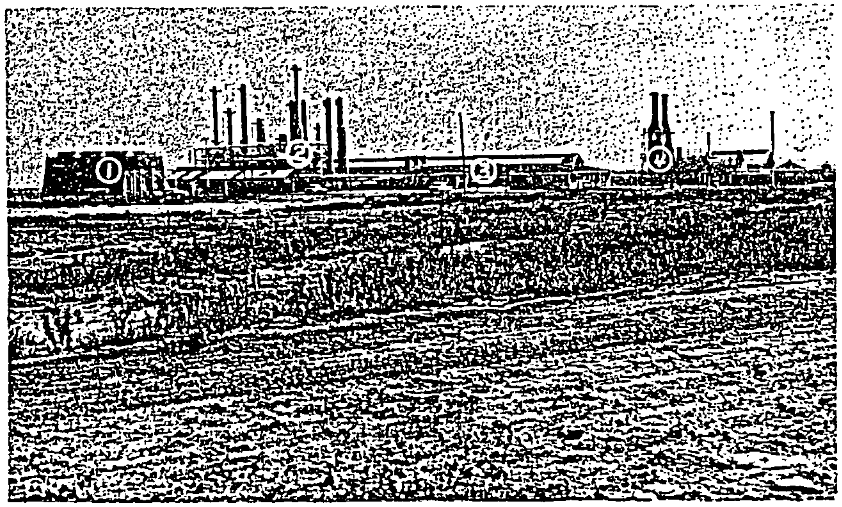

Figure 22

GULF OIL CORP. EUNICE GASOLINE PLANT NEAR EUNICE, N. MEX.

(1) Cooling towers; (2) fractionating towers; (3) compressor shed; (4) boilers.

barrels per million cubic feet in April and 88.4 barrels per million cubic feet in September.

Also, the ratio of water to quantity of raw product processed differs from plant to plant because of differences in plant design. Data from six representative gasoline plants for the year 1952 show a variation ranging from 39.1 barrels of water (42 gallons per barrel) per million cubic feet of natural gas processed to 179.6 per million. The average water consumption for the six plants was 81.3 barrels per million cubic feet of gas processed. For general estimates this was rounded to 80 barrels per million cubic feet.

On the basis of an estimated 80 barrels of water used per million cubic feet of gas processed, the total water consumed by gasoline plants in the southern Lea County area during 1952 and 1953 was estimated at 2,300 acre-feet and 2,400 acre-feet, respectively. The consumption of water by the existing plants does not vary greatly from year to year because of the limited capacity of the plants. Consequently, a significant increase in the use of ground water in gasoline production will occur only by enlargement of the present facilities.

The increase in water consumption between 1952 and 1953 was due in most part to the construction of the El Paso Natural Gas Co. Jal No. 4 plant, which went into operation in August 1952. The eight older plants which operated throughout the 2-year period accounted for only 74 acre-feet of the increase.

All the gasoline plants in the area obtain their water from the Ogallala formation near the plant sites, except for the El Paso Natural Gas Co. Jal No. 1 plant, which obtains its water from Triassic rocks.

The difficulty of providing an adequate water supply for a gasoline plant is illustrated by the water systems of the Skelly Oil Co. Eunice 2 Gasoline Plant and the Gulf Oil Corp. Eunice Plant, which are respectively north and south of the City of Eunice. Locations of the gasoline plant water wells and the plants are shown in Figure 23. Although the availability of water rights determines in part the location of wells, the wide scattering of the wells and their great distance from the plants are primarily the result of wide ranges in saturated thickness and permeability of the Ogallala formation in the area. Twenty-four wells were drilled for the Gulf plant, of which only 8 were in use in 1953. Nine wells were drilled for the Skelly plant, of which 5 were completed as water wells. It is characteristic of both municipal and industrial water supplies in southern Lea County that they require many wells and long pipelines, because there are only a very few localities where an adequate water supply is available nearby.

OTHER INDUSTRIAL USES

Industrial use of ground water in southern Lea County other than in gasoline plants represents only a small portion of the total water consumption. The largest users are oil-well drilling rigs and the two gas stripping plants.

Gas Stripping Plants

Residual gas from which the heavier distillates have already been removed is further purified in gas stripping plants by extracting hydrogen sulfide and carbon dioxide. The total water consumption in the gas stripping plants probably does not exceed 150 acre-feet per year.

One such plant of the United Carbon Co., is in sec. 8, T. 22 S., R. 36 E.; its yearly water consumption is estimated at 80 acre-feet per year. The water is obtained from three wells which are about 1,000 feet deep and probably bottom in the Santa Rosa sandstone. The wells are capable of a sustained yield of about 50 gpm each.

The stripping plant of the Southern Union Gas Co. near Oil Center also obtains water from a well bottomed in Triassic rocks, but the bulk of its water comes from shallow wells of the Continental Oil Co.

Oil-Well and Shothole Drilling

Water is widely used in the operation of drilling equipment. The quantity of water used varies over a wide range from well to well and is dependent upon such factors as the depth of the well, character of the formations, and drilling rate. The average amount used has been estimated to be about 0.5 acre-foot per well in southeastern New Mexico

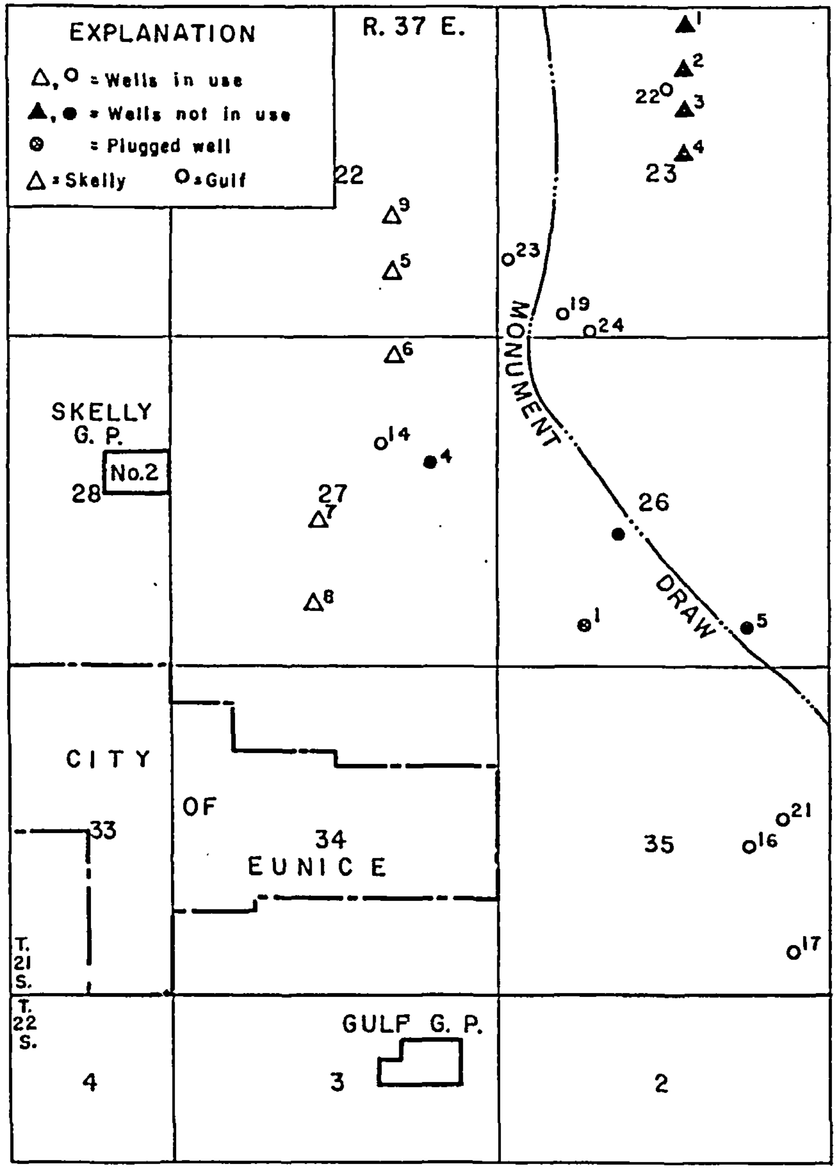

Figure 23
WATER WELLS OF THE SKELLY AND GULF GASOLINE PLANTS

(Conover and Akin, 1942). This figure has been corroborated by E. M. Rowland Tank Truck Service, which hauls water to drilling rigs. According to the Annual Reports of the New Mexico Oil Conservation Commission, 307 wells were completed during 1952 and 311 in 1953. On this basis, it can be estimated that oil-well drilling consumed about 150 acre-feet of water each year. Of this quantity about 20 percent consisted of oil-field brines, which, because of their higher salinity, are better than potable water for the preparation of salt-base mud, used for drilling through the thick sections of salt in the Permian rocks.

Seismic exploration requires the drilling of numerous shallow holes, but the water used in shothole drilling probably does not exceed 10 acre-feet per year.

Carbon-Black Plants

Carbon black is produced in southern Lea County by burning natural gas (contact process). There are four carbon-black plants in southern Lea County. Although water is sometimes used on very small fractions of the product to dampen the carbon black and form it into pellets, it is used mostly in a daily "washup" of the plant facilities and for lavatory purposes. Theis (1954) has estimated the water requirements of a carbon-black plant at 3,000 gpd for the washup and 2,000 gpd for lavatory purposes. The four plants together probably consume a total of not more than 22 acre-feet per year.

In recent years there has been a trend in the carbon-black industry to convert to a process that produces carbon black by burning oil (furnace process) instead of gas. It is estimated (Conklin, 1956) that the water consumption of this type of plant is more than 3 times that of a contact plant. Conversion of all the carbon-black plants in southern Lea County to the furnace process could therefore increase the water demand to about 65 acre-feet per year.

Oil-Pool Repressuring

Oil in the subsurface of the earth is usually under high pressure owing to gas in solution in the oil. It is this pressure, or reservoir energy, which provides the driving force that brings the oil from the oil-bearing formation into the well. As oil is removed from the formation, the reservoir energy declines because of the removal and the escape of gas. Eventually the reservoir energy becomes insufficient to move the oil into the well, and recovery by pumping alone is no longer possible. In order to recover some of the oil that otherwise would be left in the ground, it is sometimes feasible to inject water into the formation under pressure through depleted wells or specially constructed wells and so drive the residual oil into operating wells.

Two water-flood projects were in operation in 1954 in the Penrose-Skelly pool in T. 22 S., R. 37 E. Both projects were cooperative efforts involving several producers. One project is in sec. 9, where the Humble

Oil and Refining Co. and the Magnolia Petroleum Co. were injecting water into three depleted oil wells. Injection was begun in January 1951; during the 3-year period 1951 through 1953, the total quantity injected was about 52 acre-feet. The injection rate declined with time as pressure increased in the formation. During the first year the total input was 22 acre-feet under gravity flow, whereas in the third year the total input was only 14 acre-feet under pressures ranging from 450 psi to 900 psi.

In sec. 34, five injection wells were operated by the Humble Oil and Refining Co., the Skelly Oil Co., and the Gulf Coast and Western Oil Co. Injection was begun in December 1953, and the first 8 months of operation indicated an initial injection rate of about 30 acre-feet per year.

With one exception, all the water used in these repressuring projects was potable shallow water derived from the Ogallala formation near Eunice. The water produced from well 22.37.34.331 came from the Glorieta sandstone at a depth of 5,500 feet. The water from the Glorieta is of very poor quality and required treatment for the removal of hydrogen sulfide, carbonate, and sulfate before it could be used. Nearly half the water used in sec. 34 was treated sulfurous water from the Glorieta. The cost of chemicals in the treating process was estimated to be about 8 dollars per acre-foot of water treated.

Public Supplies

Eunice

Until 1954 the Eunice public water supply was obtained from the Ogallala formation. Over a period of years a well field consisting of 15 wells and covering an area of about half a section had been developed on the west and south sides of town. When initially pumped, the wells each yielded about 100 gpm; but within a few months the rate declined because the screens became clogged with very fine sand. Rehabilitation and repairs were frequently needed. With continued growth of the town, its water needs exceeded the well-field supply, and critical shortages were experienced during the summer months of the early 1950's. The need for additional water led to the abandonment of the old well field and to the construction of a pipeline to an area 10 miles north of town, where the city had bought two irrigation wells and converted them to public-supply wells. The wells (20.38.8.232 and 231) are pumped alternately, whereas in the old well field almost all the wells had to be pumped continuously in order to keep up with the demand. The water-bearing formation at the new field apparently is Quaternary alluvium; the high yield of the aquifer is due primarily to its high transmissibility. The saturated thickness in the new field is 40 to 50 feet, whereas in the old field the saturated thickness was 30 to 40 feet.

Water consumption in Eunice through 1953 was at an estimated rate of 246 acre-feet per year, or about 70 gallons per person per day for the population of about 3,100. Assuming per capita consumption to about 80 gallons per day per person the consumption rate at Eunice will exceed 500 acre-feet per year when the town reaches a population of 6,000.

Jal

The water-supply problem at Jal is a reptition of the experience at Eunice. Continued growth forced the city to abandon its old water-supply system, which consisted of five wells within the city limits, each bottomed in the Santa Rosa sandstone and each producing about 25 gpm. The city bought an abandoned irrigation well about 5 miles east of town and converted it to a public supply. It also drilled a second well so that one well could be used as a standby. The well (25.37.13.312a) is bottomed in the Ogallala formation; at the time the saturated thickness was about 80 feet, which is unusually thick for the southern Lea County area. The new well was tested at 750 gpm with a drawdown of only 15 feet. It was placed in operation in July 1954.

By 1959 this supply was no longer dependable during periods of peak demand for water, because the aquifer had been seriously depleted by pumping for industrial and municipal supply. The city undertook a program of test drilling in secs. 18 and 19, T. 26 S., R. 36 E., and developed two production wells capable of a combined yield of more than 700 gpm. This water became the prime source of supply for Jal in April 1960. The well field east of the city was kept as a standby source.

In 1960 the per capita use of water in Jal was about 100 gpd. The supply of water developed southwest of the city will permit a substantial increase in per capita consumption.

Oil Center

The entire water supply at Oil Center is provided by one well (21.36.9.222), bottomed apparently in the Chinle formation. The sustained yield of this well is about 6 gpm, or less than 8 acre-feet per year. The supply is inadequate and is made to do only by careful husbanding. It is possible that if the well were deepened another 100 to 200 feet, an adequate supply might be found in the Santa Rosa formation.

Monument

Monument has no public water supply. Water is obtained from private shallow wells bottomed in Quaternary alluvium. The wells in this area are adequate, but there is danger of contamination. One contaminated well located 1 mile south of town is discussed in the section on contamination. The total consumption probably exceeds that of Oil

Center because of the larger available supply. This consumption is estimated to be about 8 acre-feet per year.

Maljamar

Maljamar receives its water supply from wells at the edge of, or on, the High Plains. Three wells, belonging to A. C. Taylor, supply water to the Lea County Water Co., which in turn supplies water to a part of Maljamar and to Loco Hills, about 15 miles west of Maljamar. The Buffalo and Kewanee Oil Cos. supply the remainder of the town from several company wells. No data are available on consumption. However, on the basis of the number of dwellings, the population probably does not exceed 100 people, and total consumption is probably less than 8 acre-feet per year.

Stock

Stock raising is the most widespread agricultural activity in southern Lea County. The total number of stock wells is estimated at 170 and most of the total pumpage of these wells is disposed of by consumption by stock and evapotranspiration. Evapotranspiration losses are perhaps as much as 15 or 20 percent.

Sykes (1955, p. 17) reports that range cattle consume between 30 and 70 pounds of water per day, per head. High temperature and dry pasturage increase the intake and since these conditions prevail in southern Lea County, it can safely be assumed that average daily water consumption would be near the upper limit, 70 pounds (8.5 gal) of water per head.

Based on the records of the New Mexico State Tax Commission, the cattle population in southern Lea County in 1954 was about 17,800 head. At an assumed daily consumption rate of 8.5 gallons per head, the total consumption for the year must have been about 170 acre-feet. In 1952 and 1953 the cattle population was greater than in 1954, and the total consumption of water by cattle was about 210 and 190 acre-feet in those years.

Assuming an average pumping rate of 1 gpm throughout the year for 170 stock wells, the total pumpage would be about 250 acre-feet per year. The difference between total water consumption by cattle and total water pumpage represents evapotranspiration losses and storage in tanks. For the 3 years 1952 through 1954, this difference ranges from about 15 percent to about 30 percent of the estimated total pumpage.

Rural Domestic Uses

About 3,000 people in southern Lea County are not served by municipal water-supply systems. Most of these people live in "camps" which are in effect small company communities that range in size from 1 or 2 dwellings to 20 or more. The remainder live in isolated ranch houses and company-owned houses in the oil fields.

All but a very few of the dwellings outside the incorporated towns have water systems under either gravity or pneumatic pressure with hot and cold running water, interior plumbing, and septic tanks. Under such circumstances, the daily consumption rate is probably about 60 gpd per capita or about 200 acre-feet per year for the rural population of the area. Consumption in this category probably will decline in the future because of the movement of the population into the towns.

BRINE PRODUCTION

Most of the oil wells in southern Lea County produce brine with the oil. (Data on brine production have been obtained from the annual reports of the New Mexico Oil Conservation Commission.) The quantity of brine produced exceeds the quantity of oil recovered. Two wells in the Cass Pool (sec. 23, T. 20 S., R. 37 E.), for example, produced 26.6 and 13.8 times as much brine as oil in 1955. One well in the Eunice Pool (sec. 18, T. 21 S., R. 36 E.) produced 457,984 barrels of brine and only 2,629 barrels of oil in 1955, a water-oil ratio of 174:1.

The customary method of disposing of the brine is to discharge it into evaporation pits at or near the well sites. The evaporation pits are unlined dug pits, which are usually constructed by bulldozing a depression in the ground and surrounding it with an earth embankment (see fig. 24). The sizes of these pits differ according to the productivity of the wells they are intended to accommodate, and range from as little as 2,500 sq ft to nearly an acre in area. Many pits accommodate brine from more than one well.

Quantity and Sources

The total brine production of the southern Lea County fields to January 1, 1956, was more than 577 million barrels, or about 74,000 acre-feet, in contrast to 559 million barrels of oil produced to that date. Annual brine production figures for the years 1945 and 1952 through 1955 are as below:

Year	Brine production (acre-feet)
1945	2,800
1952	4,400
1953	4,600
1954	4,000
1955	3,700

The overall increase in brine production is shown by the contrast of the production of the more recent years with the production in 1945. The lower production of the last 2 years of the 1952–55 period is probably the result of the shutting down of heavy brine producers whose oil production had declined to an unprofitable level.

Figure 24

TYPICAL BRINE DISPOSAL PIT ABOUT 3 MILES SOUTHWEST OF OIL CENTER, N. MEX. (NE COR. SEC. 19, T. 21 S., R. 36 E.)

Discharge pipe is in immediate left foreground. Three oil wells are visible immediately behind the pit and in the distant background. Silver and black tanks near each well are treaters, which separate oil from brine.

A detailed breakdown of the brine production of the southern Lea County oil wells shows that most of the brine comes from the Permian formations. In 1952 the total number of brine-producing oil wells in southern Lea County was about 1,400. The brine was produced from 61 different oil pools, and from horizons ranging in age from Ordovician through Permian. Brine production in acre-feet by systems for the years 1952–53 was as follows:

System	Brine Production, acre-feet 1952	Brine Production, acre-feet 1953	Cumulative Production to Jan. 1, 1954
Permian	4,170	4,300	65,800
Pennsylvanian	15	37	85
Devonian	3	32	35
Silurian	7	30	37
Ordovician	200	200	537

About 99 percent of the brine was produced from the Permian formations of the southern Lea County area. About 97 percent of the producing oil wells drilled in the area up to the end of 1952 were bottomed in the Permian section.

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX.

LOCATION NUMBER: Explanation in section on well-numbering system.

OWNERS: EPNG, El Paso Natural Gas Co.; MCRA, Maljamar Co-operative Repressuring Agreement.

AQUIFER: Tr, Triassic rocks; To, Ogallala formation; Qal, Quaternary alluvium.

DEPTH OF WELL: M, measured; all other depths are reported.

ALTITUDE: Altitudes interpolated from topographic maps. Probable error less than 10 feet.

WATER LEVEL: Measured depths are given to nearest tenth of a foot; reported depths are given to nearest foot. All are non-pumping water levels except as noted otherwise in remarks column.

SURFACE DIAMETER OF WELLS: Expressed in inches unless otherwise indicated. Diameters of cased, drilled wells are given in inches. Diameters and rectangular dimensions of dug wells are given in feet.

METHOD OF LIFT: Lw, lift pump, windmill powered; Li, lift pump, internal-combustion-engine powered; Le, lift pump electrically driven; Te, turbine pump, electrically driven; Ti, turbine pump, internal-combustion-engine powered; Je, jet pump, electrically driven; N, unequipped or partly equipped.

USE OF WATER: D, domestic; L, domestic use other than drinking, such as watering lawns and gardens; P, public supply; I, irrigation; In, industrial; S, stock; N, none; O, observation.

REMARKS: EY, reported estimated yield; gpm, gallons per minute; gpd, gallons per day; MWP, measured while pumping; PR pumped recently; WBZ, water-bearing zone.

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
16.32.27.441	Buffalo Oil Co.	To	265	4,300	200(?)	—	—	8⅝	—	In	Perforations 194-254 feet.
35.400	Drew Taylor	To	246M	4,265	160(?)	—	—	8¼	Te	In,D	Taylor well 2. Northwest well of 3. EY 60-80 gpm.
17.32.2.433	MCRA	To	200	4,240	60	1948	—	7	Te	In,D	Well 6. EY 50 gpm.
2.434	MCRA	To	192	4,240	60	6- 1-50	1948	7	Te	In,D	Well 5. EY 50 gpm.
2.443	MCRA	To	190	—	—	—	—	7	Te	In,D	Well 7. EY 50 gpm.
3.140	Buffalo Oil Co.	To	—	—	—	—	—	—	—	In	Buffalo-Taylor well 3. Chemical analysis in table 8.
3.320a	do.	To	—	4,250	175.6	7-21-54	—	6	N	N	Buffalo-Taylor well 2. Nearby well pumping.

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
17.32.4.442	W. Taylor	Qal	—	4,180	82.9	6- 3-54	—	6	N	N	—
11.231	MCRA	To	139	4,180	—	—	1947	7	Te	In,D	Well 4.
17.32.11.233	MCRA	To(?)	140	4,200	70	9-20-47	—	8	Li	In,D	Well 2. EY 9 gpm.
11.411	MCRA	To(?)	200	4,170	70	6-15-46	—	8	Te	In,D	Well 1. EY 90 gpm.
11.411a	MCRA	To(?)	130	—	70	9-23-47	—	8	Li	In,D	Well 3. EY 50 gpm.
17.33.13.341	Potash Co. of America	To	252M	4,124	149.7	11-20-53	1952	6	N	O	—
18.322	Kewanee Oil Co.	To	220	4,230	—	—	—	10¾	Te	In,D	Two wells. Chemical analysis in table 8.
26.422	Phillips Oil Co.	To	—	4,125	161.2	11-20-53	1950	8	N	In,O	—
28.110	—	To	241M	4,185	198.0	5-11-54	—	7	N	N	—
30.124	Walter Williams	Qal	—	4,045	70.0	7-29-54	—	7	Lw	S	PR
18.33.14.111	—	Qal	40M	3,965	35.8	6- 3-54	—	5	N	N	—
19.142	—	Tr(?)	—	3,820	>140	12- 9-58	—	4	Lw	S	—
34.133	—	Tr	200M	3,760	177.4	12- 9-58	—	8½	N	N	—
19.32.8.200	—	Tr	—	3,650	365.3	12- 9-58	—	7½	Lw	S	Chemical analysis in table 8.
36.100	W. M. Snyder	Tr	485	3,565	—	—	—	—	Li	D,S	—
19.33.5.213	—	Tr	—	3,710	>299	12- 9-58	—	—	Lw	S	—
26.244	Mark Smith	Qal	101	3,600	92.9	7- 1-54	—	—	Lw	D,S	MWP
19.34.9.114	Scharbauer Cattle Co.	Tr(?)	33	3,790	28.6	6- 3-54	—	6	Lw	S	Chemical analysis in table 8.
31.131	Clark Scharbauer	Qal	—	3,625	65.8	7- 1-54	—	6	Lw	S	MWP
19.35.5.121	Gene Dalmont	To	88	3,890	50	7-28-54	—	8	Ti	I	—
5.234	Jules Smith	To	90	3,860	35	—	—	—	Lw	D,S	—
10.113	N. T. Roberts	To	36	3,860	19.9	7-28-54	—	6	Lw	S	EY 5 gpm.
12.444	—	Qal	—	3,740	34.2	7-28-54	—	3 ft.	Lw	S	—
19.35.17.122	J. D. Roberts	Qal	50	3,835	29.9	7-28-54	—	3×3 ft.	Lw	D,S	Dug 0-30 feet; drilled 30-50 feet.
22.334	—	Qal	—	3,740	23.5	7-28-54	—	8	Lw	N	—
24.121	—	Qal	—	3,735	28.6	11-16-53	—	6 ft.	N	N	—
25.424	—	Qal	—	3,675	22.6	11-16-53	—	—	N	N	Uncased shothole.
25.434	—	Qal	—	3,660	22.8	11-16-53	—	6	Lw	S	—
19.36.5.233	Tom Green	To	60	3,815	52.3	7-28-54	—	—	Lw	D,S	—
19.313	—	Qal	44.6M	3,685	18.6	11-16-53	—	—	N	N	Uncased shothole.
20.111	Tom Green	Qal	—	3,695	25.7	7-28-54	—	—	Lw	S	EY 10 gpm. PR
25.123	—	To	43M	3,680	16.0	3-18-54	—	6	N	N	Northwest well of six. Chemical analysis in table 8.
19.36.26.224	J. E. Weir	Qal	12.7M	3,650	6.7	5- 7-54	—	4×5 ft.	N	N	At Monument Spring.
28.422	Mrs. Abi Hall	To	52M	3,720	36.6	3-18-54	—	7	N	N	—
28.441	do.	To	27M	3,680	22.7	3-18-54	—	6	N	N	—
32.110	S. P. Jordan	Qal	32	3,645	19	11-20-29	—	—	—	—	Chemical analysis in table 8.
32.324	—	Qal	30	3,630	27.2	7-28-54	—	4×4 ft.	Lw	N	—
19.37.4.110	V. Linam	To	29	3,680	21	9-19-29	—	—	—	—	Chemical analysis in table 8.
18.111	Amerada Oil Co.	To	134	3,705	35	9- -47	1947	10¾	Ti	D	Monument District Camp. WBZ 67-108 feet, 112-125 feet. EY 385 gpm.
18.331	EPNG	To	—	3,710	51.9	3-18-54	—	10	N	N	—
20.242	Humble Oil Co.	—	80	3,660	Dry	—	1937	—	N	N	Plugged and abandoned.
21.132	do.	To	67	3,635	—	—	1937	—	—	—	State "D" well 2. EY 30 gpm.
19.37.25.422	—	To	—	3,600	40	4- 6-54	—	—	Lw	S	—
29.333	—	Qal	—	3,595	13.3	7-28-54	—	7	Lw	D	MWP
29.344	Hobbs School district	Qal	30±	—	21.5	3-23-60	—	8	Te	P	—
29.344a	do.	Qal	30±	—	—	—	—	6	Te	P	Chemical analysis in table 8.
30.113	Continental Oil Co.	Qal	60	3,660	—	—	—	—	Te	D	Pumps dry in summer.
20.32.1.322	W. M. Snyder	Qal	30	3,510	21.8	7- 1-54	—	6	Li	S	Water not potable.
18.233	Freeport Sulfur Co.	Tr	400	3,450	89.2	3-24-54	1954	8	Li	In	WBZ 215-243 feet.
27.144	Joel Frey	Qal	25	3,545	12.3	6-11-54	—	—	Lw	N	—
30.142	—	Qal	—	3,530	9.9	6-11-54	—	8¾	N	N	Located in sink.
36.214	Mrs. Bingham	Qal	60	3,588	46.6	6- 6-55	1950	7¼	Lw	D	West well of three.
20.33.15.221	—	Tr	—	3,570	336.1	4-20-55	—	4	Li	N	—
24.122	D. C. Berry	Tr	700±	3,630	300±	—	—	10	Lw	S	—
20.34.17.334	Mark Smith	Tr	200	3,635	140	7- 1-54	1940	10	Lw	S	MWP
22.223	D. C. Berry	Tr	235	3,655	—	—	—	10	Lw	S	—
20.35.1.221	J. L. Wood	Qal	35	3,655	24.5	11-16-53	—	4×4 ft.	N	O	—
31.113	Leo Sims	To	85	3,740	68.4	6-25-54	—	6	Lw	S	PR
33.433	do.	To	135	3,700	94.1	6-25-54	—	7	Lw	S	MWP
35.333	do.	To	105	3,690	88.9	4-15-54	—	—	Lw	D,S	MWP Southeast well of two.
20.36.1.412	Amerada Oil Co.	Qal	72M	3,565	33.1	3-30-54	—	7	N	N	—

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
20.36.5.321	—	Qal	—	3,635	28.3	11-16-53	—	6	Lw	S	—
12.141	—	Qal	40±M	3,550	29.5	3-25-54	—	—	Lw	S	—
12.222	Sunray Oil Co.	Qal	56	3,560	29.0	3-30-54	—	7	Lw	L	Water not potable.
20.36.15.222	Continental Oil Co.	Tr	700	3,575	—	—	—	—	Li	D	—
15.421	H. S. Record	Qal	50	3,575	35.7	3-30-54	1938	8½	Lw	S	Water not potable. MWP. Chemical analysis in table 8.
24.423	—	Qal	50±M	3,540	36.4	3-25-54	—	7	Lw	In	Water used to soak wooden tanks.
25.312	Stanolind Oil and Gas Co.	Tr	225	3,550	117.3	3-25-54	—	6	Lw	D	—
26.244	Amerada Oil Co.	Tr	265	3,555	—	—	—	7½	Li	In	Water used for oil well drilling.
32.112	Leo Sims	Tr	612	3,640	300	4-15-54	—	—	Lw	S	—
35.244	Humble Oil Co.	Tr	230	3,550	—	—	1938	—	—	In	Federal Fopeano well 2. EY 18 gpm.
20.27.3.341	—	Qal	—	3,560	19.5	4- 1-54	—	7½	Lw	S	Water not potable.
20.37.4.111	Jim Cooper	Qal	40	3,560	—	—	—	—	Je	L	Chemical analysis in table 8.
4.221	Nolan and Lane	Qal	45	3,555	31.4	4- 2-54	1940	6	Lw	D	Chemical analysis in table 8.
4.314	—	Qal	48M	3,550	32.8	4- 2-54	—	8	N	N	—
4.341	Humble Oil Co.	Qal	106	3,550	—	—	1935	—	—	—	Plugged and abandoned.
4.444	—	Qal	30±M	3,560	23.5	4- 1-54	—	8	N	N	—
5.333	Amerada Oil Co.	Qal	75	3,555	—	—	1954	7	Ti	In	WBZ 35-65 feet.
7.133	—	Qal	—	3,555	27.1	3-29-54	—	8½	N	N	—
7.241	—	Qal	28.5M	3,550	26.4	3-29-54	—	8½	N	N	About 70 feet northwest of windmill.
7.434	—	Qal	—	3,540	25.2	3-30-54	—	8½	Lw	S	MWP
8.321	Amerada Oil Co.	Qal	86	3,550	30	1-23-54	1954	7	Ti	In	Reportedly had no measurable draw-down at 50 gpm.
20.37.8.424	Tidewater Oil Co.	Qal	62	3,545	25.9	3-22-54	—	—	Li	D	EY less than 1 gpm.
9.110	W. H. Laughlin	Qal	53	3,558	34.0	11-16-53	—	4×6 ft.	N	O	—
9.331	Skelly Oil Co.	Qal	—	3,545	18.0	3-22-54	—	7	N	N	—
13.321	Earl Kornegay	Qal(?)	78M	3,545	75.7	4- 2-54	—	—	Lw	S	—
16.144	—	Qal	36M	3,525	13.2	2- 8-53	—	6	N	N	—
17.131	—	Qal	—	3,540	24.8	4- 1-54	—	7½	Lw	N	—
20.431	—	Qal	40	3,510	24.1	3-26-54	—	12	Lw	S	PR
21.400	—	Qal	—	3,500	43.0	3-26-54	—	7	N	N	—
28.122	Gulf Oil Corp.	Qal	60	3,500	29.3	3-26-54	—	7	N	N	—
28.244	—	Qal	42±M	3,490	37.4	3-26-54	—	6	Lw	S	PR
29.111	Mid-Continent Petroleum Co.	Qal	—	3,520	43.8	3-25-54	—	7	N	N	—
31.144	Humble Oil Co.	Qal	144	3,600	—	—	—	—	—	—	WBZ gray sand, 60-98 feet.
20.37.31.211	Humble Oil Co.	Qal	125	3,540	Dry	—	—	—	—	—	Penetrated red beds at 40 feet.
35.441	Continental Oil Co.	Qal	63M	3,480	53.4	3-23-54	—	12	N	N	—
36.330	do.	Qal	120	—	—	—	—	—	Te	In,D	One of two wells supplying pump station for lease houses.
20.38.6.143	—	To	—	3,575	45.9	4- 6-54	—	—	Lw	S	PR
7.222	William Walker	To(?)	112	—	—	—	—	24	Ti	I	—
7.411	A. E. Galloway	To(?)	125	—	—	—	—	—	Ti	I	—
8.231	City of Eunice	Qal	—	3,570	—	—	—	—	Te	P	West well of two. EY 600 gpm.
8.232	do.	Qal	—	3,570	—	—	—	—	Te	P	East well of two.
8.311	A. E. Galloway	Qal	125	3,570	64.1	4- 2-54	—	—	Ti	I	—
9.124	—	Qal	40±M	3,570	35.2	4- 2-54	—	—	Lw	S	—
11.414	—	To	33M	3,565	30.7	12- 9-53	—	3¼ ft.	N	N	—
20.38.12.244	—	To	—	3,565	43.7	12- 7-53	—	6½	N	N	—
16.133	Earl Kornegay	Qal	—	3,560	50	3-22-54	—	—	Lw	S	—
17.113	Amerada Oil Co.	Qal	120	3,565	—	—	1951	7	Ti	In	EY 40 gpm.
17.141	Earl Kornegay	Qal	105±M	3,555	59.3	3-22-54	—	7	N	N	—
17.142	do.	Qal	96M	3,555	57.2	3-22-54	—	—	N	N	—
17.333	Amerada Oil Co.	Qal	116	—	—	—	—	7	Ti	In	EY 35 gpm.
17.334	do.	Qal	168	3,550	72.8	3-22-54	—	—	N	N	—
18.242	do.	Qal	124	3,565	50	3- -52	—	7	Je	D	EY 17 gpm.
19.320	Continental Oil Co.	Qal	115	3,545	78.8	4- 2-54	—	8	Le	D	Chemical analysis in table 8.
31.341	—	Qal	70±M	3,490	66.7	3-23-54	—	6	N	N	—
20.39.7.133	—	To	—	3,565	43.6	12- 7-53	—	7½	N	N	—
18.344	Earl Kornegay	To	60±M	3,540	46.2	12- 9-53	—	—	N	N	Located northwest of windmill.
21.33.2.231	The Texas Co.	Tr	1,150	3,810	—	—	—	—	Li	D	Chemical analysis in table 8.
21.33.2.422	D. C. Berry	To	120	3,805	107.2	6-28-54	—	—	Lw	D	Chemical analysis in table 8.
2.442	do.	To	—	3,800	72.9	6-28-54	—	10	Lw	S	Located on west side of sink and west of earthen tank.

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
21.33.2.442a	do.	To	—	—	—	—	—	—	Lw	D,S	Located on east side of earthen tank. Chemical analysis in table 8.
18.112	do.	To	—	3,900	143.0	6-21-54	—	—	Lw	S	—
28.124	San Simon Ranch	Tr	224	3,690	179.5	6-30-54	—	7½	N	N	"Standard" well.
21.34.8.422	do.	To	120	3,705	105.8	6-30-54	—	—	Lw	S	—
13.324	Wilson Oil Co.	Tr	335	3,655	200	1943	1943	—	Li	D	—
23.223	do.	To	220	3,660	150	1954	—	—	Li	In,D	—
21.34.24.222	Mid-Continent Oil Co.	Tr(?)	125	3,655	—	—	—	—	Li	D	—
33.233	San Simon Ranch	To	80M	3,665	67.0	6- 6-55	—	7¼	N	N	"Christmas" well.
21.35.1.122	Amerada Oil Co.	Tr	312	3,550	175	6- 7-54	1954	7	Li	In	EY 9 gpm.
7.211	Wilson Oil Co.	Tr	430	3,700	340	1940(?)	1940	—	Li	D	One of two water wells at Wilson Camp.
14.111	San Simon Ranch	Tr	250	3,580	147.3	6- 7-55	—	6	Lw	S	"Scharbauer" well.
24.223	do.	Tr	—	3,620	205.7	4-14-54	—	—	Lw	S	—
27.321	—	To	—	3,615	21.8	12- 8-58	—	—	N	N	—
27.321a	—	To	—	3,620	—	—	—	—	Lw	S	Chemical analysis in table 8.
21.35.30.411	San Simon Ranch	To	58M	3,630	35.6	11-25-53	—	7½	Lw	S	—
21.36.9.222	W. L. Van Noy	Tr	447	3,605	<350	—	—	8	Li	P	EY 6 gpm. Public supply for Oil Center. Chemical analysis in table 8.
10.112	Humble Oil Co.	Tr	495	—	—	—	—	—	N	N	WBZ sand, 385-395 feet.
19.222	Pacific-Western Oil Co.	To(?)	230M	3,630	216.0	1- 7-54	—	8	N	N	—
23.233	Frontier Country Club	To	200	3,555	139.0	4-22-55	1955	8⅝	—	—	Unfinished well. Recently bailed.
28.243	—	To	197M	3,585	174.5	1-15-54	—	6¼	N	N	—
21.36.29.144	Humble Oil Co.	To(?)	305	3,630	—	—	1935	—	N	N	WBZ sand, 225-305 feet.
33.223	—	To	215±M	3,590	205.5	11-12-53	—	6½	N	N	—
36.242	W. M. Snyder	To	—	3,505	113.3	1-15-54	—	6	Lw	S	MWP
21.37.6.244	—	To	—	3,495	70.3	3-23-54	—	8	Li	—	—
10.211	Continental Carbon Black Co.	Qal	76	3,440	26	1953	1945	8	Te	In,D	—
11.311	—	Qal	77M	3,426	39.1	12- 8-53	—	7½	N	N	—
12.341	Terry and McNeil	Qal	100	3,450	76.3	10- 2-53	—	7	Ti	In	—
13.111	Western Oil Field Corp.	Qal	185	3,425	60	10- 2-53	1953	—	—	—	Drilled for oil.
14.123	—	Qal	—	3,420	25.4	12- 8-53	—	6	Lw	S	—
18.442	T. Davis	To	125	3,510	99.7	1-10-54	—	7	Ti	D,S	—
21.111	—	To	—	3,460	73.1	1-10-54	—	7¾	N	N	—
21.37.22.211	—	To	49M	3,420	37.7	4-21-55	—	—	N	N	—
22.413	—	To	—	3,410	75.0	10- 1-53	—	7	N	N	—
23.211	Skelly Oil Co.	To(?)	81	3,420	42.5	10- 1-53	1948	—	N	N	Skelly Eunice Plant 2, well 1. Initial yield, 55 gpm.
23.213	do.	To(?)	83	3,410	45.8	10- 1-53	1948	—	N	N	Skelly Eunice Plant 2, well 2.
23.231	do.	To(?)	84	3,410	43.0	10- 1-53	1948	—	N	N	Skelly Eunice Plant, 2, well 3. Initial yield, 100 gpm.
23.233	do.	To(?)	81	3,405	44.1	10- 1-53	1948	—	N	N	Skelly Eunice Plant 2, well 4. Initial yield, 60 gpm.
23.300	Gulf Oil Corp.	To	100	3,390	59	5-31-50	1948	10¾	Te	In,D	Gulf Eunice Gasoline Plant, well 22.
21.37.23.331	—	To	—	3,385	72.9	10- 1-53	—	8½	N	N	—
23.331a	Gulf Oil Corp.	To	96	3,390	64	5-31-50	—	7	Te	In,D	Gulf Eunice Plant, well 23.
26.323	do.	To	101	3,365	64	12- 3-48	—	—	Te	In,D	Gulf Eunice Plant, Cone well 1.
26.400	do.	Qal	160	3,365	53	7-23-51	—	5⅝	N	N	Gulf Eunice Plant, well 5.
27.232	do.	To	99	3,400	62	1948	1948	7	Te	In,D	Gulf Eunice Plant, well 14. Initial yield, 55 gpm.
27.241	do.	To	180	3,385	60	1948	—	7	N	N	Gulf Eunice Plant, well 4.
30.414	—	To	—	3,480	101.6	1-11-54	—	—	Lw	In	—
32.121	Skelly Oil Co.	To	92M	3,460	90.7	1-15-54	—	6½	N	N	—
33.110	City of Eunice	To	130	3,450	—	—	—	6	N	N	Old public-supply well. WBZ 90-130 feet. Chemical analysis in table 8.
21.37.33.111	Magnolia Oil Co.	To	110(?)	3,450	103.8	12-10-53	—	6	Ti	In,D	Water used for oil well flooding. Chemical analysis in table 8.

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
21.37.33.210	City of Eunice	Tr	350	3,430	—	1944	—	6	N	N	Old public-supply well. WBZ 320-350 feet. Chemical analysis in table 8. EY 10 gpm.
33.211	—	To	103M	3,430	99.6	11-12-53	—	10¾	N	N	—
33.233	City of Eunice	To	135	3,435	100	1944	—	8	Te	P	City well 1. Perforated 100-130 feet. Chemical analysis in table 8.
35.423	Gulf Oil Corp.	Qal	110	3,375	61	5-17-50	—	10¾	Te	In,D	Gulf Eunice Plant, well 21.
35.442	do.	Qal	87	3,360	59	11-14-51	—	7	Te	In,D	Gulf Eunice Plant, well 17. WBZ sand and gravel, 65-74 feet.
21.37.36.144	P. Wallach	Qal	66±M	3,370	47.8	10- 9-53	—	6	Lw	S	—
36.344	do.	Qal	—	3,360	49.8	10- 9-53	—	8⅝	Lw	S	—
21.38.6.133	Ray McNeil	Qal	90+	3,550	79.4	12- 7-53	—	7	N	N	—
6.133a	do.	To	90?	—	—	—	—	—	Lw	—	Chemical analysis in table 8.
6.133b	do.	To	108	—	—	—	—	—	N	N	do.
8.144	Humble Oil Co.	—	133	3,565	Dry	—	—	—	—	—	Plugged and abandoned.
22.33.13.200	San Simon Ranch	Tr	508	3,510	—	—	—	—	Lw	S	WBZ 420-470 feet.
22.34.12.111	do.	Qal	62	3,530	48	—	1951	—	Lw	D,S	—
12.114	do.	Qal	16M	3,515	12.6	3-17-54	—	—	Lw	S	Is an infiltration tunnel about 70 feet long and 5 feet in diameter feeding 2 windmills, 1 centrifugal pump and 1 siphon.
22.36.1.333	Gulf Oil Co.	To	150	3,490	111.2	11-12-53	—	—	Li	L	Chemical analysis in table 8.
2.444	—	—	—	—	—	—	—	—	Lw	S	Chemical analysis in table 8.
8.443	United Carbon Co.	Tr	1,000±	3,580	700	—	—	8	Le	In,D	Three wells. EY 30 gpm each. Chemical analysis in table 8.
11.224	Texas-Pacific Coal and Oil Co.	To	120+	3,500	113.8	11-12-53	—	8	Lw	D	Chemical analysis in table 8.
13.222	Ohio Oil Co.	Tr(?)	—	3,455	Flowing	—	—	7	N	N	Capped and flowing.
25.434	R. L. Robinson	To	—	3,430	118.5	11-23-53	—	—	Li	S	—
22.36.35.314	do.	To	197	3,490	187.4	11-23-53	—	—	Lw	S	—
1.132	G. Sims	Qal	—	3,350	47.6	10-14-53	—	—	N	N	Open, uncased hole.
1.440	do.	Qal	—	—	—	—	—	—	Lw	S	Chemical analysis in table 8.
2.442	Humble Oil Co.	Qal	86M	3,360	53.3	10- 9-53	—	7	N	N	Initial yield, 68 gpm.
3.133	Sinclair Oil and Gas Co.	To	120	3,425	90	—	1946	—	Je	D	—
3.134	do.	—	52M	3,420	Dry	9-28-53	—	—	N	N	—
3.440	Cities Service Oil Co.	To	—	3,390	75.8	9-29-53	—	7½	N	N	—
4.211	City of Eunice	To	155	3,445	110	1953	1953	10	Te	P	Well 12. Initial yield, 100 gpm; yield in 1953, 60 gpm.
4.213	do.	To	155	3,440	114.8	3- 6-54	1952	10	Te	P	Well 11. EY 60 gym.
4.214a	Eunice Cemetery Assoc.	To	115±M	3,435	108.2	9-29-53	—	6½	N	N	—
22.37.4.233	City of Eunice	To	155	3,435	110	1951	1951	8	Te	P	Well 9.
4.421	Sinclair Oil and Gas Co.	To	114±M	3,430	90.1	9-28-53	—	7⅝	N	N	—
4.424	Skelly Oil Co.	To	164	—	<139	—	1950	8⅝	Ti	In,D	Skelly Eunice Plant 1, well 13. Initial yield, 150 gpm; dropped to 20 gpm.
8.441	Shell Oil Co.	To	168	3,400	60	1953	1936	6⅝	Lw	D	—
9.313a	Humble Oil Co.	To	166M	3,400	72.7	9-29-53	1944	9½	N	N	Humble—J. L. Greenwood well 2.
9.331	do.	To	160	—	—	—	1945	7⅝	Te	D	Humble—J. L. Greenwood well 4.
9.333	do.	To	172	—	—	—	1946	4	Te	In	Humble—J. L. Greenwood well 5. Water used for oil well flooding.
22.37.9.441	Humble Oil Co.	To	104±M	3,410	85.5	9-29-53	1940	6⅝	N	N	Humble—J. L. Greenwood well 1.
10.213	Gulf Oil Corp.	To	220	3,400	100	1950	—	—	Lw	D	Gulf-Brunson lease well.
10.320	Skelly Oil Co.	To	—	3,395	81.0	9-29-53	—	11½	N	N	—
11.324	—	Qal	100M	3,350	45.3	10-16-53	1952	5	N	N	—
11.444	Leo Sims	Qal	—	3,345	58.7	10-16-53	—	8⅝	Lw	S	—
12.114	G. Sims	Qal	84M	3,340	53.9	10-14-53	—	7	N	N	—
12.443	do.	Qal	59M	3,335	53.9	10-14-53	—	15	N	N	—
12.443a	do.	Qal	59M	3,335	53.3	10-14-53	—	—	N	N	Uncased and open.
15.333	H. O. Sims	To	—	3,380	81.0	9- -53	—	4¾	Lw	D,S	—
16.432	Skelly Oil Co.	To	135	—	—	—	—	7	Ti	In,D	Skelly Eunice Plant 1, well 11. EY 40 gpm.
16.443	do.	To	136	3,385	80.9	9-28-53	1947	8⅝	Ti	In,D	Skelly Eunice Plant 1, well 10.
22.37.21.221	—	To(?)	—	3,380	76.5	9- -53	—	6⅝	N	N	—

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
22.37.21.421	—	To(?)	—	3,360	62.0	9- -53	—	4½	N	N	—
22.331	Skelly Oil Co.	To(?)	115±	3,350	69.0	9-29-53	1949	—	Ti	In,D	Skelly Eunice Plant 1, well 12. EY 40 gpm.
23.233	Leo Sims	Qal	77M	3,345	55.0	10-14-53	—	14	N	N	Open and uncased.
23.441	O. I. Boyd	Qal	70±	3,335	55.3	10-12-53	—	—	Lw	S	Dug.
23.441a	do.	Qal	70±	3,335	55.2	10-12-53	—	7½	N	N	—
24.133a	G. Sims	Qal	127M	3,322	59.3	4-21-55	—	10	Li	N	—
24.133b	do.	Qal	80	—	—	—	—	—	Lw	N	Chemical analysis in table 8.
25.313	Marshal Drinkard	Qal	69M	3,300	50.1	10-14-53	1945	13½	N	N	—
27.334b	Skelly Oil Co.	Qal	127M	3,335	54.4	9- -53	—	8½	N	N	Skelly Eunice Plant 1, well 9.
27.410	do.	To?	182	—	—	—	—	7	Te	In,D	EY 25 gpm. Perforations 150-170 feet.
22.37.28.323	Clower Drilling Co.	Qal	—	3,353	66.1	9- -53	—	9¼	N	N	—
34.221	Humble Oil Co.	Qal and Tr	229	3,520	—	—	1938	—	—	In	WBZ 58-61 feet, 138-146 feet, 185-192 feet. EY 22 gpm.
36.141a	Tom Linebury	Qal	40	3,300	32.2	10-12-54	—	—	Lw	S	—
36.141b	do.	Qal	46	3,300	31.1	6- 3-55	—	6	N	N	—
22.38.18.234	The Texas Co.	Tr	386M	3,360	180	10- -53	1953	—	Li	In	WBZ gray sand, 325-380 feet. EY 20 gpm.
19.222	do.	Tr	—	3,365	146.0	10-14-53	—	7	N	N	—
23.32.4.222	C. H. and W. O. James	Tr	550	3,630	—	—	1931	8	Lw	S	EY 10 gpm.
21.222	Frank and Charles James	Tr	550	3,700	500	—	—	8	Li	S	—
23.33.12.322	San Simon Ranch	Tr	400	3,685	—	—	1953	—	Lw	S	WBZ 370-400 feet.
23.33.28.334	Brinninstool	Tr	575	3,675	500	—	—	—	Lw	D,S	EY 2.5 gpm.
23.34.1.444	San Simon Ranch	Qal	144±M	3,360	137.3	11-25-53	—	6	N	N	—
31.340	Continental Oil Co.	Tr	678	3,620	—	—	1953	8	Li	In	EY 47 gpm. Chemical analysis in table 8.
23.35.27.444	—	To	—	3,480	117.2	3- -53	—	7	N	N	—
23.36.15.414	J. E. Matkins	To(?)	230	3,390	148.4	12- 4-53	—	6	Lw	D,S	—
16.343	do.	Tr	1,100	3,465	150	1952	—	—	Lw	S	—
22.434	Texas Pacific Coal and Oil Co.	To	210±M	3,395	188.6	12- 1-53	—	8½	N	N	—
23.111	do.	To	—	3,370	143.6	12- 4-53	—	8	Li	In	—
31.233	J. Combass	To	—	—	—	—	—	—	Lw	S	Chemical analysis in table 8.
23.36.35.211	J. Combass	To	170	3,330	123.0	3- -53	—	6½	N	N	—
36.341	EPNG	To	250	3,330	124	—	—	10¾	Tl	In,D	Jal Plant 4, well 8.
36.342	EPNG	To	261	3,330	120	—	1952	—	Tl	In,D	Jal Plant 4, well 7.
23.37.2.133	—	To	—	3,304	62.8	10-16-53	—	—	N	N	—
2.422	—	Qal	—	3,295	64.1	6- 3-55	—	6	Lw	S	—
3.421	H. O. Sims	To	80	3,295	64.1	10-16-53	—	—	Lw	D,S	—
4.114	—	To	84—M	3,341	81.8	12- 3-53	—	5½	N	N	—
4.211	Skelly Oil Co.	Tr(?)	226	3,340	—	—	1947	10¾	Le	D	H. O. Sims Camp well 1. EY 10 gpm.
6.144	—	To	—	3,375	102.9	12- 3-53	—	6½	Lw	S	—
20.333	Bert Steeler	Qal(?)	177	3,300	117	—	1939	—	Lw	D,S	—
25.132	M. L. Goins	To(?)	—	3,215	28.3	10-15-53	—	7	Lw	S	—
27.441	—	Qal	—	3,270	78.3	3- 4-53	—	5½	Lw	S	—
23.37.31.442	EPNG	To(?)	173	3,300	118	1952	1952	12½	Te	In,D	Jal Plant 4, well 4.
32.122	—	To(?)	—	3,300	99.0	7-23-54	—	6	Lw	S	—
32.331	EPNG	To(?)	173	3,310	—	—	—	20	Te	In,D	Jal Plant 4, well 1. WBZ 115-171 feet. EY 40 gpm.
33.122	—	To(?)	120M	3,310	91.2	3- 4-53	—	9	N	N	—
23.38.5.233	Humble Oil Co.	Tr	400M	3,385	189.8	10-15-53	1943	7½	N	N	W. F. Scarbrough well 1. EY 14 gpm.
8.214	Tom Linebury	Tr	—	3,372	198.3	10-15-53	—	6½	Lw	D,S	—
24.32.3.322	Frank James	Tr	550	3,650	—	—	—	10	Lw	D,S	—
10.344	do.	Qal	60	3,588	31.1	6- 3-55	1910	6	Lw	S	Located in sink.
33.422	Richard Ritz	Tr	367M	3,510	313.4	2-18-58	—	12	Lw	S	EY 0.25 gpm.
24.33.10.113	Carl Johnson	Qal	36±M	3,595	24.6	11-27-53	—	6½	Lw	S	—
24.33.23.311	—	Tr	232M	3,565	208.6	11-27-53	—	9½	N	N	—
24.444	—	Qal	—	3,530	16.9	11-27-53	—	5½	Lw	S	—
33.231	Carl Johnson	Qal	—	3,460	93.2	3-17-54	—	6	Lw	D,S	—
24.34.4.111	—	To	—	3,570	51.3	6- 3-55	—	—	Lw	S	—
5.444	—	To	78(?)	3,590	66.6	4-21-55	—	—	Lw	N	—
10.112	Madera Ranch	To	83M	3,525	71.8	4-27-53	—	6	N	N	—
10.422	do.	To	94M	3,315	63.2	4-27-53	—	7½	N	N	—

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level		Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
					Depth below land surface (feet)	Date measured					
24.34.35.122	do.	Tr	258M	3,410	223.9	3-29-53	—	6	Lw	S	—
24.35.30.341	do.	Tr	150±M	3,320	139.6	11-27-53	—	6	Lw	S	—
24.36.3.111	—	To	—	3,400	181.1	3-12-53	—	7½	N	N	—
3.333	Charles Whitten	To(?)	190±M	3,390	181.1	3-12-53	—	11½	N	N	—
9.133	do.	To	230	3,395	195.0	3- 6-53	1948	7	N	N	—
13.314	Humble Oil Co.	To	160	—	—	—	1941	—	—	—	WBZ sand, 138-158 feet. EY 10 gpm.
24.36.15.222	Canmex Oil Co.	To	200	3,370	181.3	3-12-53	1937	7	Lw	D	—
22.220	Continental Oil Co.	Tr	692	3,340	—	—	—	8¼	Li	D	A. H. Meyers "A" well 1. Intake set at about 475 feet. Maximum yield 6 gpm.
23.222	—	To	—	3,345	147.9	3- 6-53	—	6¼	Lw	I	Measurement made inside pipe column.
27.221	J. R. Wilson	To	—	3,320	122.9	3- 6-53	—	10	N	N	—
24.37.5.111	EPNG	To	173	3,275	111	9- 8-52	1952	10¾	Te	In,D	Jal Plant 4, well 6.
7.431	Fowler Hair	To	132M	3,300	119.9	3- 6-53	—	6¼	N	N	—
10.123	Trinity Production Co.	Tr	747	3,260	120	2- -53	1953	—	Li	In	EY 42 gpm. Chemical analysis in table 8.
14.211	Fowler Hair	To(?)	72M	3,205	64.5	3- 3-53	—	5	N	N	—
24.37.16.342	—	To	106M	3,235	67.7	3-11-53	—	9	N	N	—
16.423	Humble Oil Co.	To	150	3,240	—	—	1951	6⅝	Te	D	Fowler-Ellenburger Camp well 1. WBZ 90-150 feet.
17.422	Fowler Hair	To	92M	3,260	86.5	3- 4-53	—	7½	N	N	—
19.234	—	To	124M	3,290	117.4	3- 5-53	—	10	Lw	S	—
21.444	Dollarhide Water Co.	To	74M	3,210	69.6	3- 2-53	—	7½	N	N	—
25.322	Fowler Hair	To	—	3,136	76.1	3- 3-53	—	6½	Lw	D,S	—
34.320	Plains Production Co.	To	75±M	3,160	56.8	3- 2-53	—	12	N	N	—
25.33.20.443	—	Tr	—	3,395	200-250	8-18-58	—	6	Lw	D,S	—
31.244	Nick Ritz	Tr	320	3,400	257.5	7-26-54	—	8	Lw	S	—
25.34.1.132	Madera Ranch	Tr	300+	3,385	231.0	4-15-53	—	6	N	N	—
25.34.15.242	—	Tr	168	3,335	164.9	7-23-54	—	10	Lw	S	—
25.35.10.223	Georgia Bryant	To	83M	3,180	76.9	4- 2-53	—	9	Lw	S	—
21.122	—	Tr	—	3,230	173.3	4- 2-53	—	8½	N	N	—
25.36.10.313	W. D. Dinwiddie	Tr	512	3,130	300	—	—	—	Lw	S	—
15.111	do.	Tr(?)	140	3,125	120.2	3- -53	1951	—	N	N	—
23.234	—	Qal	65M	3,070	53.7	3-31-53	—	6½	Lw	S	—
24.112	Humble Oil Co.	Tr	455	3,115	292.4	4-15-53	—	—	N	N	—
25.37.1.340	Pure Oil Co.	To	217	3,108	60	—	—	20	Te	In,D	—
2.332	Richmond Drilling Co.	To	112M	3,140	98.8	3-29-53	—	7	Lw	D	—
9.333	Stanolind Oil Co.	Tr	502	3,140	—	—	1938	—	Lw	D	WBZ 470-502 feet.
10.412	EPNG	To	270	3,120	50	12-20-49	1949	12	Te	In,D	Jal Plant 3, well 2.
10.433	M. B. Owens	To	—	3,100	54.3	2-26-53	—	7½	Lw	S	MWP
13.312a	City of Jal	To	152	3,080	73	6- -54	1954	12	Te	P	New city well. EY 750 gpm. Chemical analysis in table 8.
25.37.15.221	J. M. Owens	To	—	3,100	59.2	2-26-53	—	—	Ti	In	EY 30 gpm. PR.
15.223	Sun Oil Co.	To	—	3,090	—	—	—	—	Lw	D	Chemical analysis in table 8.
15.411	—	Qal	85M	3,070	31.1	2-26-53	—	6½	N	N	—
17.114	—	Qal	—	3,105	62.8	3- 5-53	—	—	Lw	S	MWP
19.211	—	To	—	3,088	62.3	5-30-55	—	6	Je	D	—
19.221	City of Jal	Tr	500	3,110	284.0	11-11-54	1948	10	N	N	Chemical analysis in table 8.
19.240	do.	Tr	450	3,040	65	1942	—	—	—	—	Old public-supply well. WBZ 70-450 feet. EY (1942) 50 gpm. Chemical analysis in table 8.
20.310	do.	Qal	70	3,035	65	1-18-42	—	6×6 ft.	—	—	Dug. WBZ "clayey sand" 65-70 feet. EY 50 gpm. Chemical analysis in table 8.
25.37.20.413	EPNG	Tr	419	—	—	—	—	10¾	Je	In,D	Jal General Camp well 1.
21.411	G. B. Hadfield	To	46M	3,050	38.2	2-12-53	—	6	Lw	S	EY 1 gpm.
24.211	—	To	—	3,071	58.4	2-12-53	—	6	N	N	—
24.422	—	To	—	3,050	60.2	2-12-53	—	8	N	N	—
25.411	—	To	62M	3,055	56.4	2-12-53	—	6	N	N	—
33.114	Olsen Oil Co.	Qal	105	3,000	87.4	2-16-53	—	12	N	N	—
36.244	—	To	120	3,035	74.2	2-13-53	—	10	N	N	—
25.38.6.122	Fowler Hair	To	65M	3,100	60.5	3- 3-53	—	6½	Lw	S	—
6.134	—	To	—	3,095	53.1	2-25-53	—	3	N	N	Cased shothole.
9.343	—	To	—	3,130	95.7	2-25-53	—	6½	Lw	D,S	EY 30 gpm.

TABLE 6. RECORDS OF WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
25.38.19.342	Pure Oil Co.	To(?)	133	3,061	68	1952	—	—	—	In	Dollarhide Gasoline Plant well 2.
21.121	Tom Linebury	To	110	3,103	87.7	2-12-53	—	7	Lw	S	—
29.131	—	Qal	—	3,040	69.9	2-15-53	—	6	Lw	N	—
26.32.21.322	Battle Ax Ranch	Tr(?)	253	3,140	180	7-23-54	—	—	Li	D,S	—
26.33.3.444	W. D. Dinwiddie	Qal	180	3,315	102.8	7-23-54	—	6	N	N	—
3.444a	do.	Qal	—	3,315	—	—	—	6(?)	Lw	S	Chemical analysis in table 8. Located 50 feet west of 26.33.3.444.
9.443	—	Qal(?)	—	3,280	106.6	7-26-54	—	—	Lw	S	—
22.433	Battle Ax Ranch	Qal	200(?)	3,270	79.7	7-26-54	—	6	Lw	S	—
26.34.6.213	—	Tr	360	3,330	141.9	7-23-54	—	8	Lw	S	—
26.35.13.222	—	Qal	—	2,990	229.1	12-12-58	—	7	Lw	S	Chemical analysis in table 8.
26.36.9.440	Frank Antheys	Qal	184M	2,940	177.8	12-12-58	—	7	Lw	D,S	MWP
18.311	City of Jal	Qal	559	2,981	220.8	3-17-60	1960	24	Te(?)	P	Yield 453 gpm. Gravel packed. WBZ 275-300, 400-465, 500-530 feet.
19.233	do.	Qal	700	2,950	198.0	—	1960	24	Te(?)	P	Yield 408 gpm. Gravel packed. WBZ 270-280, 400-480, 550-600, 670-680 feet.
21.443	—	—	137(?)	2,900	Dry	12-11-58	—	11	N	N	—
26.37.2.133	Clyde Cooper	Qal(?)	119	3,000	103.4	2-16-53	1937	8	Lw	S	—
7.331	EPNG	Tr	476	2,960	—	—	1937	8⅛	Te	In,D	Jal Plant 1, well 1.
12.314	—	Qal	—	3,010	102.3	2-16-53	—	9½	N	N	—
12.331	—	Qal	103±M	3,000	99.9	2-17-53	—	3	N	N	Cased shothole.
12.441	Humble Oil Co.	Qal	175	—	—	—	1944	—	—	—	WBZ 125-150 feet. EY 68 gpm.
14.122	—	Qal	131M	2,985	100.6	2-17-53	—	3	N	N	Cased shothole.
26.38.7.244	Tom Linebury	Qal	73	3,000	57.1	2-24-53	—	8½	N	N	—
8.444	do.	Qal	66	3,000	64.5	2-24-53	—	6½	Lw	S	—
17.414	do.	Qal	—	2,975	39.4	2-24-53	—	5½	Lw	S	—
21.344	do.	Qal	—	2,955	29.0	2-13-53	—	3	N	N	Cased shothole.
32.141	do.	Tr(?)	—	2,950	142.4	2-13-53	—	26	N	N	—

TABLE 7. RECORDS OF SELECTED WELLS IN TEXAS ADJACENT TO SOUTHERN LEA COUNTY, N. MEX.
Explanations of symbols are included in the headnotes of Table 6.

Location No.	Owner	Aquifer	Depth of well (feet)	Altitude of well (feet)	Water level: Depth below land surface (feet)	Water level: Date measured	Year completed	Surface diameter of wells	Method of lift	Use of water	Remarks
				Gaines County Tex.							
A-12.25.341	—	To	50(?)	3,545	40.8	12- 9-53	—	6	Lw	N	—
A-28.3.413	Greenwood	—	—	3,485	35.1	12- 9-53	—	—	Lw	S	—
				Andrews County, Tex.							
A-29.17.320	H. O. Sims	To(?)	82	3,510	79.4	7-28-40	—	—	Lw	S	—
A-39.4.420	do.	To	81	3,478	72.4	10- 9-53	—	6½	Lw	S	—
A-39.14.111	Humble Oil Co.	—	215	3,410	Dry	—	—	—	—	—	—
A-40.16.330	M. L. Goins	To	80	3,305	74.1	10-15-53	—	—	Lw	D,S	—
				Winkler County, Tex.							
C-22.6	Tom Linebury	Qal	—	2,940	45.0	2-13-53	—	6	N	N	—

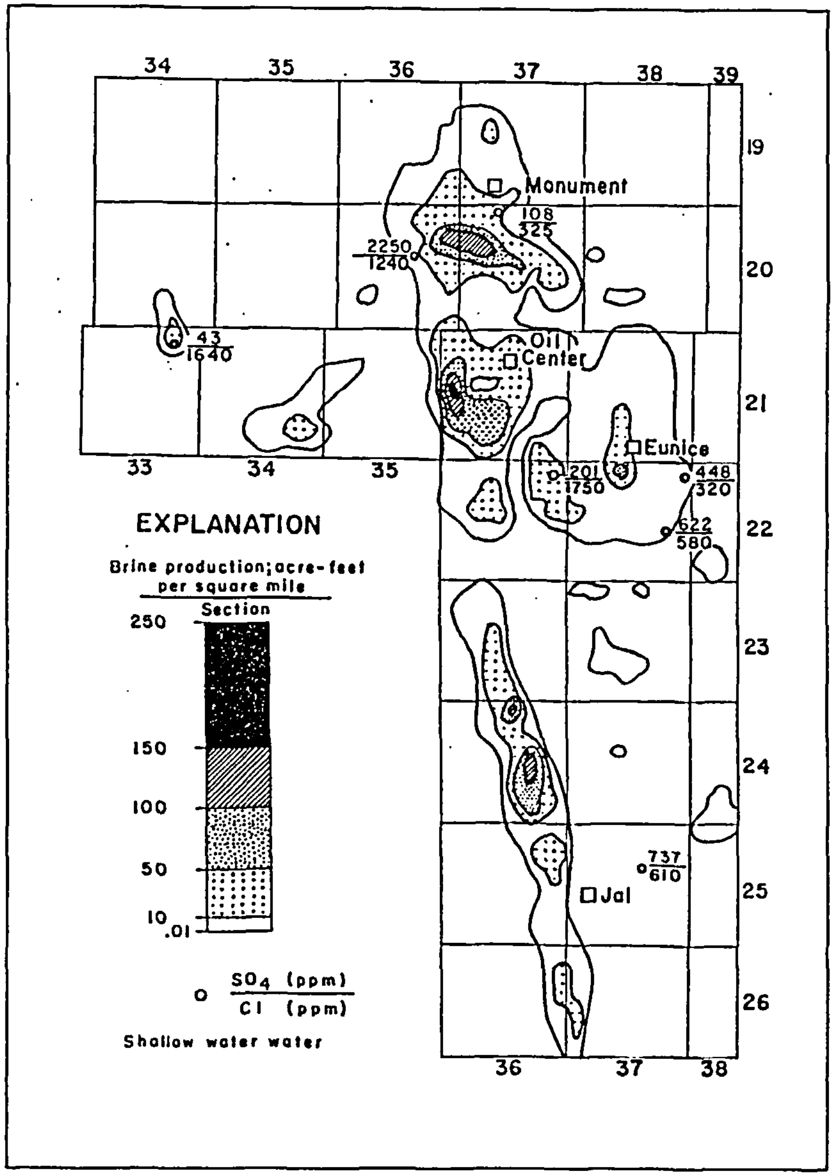

Figure 25

OIL-FIELD BRINE PRODUCTION IN SOUTHERN LEA COUNTY, N. MEX., 1952

Showing locations of selected water wells that have been contaminated by brine. Upper figure adjacent to well symbol is sulfate concentration; lower figure is chloride concentration.

AREAL DISTRIBUTION OF BRINE PRODUCTION

Figure 25 shows the distribution and magnitude of brine production as of 1952. The data were taken from the New Mexico Oil Conservation Commission Annual Report for 1952. In preparing the illustration the total brine production for all the oil wells within a 1-sq mi section was plotted, and the totals were contoured. The quantities are expressed in acre-feet per sq mi; the map should be interpreted to mean that in any section within a given shaded area a quantity of brine within the range indicated was produced. It should be kept in mind, however, that the brine is really present at pin-points of concentration; that is, in the disposal pits, and not spread out, as would appear from the illustration.

The map shows several areas of rather high brine production. In one area, on the west side of T. 21 S., R. 36 E., 23 wells scattered over secs. 18 and 19, produced 387 acre-feet of brine in 1952. Spread out over the two sections this quantity of brine would form a layer approximately 3.5 inches deep or the equivalent of about a third of the annual rainfall in that area. This and the lesser highs shown on the map constitute potential centers of ground water contamination.

Quality of Water

Rain water, having been distilled by natural processes, is relatively pure. Once water is in contact with the land surface, however, the water begins to dissolve organic and inorganic matter; and as the water moves through an aquifer, it dissolves rock materials. Ground water in arid and semiarid areas commonly contains enough dissolved mineral matter to limit its usefulness.

Among the most common chemical substances found in ground water are silica (SiO_2), iron (Fe), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), fluoride (F) and nitrate (NO_3). Of these, the bulk generally is distributed among calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride. The concentrations of silica, fluoride, and nitrate generally are a minor part of the dissolved solids, and for some purposes sodium and potassium are grouped together and treated as one. Similarly, carbonate and bicarbonate may be grouped together.

The chemical characteristics of a water may be identified through study of the concentration and relative abundance of the principal ions it contains. Table 8 gives analyses of water from wells in the southern Lea County area, and Table 9 gives analyses of water pumped from oil wells.

Other characteristics commonly reported in chemical analyses of water samples are dissolved solids, specific conductance, hardness, pH, and percent sodium. A brief explanation of these characteristics follows.

Most of the dissolved-solids concentrations presented in Tables 8 and 9 are computed values for the total mineral constituents of the water sample, based on the constituents determined in the analysis, except that bicarbonate has been reported as carbonate. The dissolved-solids content can be determined directly by evaporating a sample to dryness at 180°C. A rough measure of the dissolved-solids concentration is provided by the specific conductance, which expresses the ease with which an electrical current can be passed through the water. The conductance depends directly on the amount and nature of the dissolved solids; thus no information on the chemical nature of the dissolved mineral matter is obtained from the specific-conductance measurement. For water in the Triassic, Tertiary, and Quaternary rocks in southern Lea County, the dissolved-solids concentration is approximately equal to the specific conductance at 25°C multiplied by a factor of 0.65.

Hardness of water is attributable to the presence of alkaline earth cations, which in natural waters are principally calcium and magnesium. It is an indication of soap-consuming power of the water. The cations that cause hardness can combine with certain anions to form troublesome deposits in boilers and other heat-exchange equipment.

The pH value of an aqueous solution represents the hydrogen-ion concentration of the solution and ranges from 0 to 14. Ordinarily a value of 7.0 is considered neutral; values below 7.0 indicate acid solutions; and values above 7.0 indicate alkaline solutions. The pH values reported for many of the analyses given in Table 8 are questionable because of the long period of storage between time of collection and time of analysis, during which the pH can and does change. (The bicarbonate concentrations reported are subject to the same conditions.)

Percent sodium indicates the amount of sodium relative to the other cations present in the water and is useful in classifying the water for irrigation purposes. Inasmuch as all the analyses shown in Table 8 show the combined concentrations of sodium and potassium, the sodium percentages indicated include potassium also. However, since the ratio of potassium to sodium probably is very small, the figures shown under "percent sodium" probably are only slightly high.

The concentration of chemical constituents in water (tables 8 and 9) is expressed in ppm (part per million) and epm (equivalents per million). A part per million is a unit weight of a substance in a million unit weights of solution. Equivalents per million is a measure of the reactive weights of different ions. The atoms of the different elements have different relative weights which are know as atomic weights. The atomic weight of chlorine is 35.46 and that of sodium is 22.997. By dividing the atomic weight of sodium into the atomic weight of chlorine it can be seen that the chloride ion is 1.54 times heavier than the sodium ion. Hence, to form the simple compound of sodium chloride, in which each atom (or ion) of sodium combines with an atom of chlorine to form a single molecule of salt, the quantities required, in terms of weight, would be 1 part sodium to 1.54 chlorine. In such proportions there are equal numbers of sodium and chloride ions; that is, they are chemically equivalent. The concentration of a substance, in equivalents per million, is determined by dividing its concentration in parts per million by its chemical combining weight. The chemical combining weight is the atomic weight of the ion divided by its valence.

Usually, chemical analyses are reported in parts per million, but it is frequently more convenient for interpretative purposes to compare waters in terms of equivalents per million. In Tables 8 and 9 the concentrations of the different constituents are given in both terms. Some analyses by commercial laboratories express concentrations in grains per gallon. This expression can be converted into parts per million by multiplying by 17.12.

CHEMICAL STANDARDS FOR WATER USE

The U.S. Public Health Service (1946) sets up criteria for the quality of drinking water to be used on common carriers used in interstate traffic. These recommended limits have gained wide acceptance as stand-

TABLE 8. CHEMICAL ANALYSES OF WATER FROM WELLS IN SOUTHERN LEA COUNTY, N. MEX.

(Analyses by U.S. Geological Survey except as noted; chemical constituents in parts per million and equivalents per million [underscored].)

Sample	Location number*	Date of collection	Geologic source†	Depth† (ft)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$ Calcium, Magnesium	Percent sodium	Specific conductance (micromhos at 25°C)	pH
1	17.32.3.140	7-21-54	To	—	—	— 2.72	—	34 1.46	194 3.18	0	25 .52	17 .48	—	—	—	136	35	419	—
2	17.33.18.322	7-19-54	To	220	—	— 3.20	—	27 1.18	177 2.90	0	40 .83	23 .65	—	—	—	160	27	442	—
3	19.32.8.200	12- 9-58	Tr	—	19	10 .50	13 1.10	131 5.71	306 5.02	0	74 1.54	21 .59	1.2 .06	6.4 .10	426	80	78	682	8.0
4	19.34.9.114	12- 9-58	Tr(?)	33	41	430 21.46	65 5.34	675 29.33	189 3.10	0	1,680 34.98	560 15.79	.3 .02	139 2.24	3,680	1,340	52	4,660	7.1
5	19.36.35.123	4- 9-38	To	43	—	—	—	—	—	—	212 4.41	31 .87	—	—	—	—	—	562	—
6	19.36.32.110	11-20-29	To	32	—	84 4.44	—	158 6.86	261 4.28	0	225 4.68	79 2.23	—	6.8 .11	668	222	—	—	—
7	19.37.4.110	9-19-29	To	29	—	68 3.96	—	71 3.09	307 5.03	0	54 1.12	32 .90	—	—	383	198	—	—	—
8	19.37.29.344a	7-15-54	Qal	30±	—	— 6.44	—	52 2.27	296 4.85	0	62 1.29	91 2.57	—	—	—	322	26	865	—
9	do.	9- 9-58	Qal	30±	—	— 5.04	—	—	215 3.52	0	54 1.12	73 2.06	—	—	—	252	—	678	7.6
10	20.36.15.421	3-30-54	Qal	50	—	—	—	—	304 4.98	0	1,840 38.30	1,080 30.46	—	—	—	—	—	6,780	—
11	20.36.15.421	9- 9-58	Qal	50	—	— 34.40	—	—	292 4.79	0	2,250 46.84	1,240 34.97	—	—	—	1,720	—	7,500	7.4
12	20.37.4.111	4- 2-54	Qal	40	—	—	—	—	423 6.93	0	67 1.39	450 12.69	—	—	—	—	—	2,180	—
13	20.37.4.111	4-22-55	Qal	40	—	— 13.40	—	—	438 7.18	0	78 1.62	425 11.99	—	—	—	670	—	2,090	7.2
14	20.37.4.111	9- 9-58	Qal	40	—	— 9.20	—	—	318 5.21	0	108 2.25	425 9.16	—	—	—	460	—	1,670	7.3
15	20.37.4.221	4-22-55	Qal	45	—	— 5.56	—	—	269 4.41	0	90 1.87	51 1.44	—	—	—	278	—	758	8.1
16	20.37.4.221	9- 9-58	Qal	45	—	— 4.92	—	—	255 4.18	0	87 1.69	47 1.33	—	—	—	246	—	708	8.0
17	20.38.19.320	4- 2-54	Qal	115	—	—	—	—	227 3.72	0	—	39 1.10	—	—	—	—	—	627	—
18	20.38.19.320	9- 9-58	Qal	115	—	— 1.36	—	—	104 1.70	0	23 .48	49 1.38	—	—	—	68	—	376	8.1
19	21.33.2.231	9- 4-58	Tr	1,150	—	— .44	—	—	336 5.51	0	95 1.98	20 .56	—	—	—	22	—	778	8.0
20	21.33.2.422	6-28-54	To	120	—	—	—	—	116 1.90	0	17 .35	1,020 28.77	—	—	—	—	—	3,370	—
21	21.33.2.422	4-22-55	To	120	—	— 35.40	—	2.5 .11	115 1.88	0	20 .42	1,170 33.00	—	13 .21	—	1,770	0.3	3,730	7.3
22	21.33.2.422	9- 4-58	To	120	—	— 48.00	—	—	109 1.79	0	43 .90	1,640 46.25	—	—	—	2,400	—	5,070	7.1
23	21.33.2.442b	4-22-55	To	—	—	— 6.08	—	—	345 5.65	0	15 .31	12 .34	—	—	—	304	—	600	7.4
24	21.33.2.442b	9- 4-58	To	—	—	— 6.12	—	—	354 5.80	0	18 .37	7.0 .20	—	—	—	306	—	629	7.5
25	21.35.27.321a	12- 8-58	To	—	—	— 4.08	—	—	301 4.93	0	170 3.54	44 1.24	—	—	—	204	—	995	8.0
26	21.36.9.222	7-27-54	Tr	447	—	17 .85	7.8 .64	280 12.18	434 7.11	0	216 4.50	65 1.83	4.4 .23	0.1 .00	803	74	89	1,290	—
27	21.36.9.222	9- 8-58	Tr	447	—	— 1.46	—	—	425 6.97	0	213 4.43	64 1.80	—	—	—	73	—	1,270	8.1
28‡	21.37.33.110	7-18-42	To	130	73	45 2.25	25 2.06	96 4.07	182 2.98	25 .83	108 2.25	68 1.92	3.5 .18	10 .16	543	216	—	799	—
29	21.37.33.111	9- 9-58	To	110?	—	— 3.72	—	—	240 3.93	0	108 2.25	61 1.72	—	—	—	186	—	785	7.7
30§	21.37.33.210	8- 1-42	Tr	350	16	50 2.50	31 2.55	563 24.32	360 5.90	0	855 17.80	208 5.87	1.8 .09	.5 .01	1,900	252	—	2,850	—
31	21.37.33.233	7-31-54	To	135	—	40 2.00	20 1.64	100 4.35	247 4.05	0	97 2.02	50 1.66	3.6 .19	4.6 .07	445	182	54	768	—

See footnotes at end of table.

TABLE 8. CHEMICAL ANALYSES OF WATER FROM WELLS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

Sample	Location number*	Date of collection	Geologic source†	Depth† (ft)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	Hardness as $CaCO_3$ Calcium, Magnesium	Percent sodium	Specific conductance (micromhos at 25°C)	pH
32	21.38.6.133a	12- 7-53	Qal	90?	—	—	—	—	284 4.65	0	188 3.91	174 4.91	—	25 .40	—	—	—	1,360	—
33	21.38.6.133a	9- 9-58	Qal	90?	—	— 9.20	—	—	257 4.21	0	182 3.79	156 4.40	—	—	—	460	—	1,250	7.4
34	21.38.6.133b	12- 7-53	Qal	108	—	—	—	—	253 4.15	0	119 2.48	105 2.96	—	18 .29	—	—	—	977	—
35	21.38.6.133b	9- 9-58	Qal	108	—	— 14.20	—	—	225 3.65	0	213 4.43	340 9.59	—	—	—	710	—	1,780	7.5
36	22.36.1.333	11-12-53	To	150	59	266 13.27	178 14.64	788 34.28	522 8.55	0	201 4.18	1,750 49.36	0.7 .04	2.4 .04	3,500	1,400	55	6,170	—
37	22.36.2.444	4-22-55	—	—	—	—	—	—	234 3.83	0	333 6.93	205 5.78	—	—	—	—	—	1,590	7.5
38	22.36.2.444	9- 9-58	—	—	—	— 11.40	—	—	258 4.23	0	319 6.64	415 11.70	—	—	—	570	—	2,200	7.3
39‖	22.36.8.443	7-23-53	Tr	1,000±	—	18 .92	6 .50	425 18.49	477 7.82	—	340 6.80	200 5.64	—	—	—	—	—	—	—
40	22.36.11.224	7-31-54	To	120+	—	—	—	—	214 3.51	0	226 4.71	110 3.10	—	—	—	—	—	1,100	—
41	22.36.11.224	4-22-55	To	120+	—	— 6.30	—	—	221 3.62	0	217 4.52	106 2.99	—	—	—	315	—	1,090	7.6
42	22.36.11.224	9- 9-58	To	120+	—	— 5.20	—	—	206 3.38	0	212 4.41	110 3.10	—	—	—	260	—	1,050	7.6
43	22.37.1.440	10-14-53	Qal	—	74	222 11.08	107 8.80	375 16.31	189 3.10	0	841 17.51	525 14.81	3.1 .16	38 .61	2,280	994	45	3,330	—
44	22.37.1.440	9- 8-58	Qal	—	—	— 11.60	—	—	211 3.46	0	448 9.33	320 9.02	—	—	—	580	—	2,180	7.3
45	22.37.24.133b	10-14-53	Qal	80	82	218 10.88	131 10.77	254 11.05	187 3.06	0	482 10.03	675 19.04	2.5 .13	26 .42	1,960	1,080	34	3,200	—
46	22.37.24.133b	4-22-55	Qal	80	—	— 27.20	—	247 10.74	216 3.54	0	598 12.45	770 21.72	—	15 .24	—	1,360	28	3,540	7.2
47	22.37.24.133b	9- 8-58	Qal	80	—	— 21.60	—	—	216 3.54	0	622 12.95	580 16.36	—	—	—	1,080	—	3,020	7.2
48	23.34.31.340	12- 4-53	Tr	678	—	32 1.60	26 2.14	163 7.09	287 4.70	0	219 4.56	52 1.47	1.4 .07	.7 .01	635	187	65	1,030	—
49	23.36.31.233	3-13-53	To	—	49	127 6.34	15 1.23	53 2.31	203 3.33	0	102 2.12	132 3.72	.6 .03	41 .66	620	378	23	1,000	—
50	24.37.10.123	3-11-53	Tr	747	13	121 6.04	93 7.65	402 17.50	277 4.54	0	934 19.44	252 7.11	1.6 .08	1.2 .02	1,950	684	56	2,840	—
51	25.37.13.312a	7-27-54	To	152	—	67 3.34	20 1.64	71 3.09	220 3.61	0	136 2.83	51 1.44	2.8 .15	2.3 .04	458	249	38	772	—
52	25.37.13.312a	4-21-55	To	152	—	— 5.90	—	—	218 3.57	0	148 3.08	64 1.81	—	—	—	295	—	821	8.0
53	25.37.13.312a	9- 8-58	To	152	—	— 5.00	—	—	203 3.33	0	112 2.33	75 2.12	—	—	—	250	—	775	7.8
54	25.37.15.223	2-26-53	To	—	57	307 15.32	98 8.06	271 11.79	146 2.39	0	737 15.34	610 17.20	1.7 .09	9.0 .15	2,160	1,170	34	3,260	—
55	25.37.19.221	2- 5-53	Tr	500	12	55 2.74	49 4.03	170 7.40	376 6.16	0	280 5.83	71 2.00	2.6 .14	.4 .01	825	338	52	1,320	—
56**	25.37.19.240	7-18-42	Tr	450	9.3	34 1.70	43 3.54	175 7.61	264 4.33	25 .83	286 5.95	54 1.52	2.0 .11	0.5 .01	759	262	—	1,190	—
57††	25.37.20.310	7-18-42	Qal	70	65	102 5.09	32 2.63	77 3.35	150 2.46	13 .43	145 3.02	168 4.74	1.3 .07	7.6 .12	685	386	—	1,100	—
58	25.37.20.310a	9- 8-58	Qal	47	—	— 7.96	—	—	191 3.13	0	200 4.16	145 4.09	—	—	—	398	—	1,140	7.5
59‡‡	25.38.19.342	5- 6-52	To(?)	133	62	66 3.29	35 2.88	73 3.18	219 3.60	—	155 3.23	88 2.48	—	—	608	—	—	—	—
60	26.33.3.444a	12-12-58	Qal	—	—	— 8.72	—	—	306 5.02	0	110 2.29	57 1.61	—	—	—	436	—	948	7.3
61	26.35.13.222	12-12-58	Qal	—	—	— 6.72	—	—	207 3.39	0	233 4.85	73 2.06	—	—	—	336	—	978	7.3

* See text for explanation of location number.
† See table 6 for explanation of geologic source and depth.
‡ Fe = 0.13 ppm.
§ Fe = 0.23 ppm.
‖ Analysis by the Western Company, Midland, Tex.
** Fe = 0.14 ppm.
†† Fe = 0.16 ppm.
‡‡ Analysis by the Anderson Laboratories, Ft. Worth, Tex.

TABLE 9. CHEMICAL ANALYSES OF OIL-FIELD WATERS IN SOUTHERN LEA COUNTY, N. MEX.

PART A. SAMPLES COLLECTED FROM DISPOSAL PITS OR TREATER DISCHARGE PIPES.

(Analyses by U.S. Geological Survey. Chemical constituents in parts per million and equivalents per million [underscored]. Dissolved solids and hardness in parts per million.)

Sample	Pit location number	Date of collection	Pool name	Geologic source	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids: Sum	Dissolved solids: Tons per acre-ft.	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Percent sodium	Specific conductance (micromhos at 25°C)
62	20.37.16.300	2- 8-53	Monument	Queen, Grayburg, and San Andres	—	—	—	—	1,550 25.40	—	—	—	—	—	—	—	9,290
63	21.33.1.114	3- -53	Lynch	Yates	—	—	—	—	1,320 21.63	—	4,460 125.77	—	—	—	—	—	15,900
64	21.36.19.220	3-22-55	Eunice	Queen, Grayburg, and San Andres	—	330 16.47	236 19.41	1,480 64.42	1,730 28.35	1.6 .03	2,550 71.92	5,950	7.4	1,790	376	64	9,340
65	22.36.2.144	11-12-53	Arrowhead	Queen, Grayburg	16	170 8.48	178 14.64	2,280 99.09	1,850 30.32	255 5.31	3,070 86.58	7,880	9.4	1,160	0	81	11,200
66	22.36.2.323	11-12-53	Arrowhead	Queen, Grayburg	17	98 4.89	429 35.28	5,300 230.31	2,310 37.86	160 3.33	8,130 229.29	15,300	20.8	2,010	116	85	24,200
67	22.36.11.214	4-22-55	Arrowhead	Queen, Grayburg	—	— 34.80	—	1,890 82.18	1,930 31.63	200 4.16	2,880 81.23	—	—	1,740	158	70	10,500
68	24.36.26.400	3-11-53	Cooper-Jal	Yates, Seven Rivers	—	—	—	—	1,080 17.70	—	1,860 52.46	—	—	—	—	—	8,460

See footnotes at end of table.

TABLE 9. CHEMICAL ANALYSES OF OIL-FIELD WATERS IN SOUTHERN LEA COUNTY, N. MEX.

PART B. ANALYSES REPORTED IN ROSWELL GEOL. SOC. (1956)*

(Chemical constituents are in parts per million and equivalents per million [underscored].)

ple	Pool name	Location†	Pay zone‡	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Iron (Fe)	Bicarbonate (HCO_3)	Carbon-dioxide (CO_2)	Sulfate (SO_4)	Chloride (Cl)	Hydroxyl (OH)	Hydrogen sulfide (H_2S)	Dissolved solids	Resistivity: Ohm-meters	Resistivity: Degrees (°F)
	Arrowhead	T. 21, 22 S., R. 36 E.; T. 22 S., R. 37 E.	Queen-Grayburg	175 8.73	—	2,000 86.96	3	1,903 31.19	—	105 2.19	2,950 83.19	N	8	7,840	0.972	77
	Blinebry	T. 21, 22 S., R. 37 E., T. 22, 23 S., R. 38 E.	Blinebry (Upper Yeso)	11,400 568.9	—	52,000 2,261.0	N	380 6.23	N	1,900 39.56	103,000 2,904.6	N	N	209,000	—	—
	Bowers	T. 18, 19 S., R. 37, 38 E.	Lower Seven Rivers	3,250 162.2	22,300 1,833.9	84,163 3,659.41	95	447 7.33		1,945 40.49	198,743 5,604.5	—	—	290,100	.037	100
	Brunson	T. 21, 22 S., R. 37 E.	Ellenburger	9,481 473.1	—	35,000 1,521.8	64	122 2.00	N	1,890 39.35	77,310 2,180.1	N	N	149,140	.0648	75
	Cass	T. 20 S., R. 37 E.	Pennsylvanian	1,613 80.49	498 40.95	12,816 557.24	28	—	510	2,535 52.78	21,600 609.1	—	—	[39,440]	.188	60
	Crosby	T. 25 S., R. 37 E.	Devonian	9,740 486.0	3,740 307.58	51,450 2,237.05	—	345 5.65	—	127 2.64	107,100 3,020.2	—	—	172,502	—	—
	Dollarhide (Queen)	T. 24, 25 S., R. 38 E.	Queen	11,824 590.02	7,761 638.26	53,847 2,341.27	—	244 4.00	0	1,148 23.90	125,528 3,539.9	—	—	200,352	—	—
	Dollarhide (Drinkard)	T. 24, 25 S., R. 38 E.	Drinkard	13,126 654.98	4,802 394.9	62,836 2,732.11	—	122 2.00	0	870 18.11	133,330 3,759.9	—	—	215,086	—	—
	Drinkard	T. 21, 22, 23 S., R. 37 E., T. 22, 23 S., R. 38 E.	Drinkard (Vivian zone and Andrews zone)	7,615 379.98	2,356 193.75	45,745 1,988.91	0	195 3.20	108	1,657 34.49	98,395 2,774.7	0	0	147,033	0.056	75
	Gem	T. 19 S., R. 33 E., sec. 32	Yates	240 11.97	168 13.82	2,330 101.31	—	1,530 25.08	—	179 3.73	—	—	590	—	1+	73
	Hare	T. 21 S., R. 37 E.	Simpson (McKee and Connell sandstone members)	9,697 438.88	—	36,800 1,600.06	198	146 2.39	—	1,170 24.36	77,308 2,180.1	N	N	146,900	.066	76
	Hobbs	T. 18 S., R. 37 E., T. 18, 19 S., R. 38 E.	Grayburg-San Andres	411 20.51	179 14.72	7,352 319.66	—	2,125 34.83	—	699 14.55	10,800 304.6	—	—	21,566	.33	125
	Jalmat	T. 21 thru 26 S., R. 35 thru 37 E.	Yates-Seven Rivers	90 4.49	—	1,850 80.44	—	1,201 19.68	—	690 14.36	2,163 61.0	—	253	6,216	1.312	76

xnotes at end of table.

TABLE 9. CHEMICAL ANALYSES OF OIL-FIELD WATERS IN SOUTHERN LEA COUNTY, N. MEX. (continued)

PART B. ANALYSES REPORTED IN ROSWELL GEOL. SOC. (1956)*

(Chemical constituents are in parts per million and equivalents per million [underscored].)

Pool name	Location†	Pay zone‡	Calcium (Ca)	Magnesium (Mg)	Sodium plus potassium (Na+K)	Iron (Fe)	Bicarbonate (HCO_3)	Carbon-dioxide (CO_2)	Sulfate (SO_4)	Chloride (Cl)	Hydroxyl (OH)	Hydrogen sulfide (H_2S)	Dissolved solids	Resistivity	
														Ohm-meters	Degrees (°F)
Langlie-Mattix	T. 22 thru 26 S., R. 36, 37 E.	Yates, Seven Rivers Queen	214 10.68	233 19.16	922 40.09	—	1,364 22.36	—	29 .603	1,663 46.9	—	—	4,425	—	—
Littman	T. 21 S., R. 38 E.	San Andres	5,240 261.47	2,527 207.8	30,900 1,343.53	0	—	0	2,080 43.3	62,000 1,748.4	—	T	93,400	1.07	79
Maljamar	T. 17 S., R. 31, 32, 33 E., T. 18 S., R. 32 E.	Grayburg-San Andres	2,480 123.7	1,370 112.7	—	T	710 11.64	—	H	127,300 3,589.9	—	—	—	—	—
Maljamar (Devonian)	T. 17 S., R. 32 E.	Devonian	920 45.9	305 25.08	8,450 367.41	—	807 13.23	—	1.63 .034	14,000 394.8	—	—	25,000	—	—
Mason, North	T. 26 S., R. 31, 32 E.	Delaware	2,480 123.7	170 13.98	61,000 2,652.28	—	2,890 47.37	—	4,000 83.3	94,800 2,673.4	—	—	165,340	.06	65
Pearsall	T. 17, 18 S., R. 32 E.	Queen	6,500 324.4	4,530 372.5	—	—	95 1.56	—	M	123,000 3,468.6	—	—	—	—	—
San Simon	T. 21, 22 S., R. 35 E.	Yates	1,990 99.3	1,700 139.81	17,400 756.55	0	443 7.26	0	0	34,900 984.2	0	—	[56,208]	—	—
Skaggs	T. 20 S., R. 37, 38 E.	Queen-Grayburg	300 14.97	N	10,000 434.80	100	710 11.64	180	3,200 66.6	12,000 338.4	N	3	37,000	—	—
Skaggs (Drinkard)	T. 20 S., R. 37 E.	Drinkard	5,330 265.97	1,830 150.49	43,700 1,900.68	113	428 7.01	—	2,250 46.84	82,300 2,320.9	—	—	141,300	.052	76
Vacuum	T. 17, 18 S., R. 33, 34, 35 E.	Grayburg-San Andres	3,195 159.43	796 65.46	57,900 2,517.49	112	700 11.47	—	2,470 51.43	94,221 2,657.0	—	—	160,000	—	—
Wantz	T. 21 S., R. 37, 38 E.	Abo	3,375 168.4	0	19,500 847.86	10	744 12.19	103	1,689 35.16	44,325 1,249.9	N	175	81,208	0.08-0.106	—
Warren	sec. 27 and 23, T. 20 S., R. 38 E.	Drinkard	7,000 349.3	0	47,500 2,065.30	75	496 8.13	0	1,402 29.19	103,898 2,929.9	N	N	[166,800]	.080	60

ses are quoted verbatim except for calculated values, which are enclosed in brackets or underscored; N, none or nil; 2, trace; M, medium; H, heavy.
on: The water analyses listed in the source reference are headed "Nature of producing zone water." The wells from which the samples were taken are not given.
me: Terminology is that used in the source reference and not necessarily approved for use in the U.S. Geological Survey.

ards against which to measure water quality, although they are somewhat conservative when applied in an area such as southern Lea County, where much of the ground water is mineralized. Recommended maximum concentrations (U.S. Public Health Service, 1946) for selected chemical constituents are as follows:

	PPM
Iron and Manganese	0.3
Fluoride	1.5*
Magnesium	125
Zinc	15
Chloride	250
Sulfate	250
Dissolved solids	500†

Numerous analyses in Table 8 exceed those limits with respect to one or more constituents. Although some of these samples reflect natural conditions, many appear to be contaminated. This aspect will be discussed in the section on brine contamination of shallow ground water.

Chemical requirements for industrial uses of water vary according to the industry, but requirements are most rigid where water is used in food, paper, or other chemical-process industries. The two most common industrial uses for water in southern Lea County are for cooling and boiler feed. Excessive concentrations of dissolved solids are troublesome in water used for cooling, inasmuch as the process of evaporation, by which cooling takes place, removes water in the chemically pure vapor state, leaving behind the dissolved matter in greater concentration than before.

The chemical-quality requirements of boiler feed water depend to a great extent on the operating pressure and design of the boiler system. High operating pressures impose very strict tolerance limits; for example, suggested tolerance limits for systems operating at more than 400 psi specify a concentration of dissolved solids of 50 ppm or less. Low-pressure systems, operating at less than 150 psi can use water having a dissolved-solids concentration of 500 to 3,000 ppm ([Calif.] State Water Pollution Control Board, 1957, p. 129). Nearly all the ground water sampled in southern Lea County requires some treatment to make it suitable for use as boiler feed water.

CHEMICAL CHARACTERISTICS OF GROUND WATER IN SOUTHERN LEA COUNTY

The dissolved chemical constituents in ground water reflect, to a great extent, the lithologic characteristics of the aquifer because presumably the water is in chemical equilibrium with the rock material with which it is in intimate contact. Differences in lithology will give

* Mandatory limit.

† Unless water of better quality is not available, in which case a total solids content of 1,000 ppm may be permitted.

rise to chemical differences in waters from different aquifers. Factors other than lithology also influence the water chemistry. Principal among these are permeability, hydraulic gradient, distance from the recharge area, vegetative cover, previous hydrologic history of the water, and chemical character of the rainfall.

Although the lithologic similarities between the Ogallala formation and parts of the Quaternary alluvium derived from the Ogallala result in waters of similar chemical character, the alluvium has been derived in part also from weathering of Triassic rocks, and the resulting differences in chemical characteristics of the water are distinctive.

Figure 26 depicts graphically parts of the chemical analyses shown in Tables 8 and 9. The scale is logarithmic to accommodate the wide range in concentrations of the chemical constituents. Several features are strikingly apparent, but probably the most important are the high concentrations of sodium-plus-potassium and chloride from the samples of oil-field waters (table 9). Some of these are highly concentrated brines. Another important aspect is the fact that several constituents in the samples from alluvium and from the Ogallala formation show a bimodal distribution; that is, the analyses cluster around two central values rather than a single value. This is particularly evident with the chloride determinations.

Water from the Quaternary alluvium generally is high in silica (65 to 82 ppm), moderately high in calcium-plus-magnesium (fig. 26), low in sodium-plus-potassium, moderately low in sulfate and chloride, and moderately high in dissolved solids. Uncontaminated water from the Ogallala formation is high in silica (49 to 73 ppm), contains moderate concentrations of calcium and magnesium, is probably low in sodium (although too few analyses are available to make this statement definitely), and is very low in sulfate and low in chloride. The dissolved-solids content is relatively low, being typically less than 1,100 ppm. Water from Triassic rocks in southern Lea County is typically low in silica (9 to 41 ppm), shows a wide range in calcium and magnesium, is high in sodium, moderately high in sulfate, and moderately low in chloride. Both the sulfate and chloride show a wide range in concentration. The dissolved-solids concentration is typically somewhat higher than in water from the Ogallala formation.

Only a few of the analyses shown on Table 8, and none on Table 9, include fluoride determinations. Of 17 analyses, only 6 show fluoride concentrations less than 1.5 ppm. Excessive concentrations are found in water from all three principal aquifers.

High concentrations of nitrate may indicate the presence of nitrogenous biological waste. Only one well sampled yielded water that showed a dangerously high concentration. Water from well 19.34.9.114 contained 139 ppm nitrate; this well is finished in the Dockum group, but may produce some water from shallow alluvium. Local contamination is suspected because of the abundance of animal refuse in the vicin-

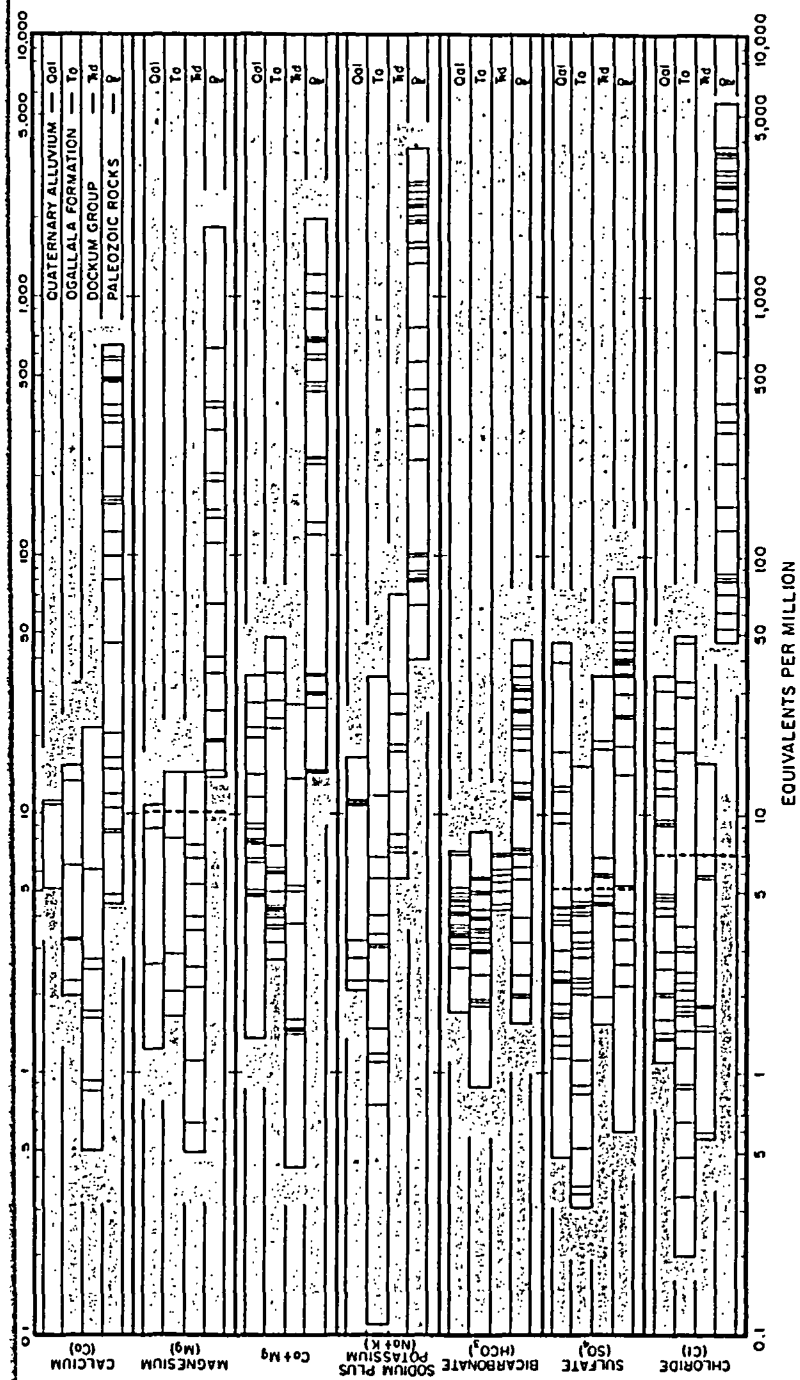

Figure 26

DISTRIBUTION OF PRINCIPAL IONS IN SAMPLES OF GROUND WATER FROM DIFFERENT AQUIFERS IN SOUTHERN LEA COUNTY, N. MEX.

The length of each bar shows the range in concentration; each vertical line within the bars represents an analysis. Heavy dashed lines indicate U.S. Public Health Service (1946) limits for drinking water.

ity of the well. Most of the samples that contained 10 to 40 ppm of nitrate came from wells finished in Quaternary alluvium. Water from wells finished in the Triassic rocks generally had the lowest nitrate concentrations; many samples contained less than 2 ppm.

Water samples from the oil-producing zones of the Paleozoic rocks of southern Lea County (table 9) are all highly mineralized but range in salinity from less than 6,000 to nearly 300,000 ppm. Silica determinations are available for only two samples, and these are low. However, the waters in which silica was determined (samples 65 and 66, table 9A) are much less saline than the average oil-field water. All other major constituents except sulfate are 100 to 1,000 times as concentrated in oil-field waters as in the water from the other aquifers. The sulfate concentrations reported for the brine samples are all less than 100 epm. It is significant, however, that several brine samples contained high concentrations of hydrogen sulfide, which would tend to become oxidized to sulfate in an oxygen-rich environment such as a near-surface aquifer.

Several of the brine samples have high concentrations of iron. This is in sharp contrast to the water from the Quaternary, Tertiary, and Triassic aquifers, which had a maximum iron content of 0.23 ppm.

BRINE CONTAMINATION OF SHALLOW GROUND WATER

Brine production fluctuates according to the amount of oil production allowed by the New Mexico Oil Conservation Commission. The ratio of water to oil also fluctuates, but in most wells the ratio of water to oil and the rate of production of water increase with time. Thus, the problem of brine disposal becomes more serious with increasing time. The standard method of dumping brine into pits to be evaporated is questionable from the standpoint of water conservation. Unless the pits are adequately sealed to prevent seepage into the ground and unless they have enough surface area to allow removal by evaporation equal the rate of brine production and to prevent overflow, the brines will migrate to the water table and contaminate the shallow water.

An earlier review of the data regarding brine disposal in southern Lea County by Nicholson (Parker, 1955, p. 626) led to the conclusion that contamination of the ground water must be taking place. No pits observed in the southern Lea County area have waterproof linings, and the surface areas of many pits are inadequate to allow for natural evaporation of the brine discharged. No pits with any appreciable amounts of precipitates, indicating the effective evaporation, were seen. In the areas where the surface is underlain by caliche, the caliche is in many places impermeable, and instances have been reported where the caliche has been deliberately broken up to promote seepage from pits that were receiving excess brine. It is evident that a considerable amount of brine

must be seeping into the shallow-water aquifers in Quaternary and Tertiary sediments.

The ineffectiveness of brine disposal by evaporation is demonstrated by a brine pit in the NE¼ sec. 19, T. 21 S., R. 36 E. (fig. 24). The pit is divided into two parts, an initial pit that receives brine directly from the treater and an overflow pit. When it is completely full, this pit has a free water surface of about 38,000 sq ft. The evaporation rate from a pond or lake in southern Lea County is estimated to be about 70 inches, if no allowance is made for rainfall.

A check on the rate of evaporation of brine relative to that of fresh water was made in the form of a simple experiment. A sample of the brine from this pit and a sample of Albuquerque tapwater were evaporated in beakers in open air for a period of 24 hours. The rate of evaporation of the brine was only one-third that of the tapwater, presumably because of the presence of a very thin film of oil on the brine. Although the experiment was conducted in relatively calm air, the wind might tend to break up an oil film and thus reduce its effectiveness in inhibiting evaporation. However, the results can be used as a rough approximation in calculating a lower limit for the amount of water that would evaporate from a pit. Other factors, such as the dissolved solids, may affect the evaporation rate also.

Using an estimated evaporation rate of about 2 feet per year for the brine, the total volume of brine that would evaporate from a pit covering 38,000 sq ft is about 1.7 acre-feet per year. However, the quantity of brine discharged into this particular pit was about 82 acre-feet in 1952 and about 30 acre-feet in 1953. Thus it can be concluded that about 108 acre-feet of brine has seeped into the ground from this pit during that 2-year period alone. Even if it is assumed that 100 inches per year of brine could be evaporated, the evaporation capacity of a 38,000-square foot pit would be only 7.2 acre-feet per year, in which case about 98 acre-feet of brine would have seeped into the ground.

At an evaporation rate of 2 feet per year, a pit having a surface area of roughly 40 acres would be required to dispose of the 98 acre-feet of brine produced in 1952. At an evaporation rate of 100 inches per year, the area of the pit would have to be about 10 acres. But, even if pits were designed so that they had adequate evaporation capacities, they would be still ineffective if they were not properly sealed. As evaporation proceeds, the salts will be concentrated in the remaining brine; and, as long as they remain in solution, the salts will be carried to the water table if the pit is leaky. Hence, the net quantity of contaminants added to the shallow ground water will be the same whether or not partial evaporation takes place.

Movement of Brine Underground

As brine seeps downward from the bottoms of the disposal pits, it moves downward under the influence of gravity until it comes to a layer

of rock that is less permeable than the material through which it is moving. It may then move horizontally, in the direction of dip of the less permeable material. Such a layer of lower permeability could be a clayey bed within the Ogallala formation or the alluvium or the red-beds surface at the base of the aquifer. When the brine reaches the water table of the shallow aquifer, the two waters will mix to some extent; but because of the greater density of the brine, it will tend to move toward the lowest part of the aquifer with a minimum of mixing.

The configuration of the base of the aquifer probably has an important influence on the occurrence of brine in the shallow aquifer. For example, the effluent from a brine pit situated above a channel might be confined to a narrow band along the channel down the hydraulic gradient from the pit. On the other hand, if the pit were above a local ridge or mound in the red-beds surface at the base of the shallow aquifer, the effluent would be dispersed into more than one channel. Although density differences between brine and fresh water tend to inhibit mixing, permeability differences within the shallow-water aquifer facilitate mixing.

Under certain circumstances brine or a mixture of brine and fresh water in the shallow aquifers of southern Lea County can be pumped by wells. The brine might move very near a producing well and still not be pumped by the well. If, for example, a well does not extend to the base of the aquifer, stratification and the presence of beds of low permeability between the bottom of the well and the brine layer at the bottom of the aquifer will retard the movement of brine into the well. The pumping schedule of a well that is subject to brine contamination may also influence the way in which contamination shows up in the well. If the interface between brine and fresh water is at some distance from the well, brine may move into the well only after prolonged periods of pumping, and the contamination might appear less intense on the basis of samples collected during short pumping cycles. Further, if a sample is taken from a well by means of a sampling tube or bucket, with no prior pumping, the effects of contamination might not show up at all.

Reported Instances of Brine Contamination

The locations of seven shallow-water wells that produce nonpotable water are plotted on the brine production map (fig. 25). Adjacent to each location the sulfate and chloride contents of the waters are indicated; the number above the line is the sulfate concentration, and the number below the line indicates the chloride content, both in ppm. The most recent analyses available are shown. Most of the samples were collected in 1958. Of the seven wells plotted, five have been reported by their users as having produced potable water that had been used domestically until the past decade or so. No historical information was obtained on the other two wells.

Well 20.37.4.111 yields water with a decidedly strong taste and odor of hydrocarbons. The owner stated that the water had been suitable for all domestic purposes until about September 1953, when the taste and odor became so offensive that the well had to be abandoned for domestic use. The high chloride content of the water from this well (450 ppm in 1954; 325 ppm in 1958) suggests brine contamination, but the odor and taste are strong enough to suggest leakage from oil wells or pipe lines. The series of samples collected from this well (table 8, analyses 12-14) indicates that the water from this well is improving in quality. The exact reason for this is unknown; however, gradual abandonment of the well could easily result in such a trend in water quality. Well 20.37.4.221, less than 1 mile east of the contaminated well, still yielded potable water at the time the area was visited (April 1955), and a sample of the water from this well showed a chloride concentration of only 51 ppm in 1955 and 47 ppm in 1958.

Well 22.36.1.333 was reported by the user to have produced potable water as recently as 1951 but had become contaminated since then. When sampled in December 1953, its chloride content was 1,750 ppm. Well 22.36.11.224, about 0.7 mile southwest of this well, draws water from the same aquifer, but the water has a chloride content of only 110 ppm. The badly contaminated well is located down the hydraulic gradient from three large brine pits and from well 22.36.11.224. The extraordinarily high chloride concentration of the contaminated well and the recent date of the change in water quality indicates that brine is seeping into the shallow water body and moving in an easterly and southeasterly direction in such a manner as to bypass well 22.36.11.224 to some extent.

Well 22.37.1.440 (analyses 43 and 44) is located on the fringe of a brine production area. When first sampled, in October 1953, it showed concentrations of chloride of 525 ppm; sulfate, 841 ppm; and nitrate, 38 ppm. When the well was resampled in September 1958, the chloride concentration was 320 ppm and the sulfate concentration was only 448 ppm. These decreases in concentration with time might result from a decrease in the discharge of brine upgradient from the well, or from differences in method of sampling or pumping schedule. Although excessive chloride would ordinarily indicate contamination resulting from brine seepage, the moderately high nitrate concentrations also suggest organic contamination, possibly from close-by septic tanks. It is probable that this well is receiving contaminants from two different sources.

In October 1953, well 22.37.24.133b had 675 ppm chloride, 482 ppm sulfate, and 26 ppm nitrate (table 8, analysis 45). The well was re-

sampled in April 1955 and again in September 1958. The analyses are summarized below:

DATE OF COLLECTION:	*Oct. 14, 1953*	*Apr. 22, 1955*	*Sept. 8, 1958*
Sodium plus potassium	254	247	—
Bicarbonate	187	216	216
Sulfate	482	598	622
Chloride	675	770	580
Nitrate	26	15	—
Specific conductance (micromhos at 25°C)	3,200	3,540	3,020

Interpretation of the changes indicated by these three analyses is virtually impossible. This well may also be receiving contaminants from two different sources.

In June 1954, well 21.33.2.422 had a chloride concentration of 1,020 ppm and a sulfate concentration of only 17 ppm. The user of this well has stated that the quality of the water began to deteriorate noticeably during 1952 and that prior to that time the water was suitable for domestic use. A second sample, taken in June 1955, showed that the chloride concentration had increased to 1,170 ppm during a 12-month interval and by September 1958 the chloride concentration had risen to 1,640 ppm.

Wells 20.36.15.421 and 25.37.15.223 show excessive concentrations of both sulfate and chloride. However, no historical data are available as to whether or not these wells have ever produced potable water. It is quite likely that they are contaminated wells. Well 20.36.15.421 was sampled in 1954 and in 1958 and the analyses (10 and 11, table 8) suggest appreciable increases in chloride and sulfate over the 4-year period.

Chemical Criteria for Recognition of Brine Contamination

Difficulties in determining whether a particular water sample shows the effects of brine contamination arise from several factors. The most important of these is the variability of the chemical characteristics of water from the Triassic, Tertiary, and Quaternary aquifers. Another important difficulty is imposed by the fact that most routine chemical analyses of water are incomplete; and although such analyses may give a clue as to anomalous chemical characteristics, they do not give sufficient detail to determine the cause of the anomaly. Chemical changes in brine as a result of reaction with the rock materials of the shallow aquifers impose problems in interpretation, because the exact nature of the reactions is unknown. Chemical properties that are most useful in interpretation are those that show the greatest contrast between fresh water and oil-field water, brine constituents that are stable and do not react with the rocks of the new environment, or those that are unique to brine and absent from fresh water.

Figure 26 shows that the chloride concentration of virtually all the samples of oil-field waters is much greater than that of the waters from other aquifers. This is so, even considering the fact that most of the samples from the alluvium and the Ogallala formations with high chloride concentrations probably are contaminated. Chloride also is useful for interpretation because it is stable in a wide range of geochemical environments. The cations, calcium, magnesium, sodium, and potassium also show contrasting concentrations between brine and fresh water, but these ions are very susceptible to ion-exchange reactions, and comparisons of water samples based on the idea of simple mixing of brine and fresh water are not reliable. Bicarbonate analyses are not very useful in developing criteria for contamination, because the concentration in a sample tends to change with time and because of the limited range in concentrations, as shown on Figure 26. Sulfate might be useful for comparisons but for several complicating factors. Principal of these is the fact that oil-field waters commonly contain hydrogen sulfide. This may evolve as a gas prior to analysis. Further, if hydrogen sulfide gas is not determined, it is common laboratory practice to boil a sample that has the hydrogen sulfide odor in order to remove the gas prior to making a sulfate analysis. Several analyses shown in Table 9 indicate the possibility of appreciable concentrations of hydrogen sulfide in brines of southern Lea County. It is doubtful that hydrogen sulfide would be stable in the shallow aquifers, which are in contact with air, and it probably would be converted to sulfate or pass off as gas. Thus a mixture of brine and fresh water might show a higher sulfate concentration than either of the two components of the mixture because of the oxidation of sulfide to sulfate (p. 112).

The dissolved-solids content, either as the sum of the determined constituents or the residue on evaporation, is very useful for comparisons of analyses, because at least one of these items is commonly determined and because of the pronounced contrast in this property between fresh water and brine.

The dissolved-solids content has been estimated for the analyses in Tables 8 and 9A in which the specific conductance was determined. The basis for the estimates is shown on Figure 27, on which are plotted the analyses that have both the specific conductance and the dissolved-solids content. The data indicate that if the conductance of the sample is less than 1,500 to 2,000 micromhos, the dissolved-solids content can be estimated by multiplying the specific conductance by a factor of 0.65. The estimate should be within 10 percent of the true dissolved solids, judging from the scatter of the data about curve A. In the samples that have conductances ranging from about 2,000 to 12,000 micromhos, the factor for estimating dissolved solids is 0.69. Scatter of the points about the correlation curve indicates that in this range an estimate of the dissolved-solids content might be in error by as much as 15 percent.

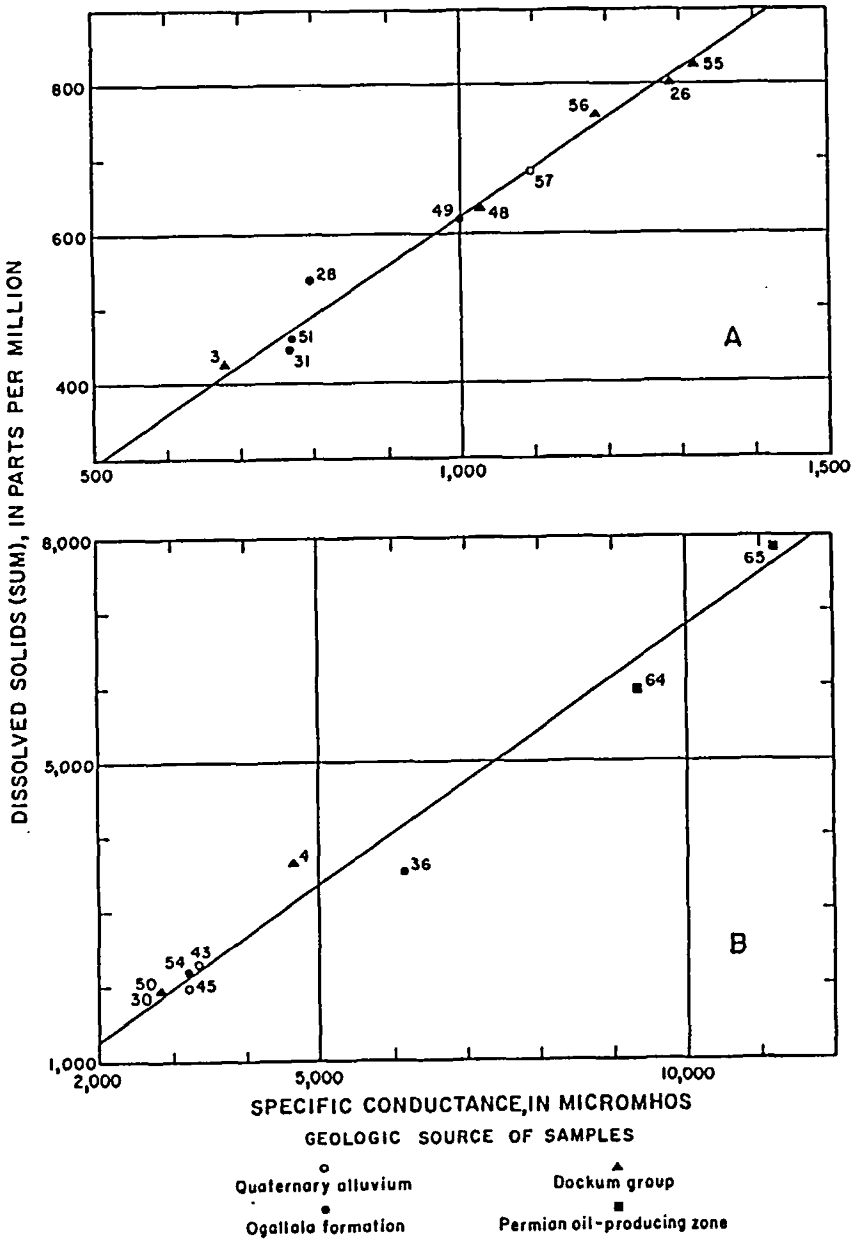

Figure 27

Relation of dissolved solids (sum) to specific conductance in samples of ground water from southern Lea County, N. Mex.

Numbers refer to Tables 8 and 9A.

In seven of the analyses in Tables 8 and 9B, the dissolved solids have been calculated, even though silica was not determined. Only 5 of these are shown on Figure 27. Assuming that none of these samples contained more than 82 ppm of silica (the highest concentration reported), the error introduced by omitting the silica content from the dissolved-solids calculation is not more than about 20 percent for a sample with 400 ppm dissolved solids. On the average the dissolved-solids content would be about 45 ppm too low if computed without the silica.

For the analyses of oil-field water reported in Table 9B, the sums were calculated if the analyses were sufficiently complete and were found to be in reasonably good ionic balance. In a few of the analyses, the magnesium content was assumed to be equal to the difference between the sum of the anions and the sum of the cations if the magnesium was the only principal ion missing from the analysis. It should be pointed out that although the analyses in Table 9B contain some determinations that may be questionable, they have been selected from the most complete compilation of chemical data on oil-field water that is readily available.

In the discussion that follows, the emphasis, as far as interpretation is concerned, is placed on the dissolved solids (sum of determined constituents) and chloride concentrations; however, the effect of an apparent increase in sulfate is illustrated by a plot of sulfate and chloride concentrations, and the effect of ion exchange is illustrated by a plot of calcium plus magnesium and sodium plus potassium.

Figure 28 shows the relation of dissolved solids (sum of determined constituents) to chloride in the water samples available for southern Lea County. Key numbers refer to Tables 8 and 9. Numbers designated by the prime (′) sign indicate analyses in which the sum has been estimated. The plotted positions of analyses 69 to 93 represent the dissolved-solids contents computed from the analyses rather than the determined dissolved-solids values shown in Table 9B.

The curved lines that connect analyses 18′ and 72, 24′ and 68′, 18′ and 4, and 24′ and 30 are loci of points representing all possible simple mixtures of the analyses that fall on the lines. The lines are curves because the data plot is on logarithmic coordinates, which have been used because of the wide range of values.

Analyses 18′ and 24′ show the lowest dissolved-solids and chloride concentrations, respectively, for the water samples available, and analyses 68′ and 72 lie on the outer limits of the band of points representing oil-field waters. Any simple mixture of brine and fresh water represented by points between or on lines 24′–68′ (projected) and 18′–72 will also lie between the two lines.

The dashed lines 24′–30 and 18′–4 connect the lowest values of dissolved solids and chloride in water samples from the Ogallala formation and the alluvium, with the highest such values found in water from Triassic aquifers.

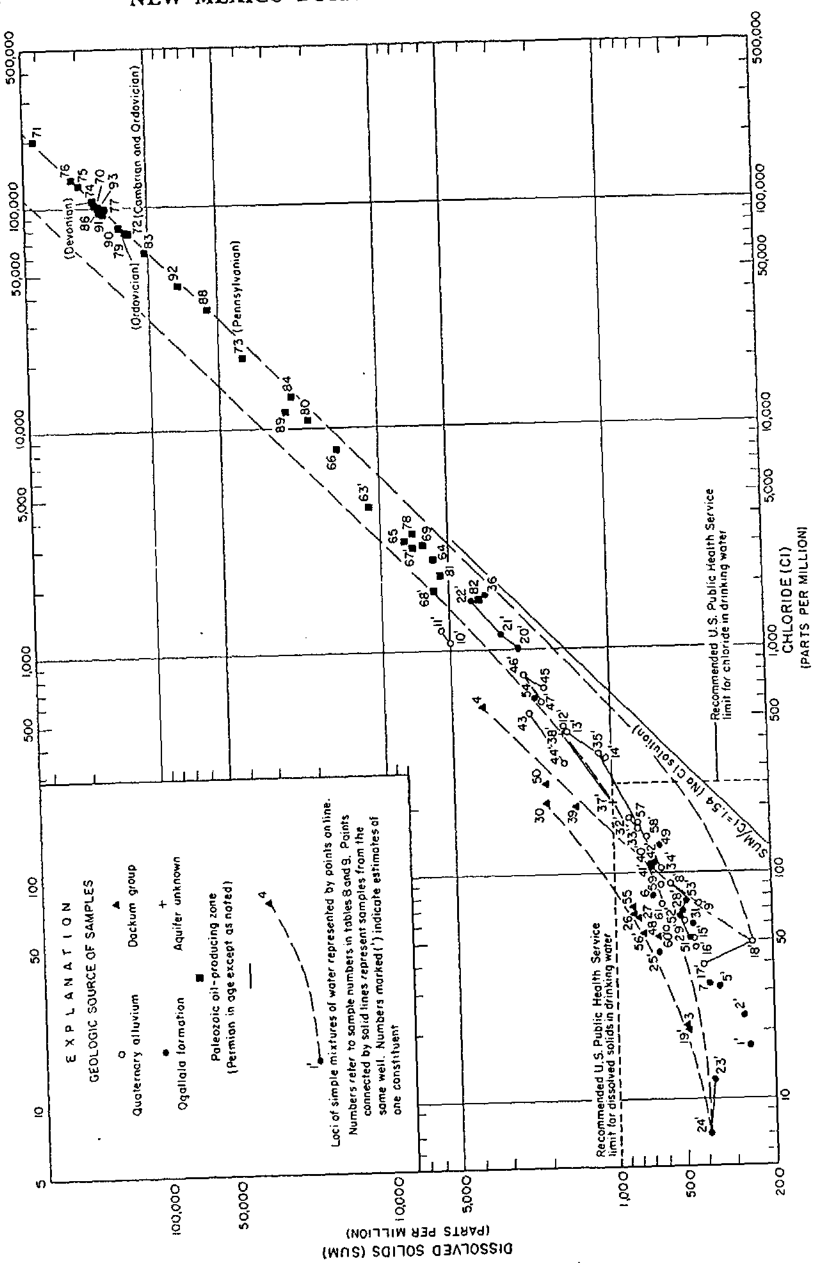

Figure 28

Relation of dissolved solids to chloride in samples of ground water from southern Lea County, N. Mex.

Several features of the data plot are significant: (1) Most of the points plot in a very narrow band; (2) the points representing samples from Triassic aquifers plot outside this narrow band; (3) of 14 sets of repeat samples (table 8), 9 show significant changes in chloride and dissolved-solids concentrations. Eight of the 9 show changes that are alined with the band of potential mixtures, and 6 show generally increasing concentrations with time.

Of the 16 analyses of water from the Ogallala and the alluvium that exceed the U.S. Public Health Service limits for dissolved solids and chloride, 12 can be readily interpreted as mixtures of brine and fresh water. Four lie outside the band of potential mixtures and thus cannot be readily explained as simple mixtures of brine and normal water from Tertiary or Quaternary rocks. Neither can they be explained by assuming contamination by water from Triassic rocks. In fact, analyses 10 and 11 have higher dissolved-solids and chloride concentrations than the most highly mineralized sample of Triassic water (analysis 4). Possibly these four samples represent mixtures of water from three sources, Tertiary or Quaternary rocks, Triassic rocks, and Paleozoic rocks.

All the analyses represented by points to the left of line 18'–4 are potentially mixtures of water from the alluvium and the Ogallala formation with water from the Dockum group.

The distinctive character of water from the Triassic rocks is illustrated by the relations of sulfate to chloride in southern Lea County water samples shown on Figure 29. The triangles on the data plot represent waters from Triassic rocks (Dockum group), and it is immediately apparent that, except for one sample, the ratio of sulfate to chloride, in equivalents per million, is greater than 2. The sulfate-chloride ratio of oil-field waters from Paleozoic rocks is less than about 0.25 and only two samples have ratios greater than 0.1. The samples from the Tertiary and Quaternary deposits have sulfate-chloride ratios generally less than 2 but greater than 0.1.

Because the points for the various analyses are so widely scattered, curves showing simple mixtures (fig. 28) have not been drawn on Figure 29; however, similar curves marking the loci of mixtures of two waters having the sulfate-chloride relations of analyses 81 and 6 or 7 would lie below analyses 10 and 11, 37 and 38, 43–47, and 54. This indicates sulfate enrichment in the mixture of brine and fresh water. It could be caused by the oxidation of sulfide in the brines to sulfate as the brine is transferred from the environment of the oil-producing zone, which has a low oxidation potential, to the environment of the shallow aquifers, which has a higher oxidation potential. The sulfate-rich mixtures might result from contribution of sulfate-rich brines that are not represented among the samples of oil-field waters, but this seems unlikely.

Figure 30 illustrates additional chemical characteristics of the ground waters of southern Lea County. It is a plot of the calcium-plus-magnesium (alkaline earths) concentration against the sodium-plus-potassium

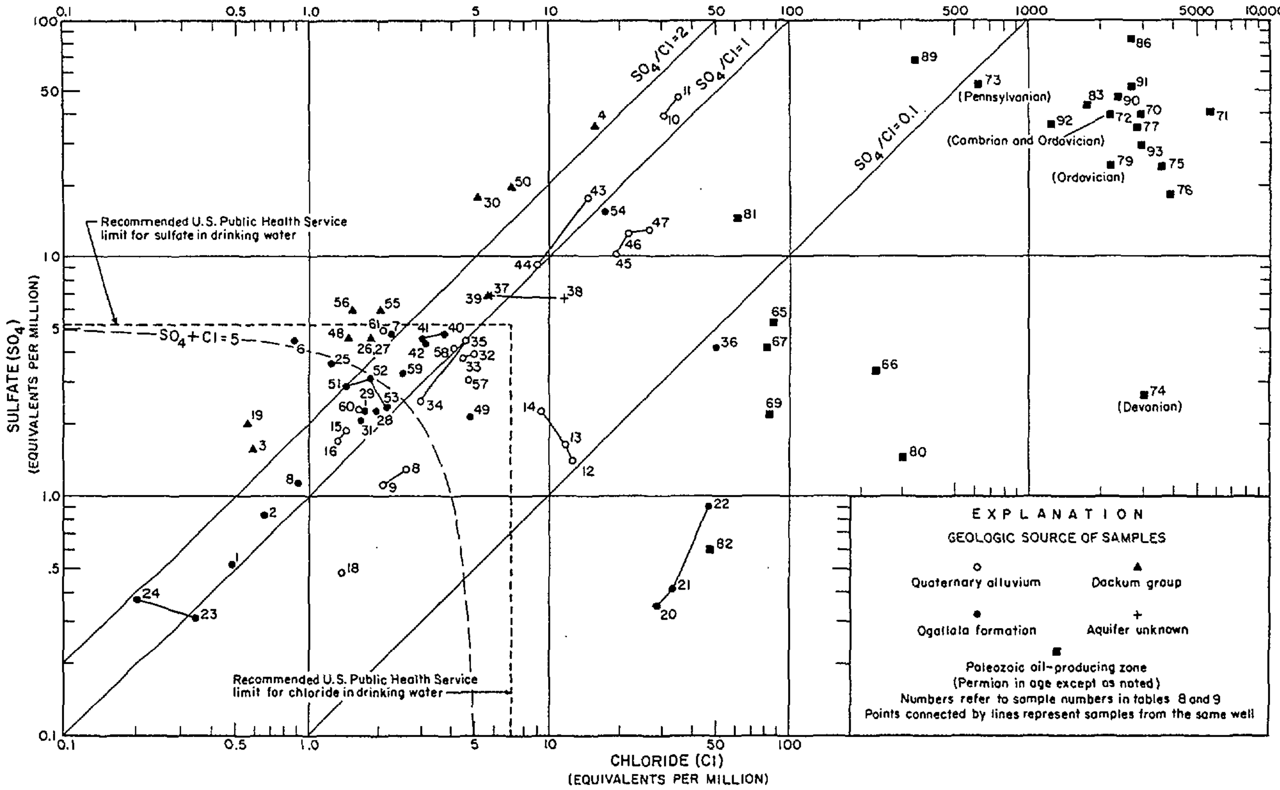

Figure 19.--Relation of sulfate to chloride in samples of ground water from southern Lea County, N. Mex.

Figure 29

RELATION OF SULFATE TO CHLORIDE IN SAMPLES OF GROUND WATER FROM SOUTHERN LEA COUNTY, N. MEX.

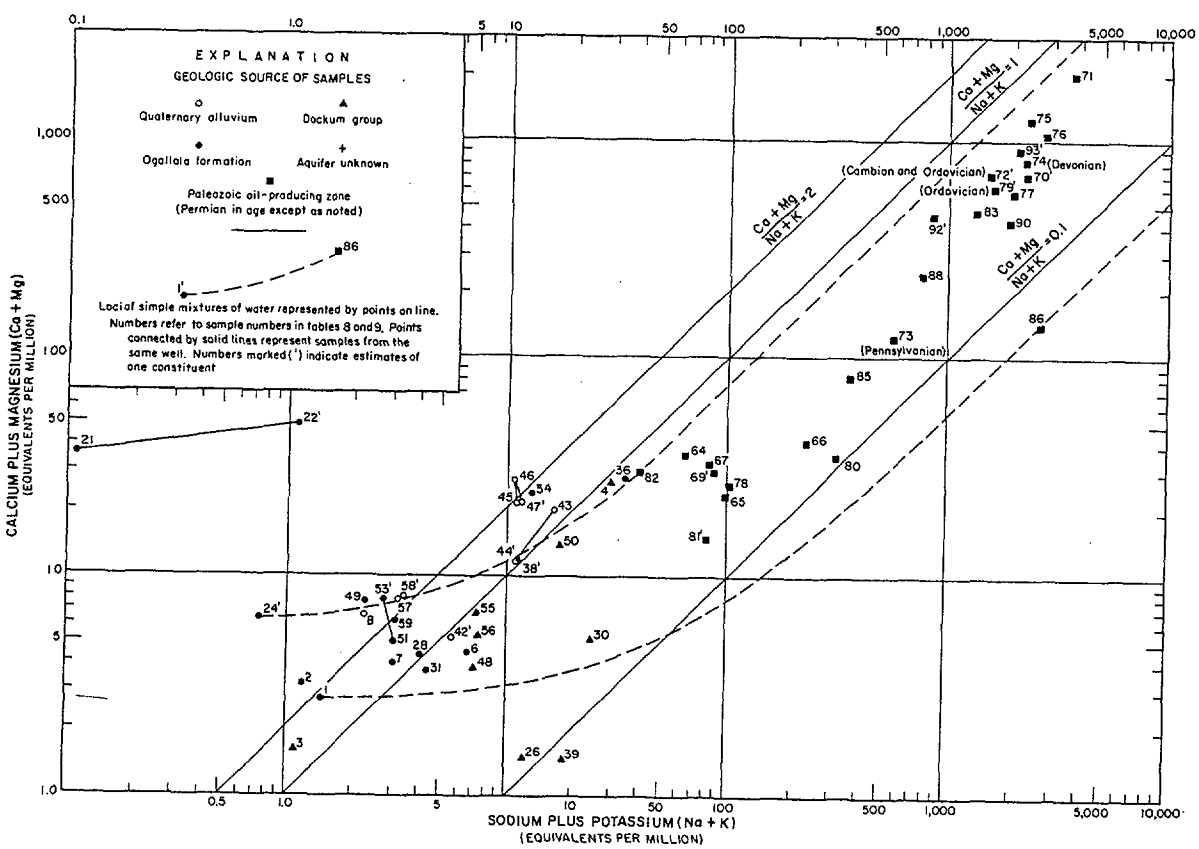

Figure 30.--Relation of calcium plus magnesium to sodium plus potassium in samples of ground water from southern Lea County, N. Mex.

Figure 30

RELATION OF CALCIUM-PLUS-MAGNESIUM TO SODIUM-PLUS-POTASSIUM IN SAMPLES OF GROUND WATER FROM SOUTHERN LEA COUNTY, N. MEX.

(alkali) concentration. The ratios of alkaline earths to alkalis is similar for both the oil-field brines and the waters from the Dockum group, even though the concentrations are greatly different. All the brines and all but one of the samples of Triassic waters have a ratio of alkaline earths to alkalis of less than 1. The samples from the Ogallala formation and the alluvium are in contrast to this; most of them have alkaline earth to alkali ratios of more than 1.

Also shown on Figure 30 are lines of simple mixtures, analyses 1 and 24′ and the "extreme-value" analyses of brine, for 82 and 86. Whereas less than 20 percent of the analyses plotted on Figure 28 are outside the band of potential simple mixtures, about 50 percent of the points representing water from the shallow aquifers plot outside the band of potential simple mixtures on Figure 30; and all of them are above the band or in the direction of increased calcium and magnesium. This appears to be caused by the exchange of sodium and potassium in the brine for calcium and magnesium in caliche, which underlies many brine pits, and in the calcareous cementing material of the Ogallala formation and the Quaternary alluvium.

All the samples of water known to be contaminated, by reason of the history of the wells from which they were obtained, have ratios of sulfate to chloride of less than 2 and a total concentration of sulfate plus chloride of greater than 5 epm (fig. 29). This, then, could be used as a tentative criterion for contamination. Such a criterion apparently could be used for water from the Dockum group as well as water from the younger rocks. Where the sulfate-plus-chloride concentration is less than 5 epm, contamination might be suspected if the sulfate-chloride ratio is less than the range of 0.5 to 1.0

A better criterion of brine contamination is an increase in chloride concentration along with a slight increase in the dissolved-solids concentrations, as shown by the trend of the lines of simple mixtures on Figure 28. It is necessary to know the aquifer before applying the chloride-dissolved solids criterion because natural water in the aquifers of the Dockum group may have very high concentrations of dissolved solids and chloride (fig. 28).

Any sample whose analysis plots to the right of line 18′–4 on Figure 28 should be suspected of contamination by Permian water. Further, even though analyses plot to the left of this line, contamination might be suspected if a series of analyses plot generally parallel to the band of mixtures. In these lower ranges of chloride concentration, however, a natural variation of only a few parts per million could cause an apparent trend.

DISPOSAL OF BRINE INTO DEEP WELLS

There are two possible alternatives to the use of pits for brine disposal. One is the demineralization of the brines to produce usable fresh water. The southern Lea County area would be a very favorable site for the utilization of such a process. As much brine is produced as there is water consumed. Thus, the conversion of brines into a usable form of water might nearly double the water resources of the area. Much of the brine produced in southern Lea County contains less than 15,000 ppm dissolved solids or only about half that of average sea water. These waters might be suitable for a demineralization process, and fuel for such a process is abundant and available.

The other and more practical alternative is to return the brine to deep, permeable horizons in the Permian and older formations. In this manner the brines may be safely discharged without danger of contaminating usable water supplies. This can be accomplished by using brines to repressure oil pools or by constructing wells solely for the purpose of brine disposal. Repressuring with oil-field brines is the ideal approach since the brine thus serves a useful function. Wells may be specially constructed, or oil wells that are no longer productive may be converted into disposal wells. The brine may be introduced into a permeable, oil-barren formation or into a depleted oil-bearing formation.

The Gulf Oil Corp. has constructed one such well in the vicinity of Eunice to dispose of brines from its oil wells in the Brunson and Hare pools. The Brunson pool yielded about 265 acre-feet of brine from 1945 through 1952. The Hare pool produced about 41 acre-feet of brine from 1947 through 1952. During the succeeding 3 years (1953 through 1955) the Brunson pool yielded 434 acre-feet of brine or more than 1½ times the brine production of the previous 8 years. For the same period the Hare pool produced 37 acre-feet of brine, nearly matching the total production of the previous 6 years.

The Gulf disposal well was constructed because the sharp increase in the rate of brine production indicated an evident danger of shallow-water contamination. The well, located at 21.37.28.111, was originally an oil well producing from the Queen and Grayburg formations of the Penrose–Skelly pool. Converting it into a disposal well involved drilling into a porous, oil-barren section of the San Andres limestone to a depth of 4,578 feet from its original depth of 3,800 feet. After being deepened and acidized, the well was tested and found capable of accepting 12,000 barrels of water per day (about 325 gpm) by gravity flow.

The installation began operation in May 1952 and by 1955 was accommodating 14 brine-producing wells. At that time nine brine-free oil wells were also tied into the system in anticipation of the time when they would begin to produce brine. The equipment at the installation consists of two emulsion treaters for the separation of brine and oil, two conditioning tanks in which suspended matter is filtered from the water, and an accumulator and backwash tank. The entire system is closed and under low pressure. The system includes two positive displacement pumps capable of pumping 8,340 barrels per day at 1,200 psi pressure. These are available in the event that forced injection should become

necessary in the future. In 1955 the well was accepting by gravity flow between 50,000 and 60,000 barrels (6.5 and 7.8 acre-feet) of brine per month.

A tabulation of the brine production and disposal from these pools is as follows:

	Brunson Pool (acre-feet)	Hare Pool (acre-feet)
Cumulative production to January 1, 1954	420	52
1952:		
Total production	170	15
Quantity injected into Gulf disposal well	56	.1
Quantity discharged into pits	114	15
1953:		
Total production	150	11
Quantity injected into Gulf disposal well	105	4.7
Quantity discharged into pits	45	6

The above figures indicate that about 70 percent of the brine produced from the two pools was being safely discharged in 1953. Although this reduced the danger of contamination of the shallow ground water, nevertheless, the danger is still present as long a leaky pits are used for brine disposal.

Summary

Southern Lea County is situated in a semi-arid region where water deficiencies have been intensified by economic development. Prior to the development of the oil and gas industry and its impetus to population growth, the water supply of the area was used only to satisfy stock, domestic, and small public-supply requirements. The development of the oil and gas industry has brought about more than a six-fold increase in population since 1930. Population growth and the establishment of gasoline plants, which use large quantities of water in processing natural gas, have increased the water need to a point where in 1955 the annual water use of the area was well over 6,000 acre-feet.

The water needs of the area are filled almost entirely by ground water obtained from Triassic rocks of the Dockum group, the Ogallala formation, and Quaternary alluvium. A very small quantity of impounded runoff is used for stock purposes. Of the three principal water-bearing formations of the area, the Triassic formations supply only a minor part of the water needs. The principal portion of the water supply comes from the Ogallala formation and the Quaternary alluvium on the eastern side of southern Lea County, where the two form a continuous water-table aquifer. This single ground-water body provides about 80 percent of the area's water needs.

Procurement of the needed water is made difficult by restricted occurrence, variable and generally low transmissibility of the sediments, and an evidently low recharge rate. A large part of the water used is being removed from storage.

Contamination of the water supply, caused by seepage of oil-field brines from brine-disposal pits into the shallow aquifers, creates additional difficulty in obtaining water. Some contamination has already occurred, and it is expected that in time this will become a more difficult problem because the contaminants will migrate and spread to areas where contamination does not now exist.

It is anticipated that the water needs of the area will continue to increase. This anticipation is based on the assumption that the oil and gas industry will continue to expand. To date its development has been restricted almost entirely to the shallower oil-bearing structures of the Central basin platform and the Back Reef or Shelf area of the Delaware basin. The Delaware basin proper probably will provide a field for expansion and development for a long time to come.

With continued economic development, depletion of ground-water supplies through pumping from storage, and loss of water supplies by contamination, the water-supply problem of the area will become more and more acute. There is little hope that additional supplies can be

found in the area. Water-bearing horizons below the top of the Permian formations will not yield water of suitable quality, and there appear to be no highly productive water-bearing horizons within the Triassic formations. Therefore, recourse must be made to conservation methods that will yield the most value from the water available.

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