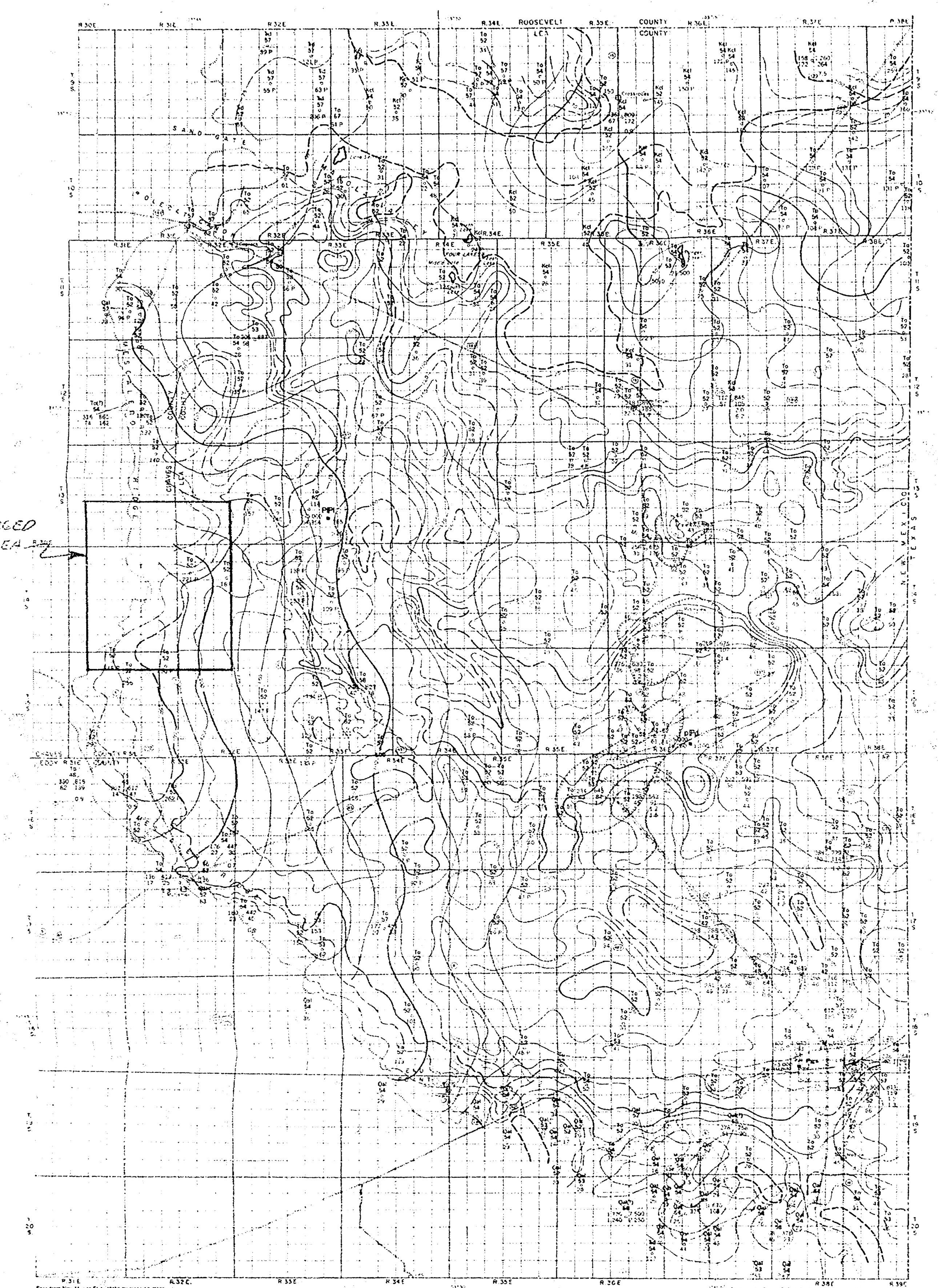
Case No
3635

Large Exhibits

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH
THE NEW MEXICO STATE ENGINEER

ENLARGED AREA



Base from New Mexico State Highway planning maps 1951. Roads revised 1956

Compiled by Sidney R. Ash, 1960; revised August 1961. Control for the contour lines connecting points of approximately equal saturated thickness of the Ogallala formation and control for the contour lines connecting points of approximately equal depth to water below land surface taken from published and unpublished data collected by the U.S. Geological Survey and the New Mexico State Engineer

FIGURE 5.—MAP OF NORTHERN LEA COUNTY, NEW MEXICO, SHOWING THE SATURATED THICKNESS OF THE DEPOSITS OF CENOZOIC AGE AND APPROXIMATE DEPTH TO WATER IN 1952 AND THE CHEMICAL QUALITY OF GROUND WATER

SCALE 1:250 000

CONTOUR INTERVAL 25 FEET

EXPLANATION

AQUIFERS

Qal — Alluvium (Recent; QUATERNARY; CENOZOIC)
Sand and gravel; may include some redeposited material from Ogallala formation and the underlying Cretaceous and Triassic rocks

To — Ogallala formation (Pliocene; TERTIARY; CENOZOIC)
Irregularly-bedded sand, grit, and local gravel conglomerate cemented by lime or caliche, and local beds of sand, clay, and limestone; may include some redeposited material from the underlying Cretaceous and Triassic rocks

Kcl — Clay and limestone (Lower Cretaceous(?); CRETACEOUS; MESOZOIC)
Yellow and blue clay with thin stringers of brown, and gray, limestone; probably equivalent to the Tucumcari shale

Td — Dockum group, undivided (Upper Triassic; TRIASSIC; MESOZOIC)
Maroon, red, and gray irregularly-bedded sandstone, bright- and dark-red shale and sandy shale, and purplish limestone pebble beds

Pgs — Grayburg formation and San Andres limestone, undivided (PERMIAN; PRE-MESOZOIC)
Sandy dolomite with interbedded dolomitic sand; porous white limestone; known only from logs of oil wells

PPl — Limestone (PENNSYLVANIAN AND PERMIAN; CARBONIFEROUS; PRE-MESOZOIC)
White to light gray crystalline limestone with vuggy porosity and occasional green shale partings; known only from logs of oil wells

pPd — Dolomite (PRE-PENNSYLVANIAN; PRE-MESOZOIC)
Sandy porous dolomite and vuggy crystalline dolomite; known only from logs of oil wells

Water well — Oil and gas well location near center of field — Spring

Aquifer — To; 57 — Year sampled
Hardness as $CaCO_3$ (ppm) — 195; 543 — Specific conductance (micromhos at 25°C)
Chloride (ppm) — 45; 95 — Sulfate (ppm); 1.2 — Fluoride (ppm); 1.5 — Sodium-adsorption ratio

Depth to water, in feet, below land surface datum. Static-level measurement unless the figure is followed by the capital letter "P" which indicates that the measurement was made while the well was being pumped

Data are grouped around the source-of-water symbol. Undetermined information is noted by the absence from the designed position in the group of data

Line connecting points of approximately equal depth to water below land-surface datum as of 1952
Dashed where inferred; interval 25 feet

Line connecting points of approximately equal saturated thickness of the deposits of Cenozoic age as of 1952
Dashed where inferred; interval 25 feet

Approximate boundary of bedrock highs that interrupt the water table in the deposits of Cenozoic age

THE WATER TABLE IN THE DEPOSITS OF CENOZOIC AGE

The shape and approximate altitude of the water table is shown (fig. 2) by contour lines based on water-level measurements made mostly during 1952. A few measurements in Tps. 9 and 10 S., were made in later years; the data are comparable because the level of the water table in these wells has not changed appreciably for a number of years. The water table slopes generally toward the southeast at about 12 feet per mile, slightly less than the slope of the land surface. The irregularities in the surface of the water table are caused by differences in the permeability of the aquifer and heavy pumping in certain areas.

Records of water levels in observation wells indicate that since 1929 the water table has fluctuated erratically in the east-central part of northern Lea County, but the overall trend during the period 1929-60 has been downward.

The declines during the period 1929-40 were localized because of the relatively slight pumpage and average to above-average precipitation. Above-average precipitation from January 1940 to January 1950, caused the water table to rise generally except in the vicinity of McDonald, Lovington, Humble City, and Hobbs where pumpage increased appreciably during 1947 to 1950 (fig. 4). During the period 1950-60 the water table declined over a much larger area than in the previous 10-year period because of increased pumpage and generally below average rainfall during that time. The greatest decline during the period 1950-60 was 31.7 feet about 14 miles northeast of Lovington.

DEPTH TO WATER AND SATURATED THICKNESS OF THE DEPOSITS OF CENOZOIC AGE

The depth to water ranges from a little less than 12 feet in an area about 13 miles east of Caprock to almost 300 feet along the Mescalero Ridge northwest of Maljamar (fig. 5). When the Lea County Underground Water Basin was declared in 1931 it included an area of about 1,080 square miles where the depth to water was known to be generally 50 feet or less; by 1952 the area in which the depth to water was 50 feet or less had been reduced about one-sixth.

The saturated thickness of the deposits of Cenozoic age generally ranges from less than 25 feet to about 250 feet. The zone of saturation is thinnest in the northeast part of the county where the Ogallala formation is thin and is underlain by sediments of Cretaceous age. The thickest zone of saturation generally is where the Ogallala formation is the thickest and where there has been little use of ground water. The zone of saturation locally has become progressvely thinner as water has been withdrawn for irrigation. The average thickness of the zone in the declared basin was about 100 feet in 1952.

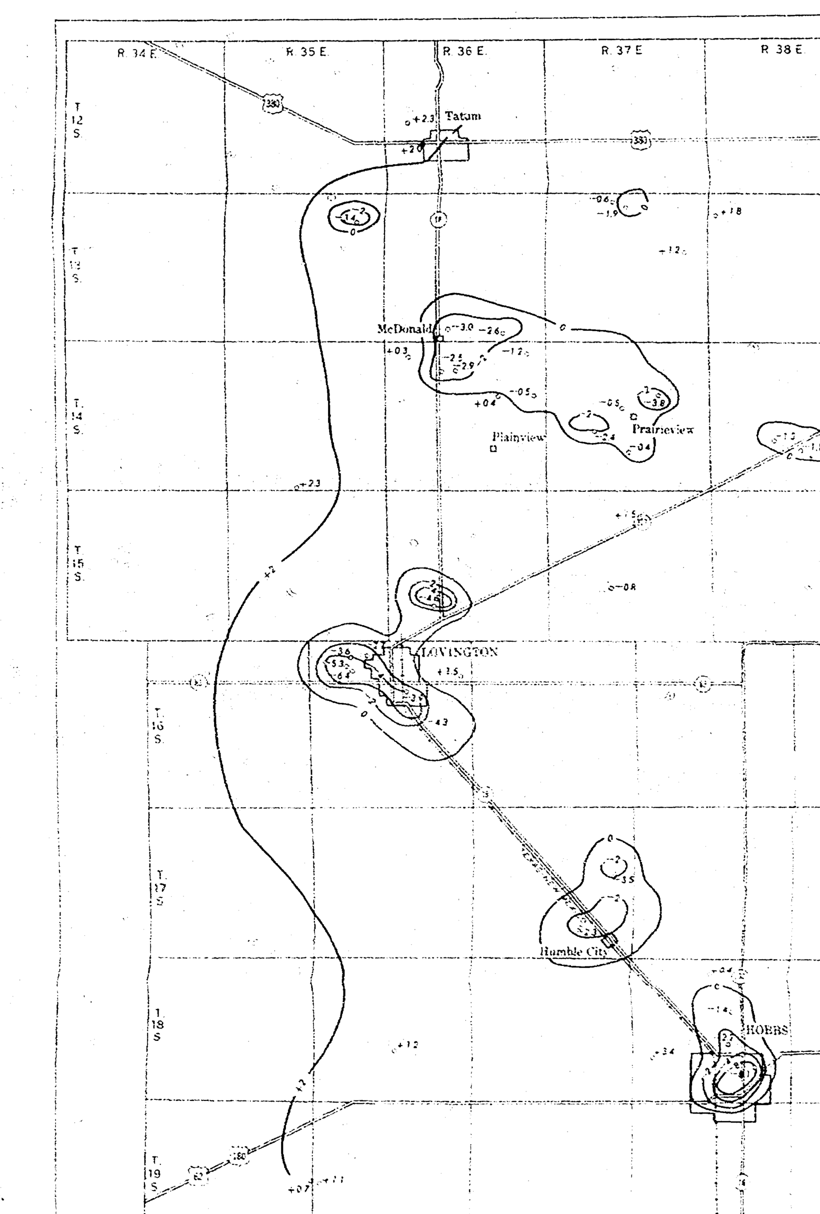
MOVEMENT OF GROUND WATER IN THE DEPOSITS OF CENOZOIC AGE

Ground water moves southeastward down the slope of the water table throughout ... ment of ground water ... trolled by the gradient ... of the material in the ... grain size of the materi... and the extent of cem... of movement to vary fr... true of the Ogallala fo... water moves more ra... and gravel than throu... and clay. Data avail... movement of ground ... the order of 150 feet p... oral communication, 19...

DISCHARGE OF GRO...

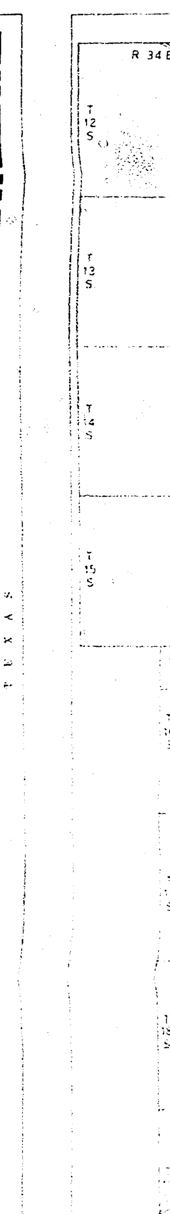
Ground water stored ... removed by both natur... discharge is by subsur... and transpiration, and ... discharge is through w...

Natural discharge.—... discharge of ground w... subsurface outflow at t... additional quantity mo... along the southern an...



January 1940 to January 1950

Adapted from Berkstresser, 1959, p. 114



EXPLANATION

Observation well
Number indicates rise (+) or decline (−), in feet, of water level during the period

Line showing rise (+) or decline (−), in feet, of water level
Interval variable, dashed where estimated

FIGURE 4.—MAPS SHOWING WATER LEVEL CHANGES IN EAST-CENTRAL

GROUND-WATER CONDITIONS IN NORTHERN LEA COUNTY, NEW

By
Sidney R. Ash

1963

HYDROLOGIC INVESTIGATIONS
ATLAS HA-62 (SHEET 2 OF 2)

THE WATER TABLE IN THE DEPOSITS OF CENOZOIC AGE

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The depth to water ranges from a little less than 12 feet in an area about 13 miles east of Caprock to almost 200 feet along the Mescalero Ridge northwest of Maljamar (fig. 3). When the Lea County Underground Water Basin was declared in 1931 it included an area of about 1,080 square miles where the depth to water was known to be generally 50 feet or less; by 1952 the area in which the depth to water was 50 feet or less had been reduced about one-sixth.

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MOVEMENT OF GROUND WATER IN THE DEPOSITS OF CENOZOIC AGE

Ground water moves southeastward down the slope of the water table throughout most of the area. The rate of movement of ground water in the deposits of Cenozoic age is controlled by the gradient of the water table and the permeability of the material in the zone of saturation. Variations in the grain size of the material, the degree of sorting of the deposits, and the extent of cementation of the material cause the rate of movement to vary from place to place. This is particularly true of the Ogallala formation especially near the base where water moves more rapidly through stringers of coarse sand and gravel than through the surrounding beds of fine sand and clay. Data available indicate that the average rate of movement of ground water in the Ogallala formation is on the order of 150 feet per year (H. O. Reeder, U.S. Geol. Survey, oral communication, 1960).

DISCHARGE OF GROUND WATER FROM THE DEPOSITS OF CENOZOIC AGE

Ground water stored in the deposits of Cenozoic age is being removed by both natural and artificial discharge. Natural discharge is by subsurface flow out of the area, evaporation and transpiration, and through springs and seeps. Artificial discharge is through wells.

Natural discharge.—The greatest part of the total natural discharge of ground water from northern Lea County is by subsurface outflow at the New Mexico-Texas State line. An additional quantity moves out of the area by subsurface flow along the southern and western boundary where the contact between the Ogallala formation and the rocks of Triassic age is covered by Quaternary alluvium.

The amount of ground water lost by evaporation and transpiration is relatively small because there are no large bodies of surface water and there are few areas where the water table is shallow.

Evaporation from the zone of saturation in general can take place only where the water table is within 10 feet of the land surface; such a condition prevails around the perennial lakes, along Mescalero Ridge, and south of Mescalero Ridge from Rgs. 35 to 38 E.

Most transpiration by native vegetation is near the perennial lakes and the springs and seeps where the depth to water is less than 20 feet. Native grass, weeds, mesquite, and hackberry and cottonwood trees are the principal users of ground water by transpiration.

Flow from springs and seeps is small in proportion to the total discharge from the Ogallala formation. Some of the springs and seeps discharge along the contact between the sediment of Tertiary and Triassic age exposed in the escarpment of Mescalero Ridge in Tps. 11 and 12 S., R. 31 E., other springs discharge into the lakes; Ranger Lake and North Lake receive the greater part of the water discharging to the lakes.

Artificial discharge.—The ground water discharged through wells from the deposits of Cenozoic age is utilized for irrigation, public supplies, rural-domestic supplies, industrial uses, and stock. The amount pumped each year is estimated by the U.S. Geological Survey; and the data are published by the New Mexico State Engineer.

The quantity of water pumped from the deposits of Cenozoic age during 1952 was about 185,000 acre-feet; of this amount 166,000 acre-feet was used for irrigation. About the same quantities of water were pumped each year during the period 1953-57. Because of above average precipitation during the growing season of 1958, however, the amount of water pumped for irrigation decreased to about 107,000 acre-feet; the use for other purposes remained about the same—19,000 acre-feet.

The estimated amount of water pumped from the deposits of Cenozoic age for irrigation during the years of record was as follows:

Year	Acre-feet	Year	Acre-feet
1937	1,800	1949	60,000
1938	1,700	1950	95,000
1939	2,200	1951	153,000
1940	3,300	1952	166,000
1941	1,500	1953	165,000
1942	2,500	1954	163,000
1943	6,000	1955	170,000
1944	3,500	1956	180,000
1945	6,900	1957	140,000
1946	3,500	1958	107,000
1947	19,900	1959	149,000
1948	39,000	1960	105,000

RECHARGE OF GROUND WATER IN THE DEPOSITS OF CENOZOIC AGE

The deposits of Cenozoic age are recharged chiefly by precipitation; in addition there is some recharge from subsurface flow into the area from Chaves and Roosevelt Counties, from irrigation return, and from seepage from brine disposal pits.

Recharge to the reservoir by the downward percolation of water generally cannot take place where the land surface is underlain by a thick layer of caliche. Only where the caliche is absent, relatively soft, broken by joints, or removed or disturbed by man can water move downward to the water table.

The average annual recharge from precipitation to the zone of saturation in the southern High Plains is between ¼- and ½-inch per year, depending on the amount of precipitation (Theis, 1937). The area of northern Lea County is about 1,800,000 acres; therefore, the amount of annual recharge probably varies between 38,000 and 75,000 acre-feet per year. The area of the Lea County Underground Water Basin is about 1,400,000 acres; therefore, the average annual recharge to the declared basin is approximately 29,000 to 58,000 acre-feet.

The greatest amount of recharge from precipitation occurs in the areas covered by dune sand, and in those areas where the shallow closed depressions are most numerous.

The deposits of Cenozoic age receive a small amount of recharge from surface inflow derived from precipitation that falls on the Llano Estacado outside Lea County, but near its northern boundary. The southeast-trending stream channels carry some runoff into the northern part of the area where it is caught in shallow closed depressions. Some of this water reaches the water table by infiltration but most probably is lost by evaporation and transpiration.

Ground water in the Ogallala formation in adjacent areas in Roosevelt and Chaves Counties, New Mexico, flows in a southeasterly direction and a small amount enters the area as underflow along its northern boundary.

Some of the water pumped from the deposits of Cenozoic age for irrigation, domestic, stock, municipal, and industrial uses is not consumed but instead percolates back to the aquifer. It may be called return discharge, but it does not constitute an addition to the supply of water, rather, it represents a decrease in the net discharge.

Brine-disposal pits for oil-field water also are a source of recharge. Data supplied by Alexander Nicholson, Jr., and Alfred Clebsch, Jr. (1961, p. 102-103) indicate that about 96 percent of the brine discharged to disposal pits for evaporation instead seeps to the water table.

GROUND WATER IN STORAGE

The total quantity of water in storage in the deposits of Cenozoic age can be estimated by using the formula

$$V = Apm$$

where V is the quantity of water in storage, A is the surface area of the aquifer, p is the porosity of aquifer, and m is the saturated thickness of the aquifer. The area (A) of the Lea County Underground Water Basin is about 1,400,000 acres; the average porosity (p) is about 35 percent; and in 1952, the saturated thickness (m) averaged about 100 feet. On the basis of the above figures, it is estimated that about 49,000,000 acre-feet of water were in storage in the aquifer at the end of 1952. However, not all of the water in storage in the reservoir can be recovered for large scale irrigation development because of two principal factors. First, it usually is not economically feasible to pump large quantities of water in areas where the zone of saturation is or becomes less than 30 feet in thickness. Thus, on the average, only the water in the upper 70 feet of the reservoir can be considered as available for large scale pumping. Secondly, much of the water will be retained by adhesion on the surfaces of the grains which make up the reservoir. The yield of water from the sediments is estimated to be 0.2 of the volume of saturated sediment. Thus about 40 percent of the total amount of water in storage in the deposits of Cenozoic age in the northern Lea County Underground Water Basin can be recovered for large-scale irrigation, or about 20,000,000 acre-feet. If ground water pumping was distributed evenly throughout the Basin, the amount in storage would last approximately 100 years at the present rate of use. But some of the water underlies areas that are unsuited for farming and will not be used for this purpose while in other areas the supply will be exhausted in 40 years or less, from 1952, because of extensive local development.

Probably enough water for domestic and municipal uses will be available in the reservoir for a considerable length of time after water is no longer available for large-scale irrigation use.

CHEMICAL QUALITY OF THE WATER

Ground water in the deposits of Cenozoic age is suitable for most uses. Water from the Triassic and Cretaceous formations generally is harder and has a higher dissolved-solids content than water from the younger rocks, and the water is unsuitable for some uses. Water from aquifers of pre-Mesozoic age are generally saline, but have been used to a limited extent in water flooding of oil fields. The chemical quality of the waters is indicated by the analyses in figure 5 which show the concentration of sulfate (SO_4), of chloride (Cl), and of fluoride (F), the hardness, the specific conductance, and the sodium-adsorption ratio.

Water for domestic use.—The quality standards for drinking water recommended by the U.S. Public Health Service (1946) have been adopted by the New Mexico Public Health Department. These standards were reviewed recently by Welsh and Thomas (1960) and they agree (p. 299) that "the present limits appear to be satisfactory . . ." although limits for certain other substances should be considered. The recommended limits for the substances shown in the analyses in figure 5 are 1,000 ppm (parts per million) (preferably 500 ppm) of dissolved solids, or a specific conductivity of less than 1,500 micromhos and preferably less than 750 micromhos; 250 ppm of sulphate; 250 ppm of chloride; and 1.5 ppm of fluoride. The preferred limits for one or more substances were exceeded in 19 of the 36 analyses of water from the Cenozoic deposits. They were exceeded in the three analyses of water from the Tucumcari shale, and in the three analyses of water from rocks of pre-Mesozoic age. None of the water occurring in the Triassic rocks in the area has been analyzed.

Water which has an excess of some of these substances may not have an undesirable taste or odor; a chemical analysis generally is necessary to determine its suitability for drinking. The New Mexico Department of Public Health will analyze, free of charge, drinking water for residents of the State. Sample containers and instructions for sampling can be obtained from the New Mexico Department of Public Health in Santa Fe or Albuquerque.

Water for industrial use.—Water from deposits of Cenozoic age may be considered satisfactory for most industrial uses, even though the water is hard. Water from the formations of Mesozoic age are generally harder and have a higher dissolved-solids content than water from Cenozoic rocks. Water from the rocks of pre-Mesozoic age generally is of such poor quality that it is suitable for use only where quality of water is of little or no importance, such as drilling shotholes and water-flooding of oil and gas fields.

Water for irrigation.—Water from deposits of Cenozoic age generally is suitable for irrigation according to the criteria of the U.S. Department of Agriculture (Richards, 1954). The total concentration of soluble salts (salinity hazard) ranges from medium to high; however, the quantity of exchangeable sodium (alkali hazard) is low, (Richards, 1954, p. 80). The few wells near Hobbs that have a relatively high concentration of chloride also tend to have a moderately high alkali hazard. A high concentration of sulfate in association with a high concentration of sodium lessens the alkali hazard. Boron is not known to occur in concentrations high enough to affect the plant growth.

Without exception, the water in the rocks of pre-Mesozoic age which was analyzed has been of very poor quality with respect to use for irrigation. Most of the water, which commonly is called brine, has an extremely high salinity and alkali hazard. Ground water in rocks of pre-Mesozoic age is not considered suitable for irrigation.

Contamination.—In some wells potable water in the Ogallala formation is being contaminated with water containing a high concentration of chloride, sodium, calcium, magnesium, and other dissolved solids. A well in NW¼SE¼NE¼ sec. 15, T. 18 S., R. 38 E., approximately 2 miles north of Hobbs, was sampled during 1951, and the analyses showed the water to be potable. The well was sampled again in 1954 and the chloride content had increased from 75 to 152 ppm, the sulfate content had increased to 359 ppm since 1954, and the concentration of chloride had increased to 259 ppm. The hardness (as $CaCO_3$) had increased from 296 ppm to 612 ppm during the 7-year period and the SAR (sodium adsorption ratio) had increased from 1.3 to about 2.4. The water had become impotable according to the U.S. Public Health Service standards (1946).

Contamination apparently is taking place only where the production of brine with oil has continued for a relatively long time, as in the vicinity of Hobbs and Monument. Analyses of samples collected periodically from 1951 to 1957 from a well in SW¼SW¼SW¼ sec. 31, T. 14 S., R. 37 E., and a well in NW¼NW¼NW¼ sec. 8, T. 15 S., R. 36 E. show little or no change in the quality of water. There is little oil production in the vicinity of these two wells.

Contamination may not be detected for many years after its inception unless water wells are located within a few hundred feet of the source of the contamination because of the slow rate of movement of ground water in formations of Cenozoic age. When the quality of the water from a well begins to deteriorate, it is usually too late for remedial measures.

Further contamination of the potable ground-water supplies can be prevented by using any of the following methods or a combination of the methods:

(1) Line the disposal pits with impervious material so that the brine does not seep downward.
(2) Return the brine to deep-lying formations either by using the brine to repressure oil pools or by using wells solely for waste disposal.
(3) Demineralize the brine. This method would significantly improve the water situation by removing a contamination hazard and would increase the supplies of potable water.

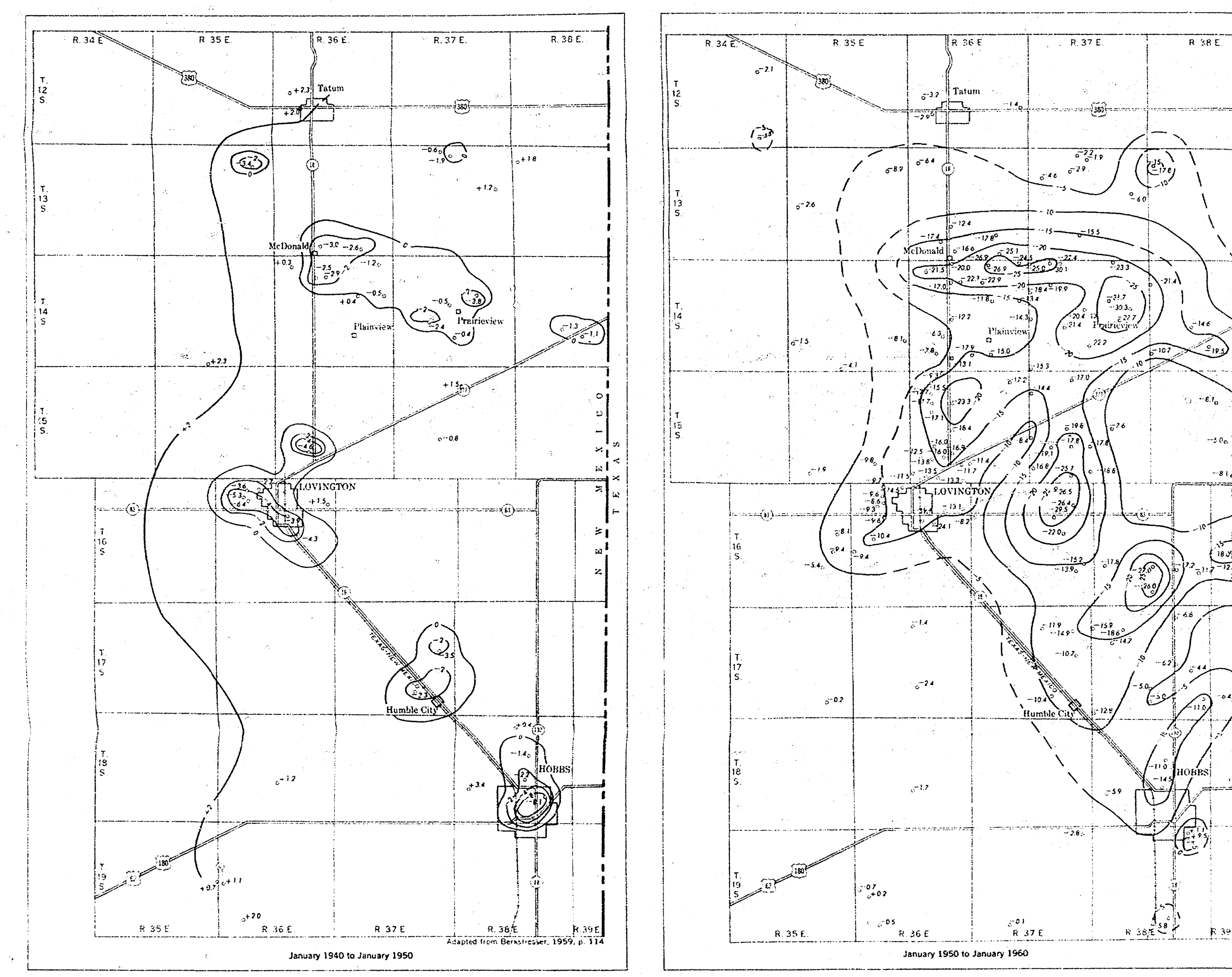

FIGURE 4.—MAPS SHOWING WATER LEVEL CHANGES IN EAST-CENTRAL LEA COUNTY, NEW MEXICO

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-WATER CONDITIONS IN NORTHERN LEA COUNTY, NEW MEXICO

By
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1963

PREPARED IN COOPERATION WITH
THE NEW MEXICO STATE ENGINEER

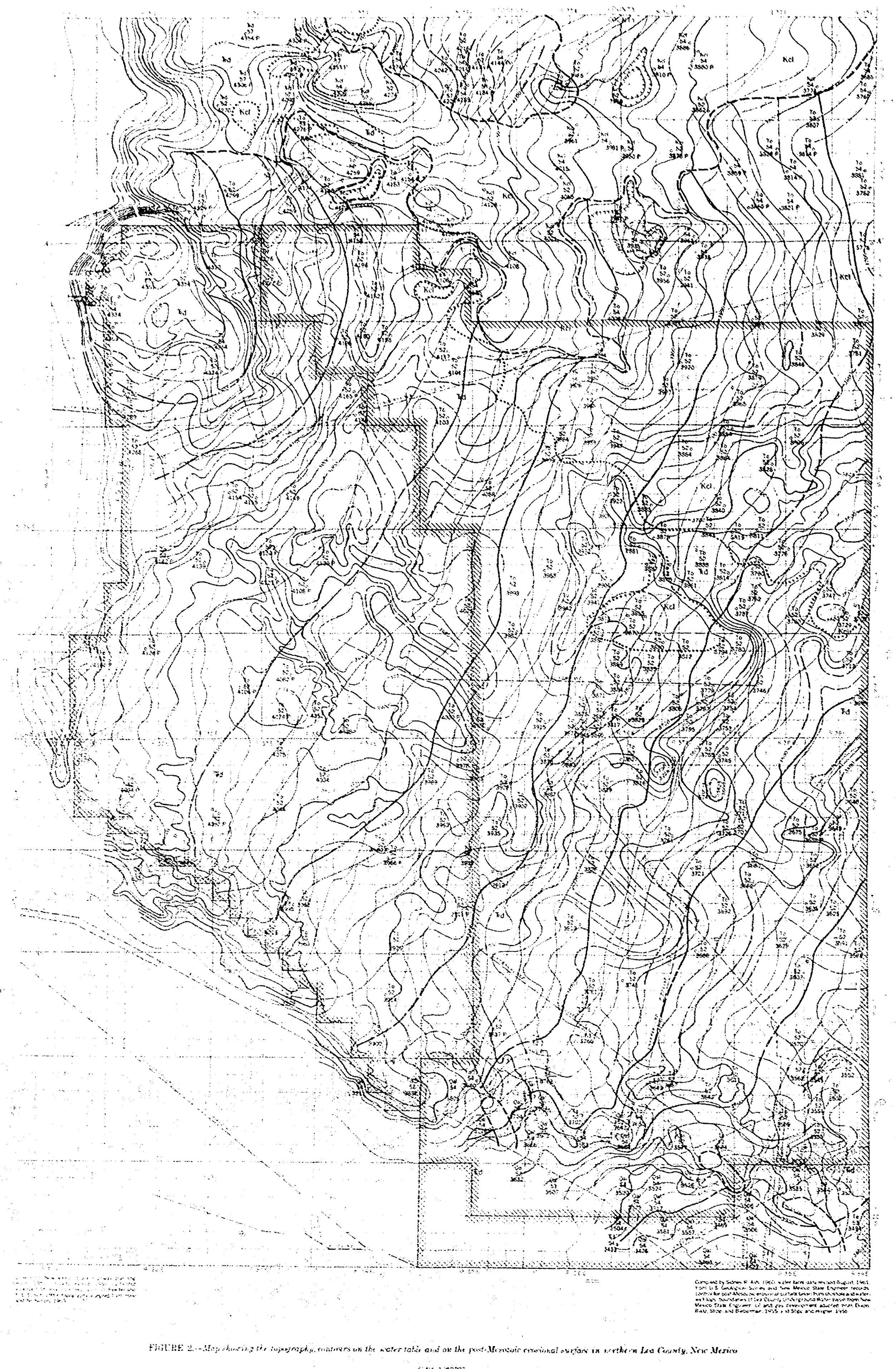


FIGURE 2.—Map showing the topography, contours on the water table and on the post-Mesozoic erosional surface in northern Lea County, New Mexico

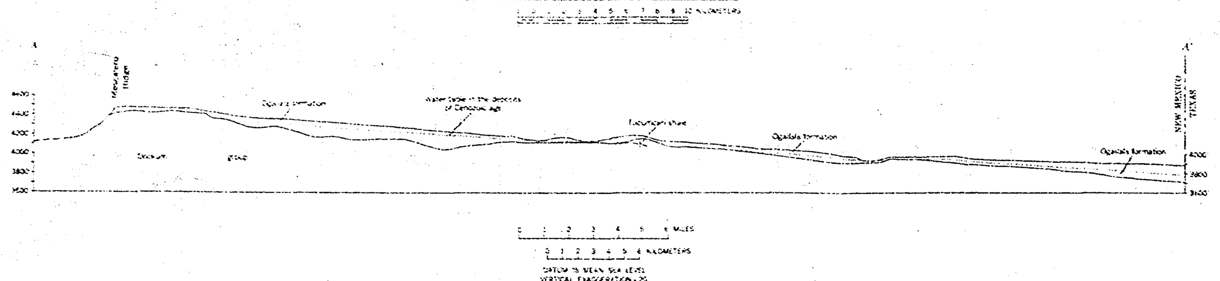
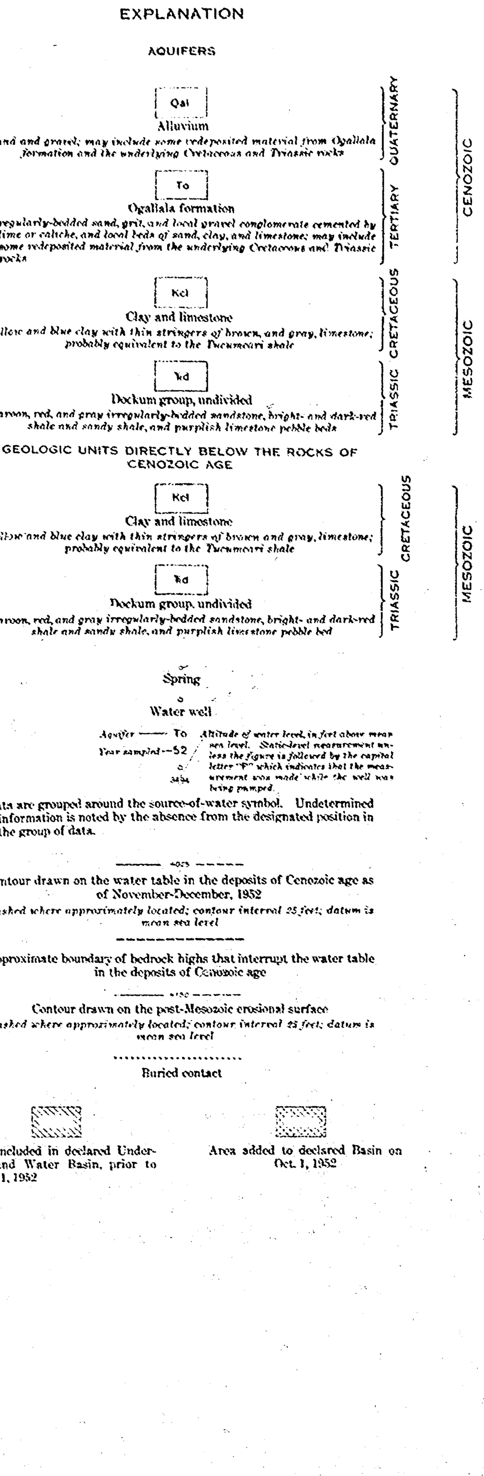


FIGURE 3.—SECTION ALONG A-A' FROM MESCALERO RIDGE TO THE NEW MEXICO—TEXAS STATE LINE IN NORTHERN LEA COUNTY, NEW MEXICO



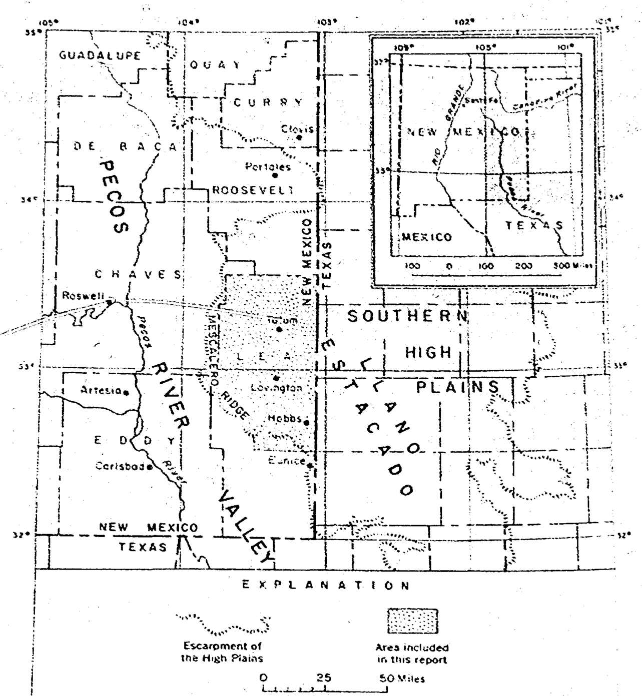


FIGURE 1.—INDEX MAP SHOWING THE LOCATION OF THE NORTHERN LEA COUNTY AREA AND ITS RELATION TO THE HIGH PLAINS AND THE PECOS RIVER VALLEY

tion. The loam strips are surrounded, in most places, by uncultivated scabland or by sand hills. The scabland is chiefly thin, rocky loam, and the sand hills are chiefly sandy loams. The sand hills, like the loams, occur in long narrow strips.

The northwest-southeast lineation of the soils and sand hills is well illustrated on the soil map of the area around Lovington (Harper and Smith, 1935). The cause of the lineation is unknown; however, the trend, thickness, and location of the soil strips suggest that the lineation may be related to streams of Tertiary age which originated to the west and flowed southeastward at the time the Ogallala formation was being deposited. The lineation may also be related to older sand-dune patterns developed from prevailing southwesterly winds.

Generally, only clay is found on the floors of the shallow closed depressions because the coarser materials are deposited at the margins as the water flows to the depressions; only very fine materials can be carried by the weak currents in the ephemeral lakes.

CLIMATE

The climate of northern Lea County is semiarid; the humidity is low, the rate of evaporation is high, and the mean annual temperature is about 60°F. The average annual precipitation at Tatum is 16.20 inches, at Lovington 14.82 inches, and at Hobbs 15.26 inches. More than two-thirds of the annual precipitation falls during the growing season, which lasts from April through September. At Hobbs and Lovington the average number of frost-free days per year is 206 and at Tatum is 193 days per year. The average date of the last killing frost at Lovington is April 11 and the first killing frost is November 3. Climatological data, from records of the United States Weather Bureau (1953-59) are summarized in the following table for three stations in northern Lea County:

Station	Average annual precipitation (inches)	Mean annual temperature (°F)	Mean annual maximum temperature (°F)	Mean annual minimum temperature (°F)	Average number of frost-free days per year
Hobbs	15.26	60.8	75.4	45.6	206
Lovington	14.82	59.9	76.7	43.6	206
Tatum	16.20	58.8	74.5	42.1	193

ECONOMY

The economy of northern Lea County has changed gradually in the period 1929-60 from one based predominantly on stock raising and dry farming to one based on irrigated farming and the production of oil and gas.

Prior to 1929 most of the farmers in northern Lea County relied on precipitation for their crops. The general use of ground water for irrigation began during the drought of the early thirties; however, until 1946, irrigation was limited principally to small tracts in the vicinity of Lovington and Hobbs. The amount of irrigated acreage began to increase rapidly in 1946 and by 1954 nearly 93,000 acres were under irrigation; after 1954 the expansion continued but at a much reduced rate.

Most of the irrigated acreage (fig. 2) is between Tatum on the north, Hobbs on the south, the Texas border on the east, and an irregular northward-trending line about 15 miles west of Tatum and Lovington. In 1954 about 66 percent of the irrigated land was used to grow cotton, sorghum, and alfalfa; about 31 percent was used to raise vegetables, fruits, berries, oats, and wheat; and about 3 percent was devoted to pasture.

The Lea County Underground Water Basin (fig. 2), as redefined by the New Mexico State Engineer in 1952, is included in the northern Lea County area. Drilling for water in the declared basin is controlled by the New Mexico State Engineer so that the ground water can be conserved and the rights of prior users will be preserved to the extent possible. If the State Engineer determines that additional wells may seriously deplete the supply of water, he can close part or all of the basin to further appropriation of water.

The basin was declared under regulation by order of the State Engineer in 1931, but the amount of water pumped in the basin remained so small that it was not closed to further appropriation of ground water until December 31, 1948. The State Engineer extended the area of the basin October 1, 1952. Some parts were reopened to further appropriation on December 31, 1952 and on February 2, 1953. At present the declared basin includes an area of about 2,180 square miles.

About two-thirds of the cattle and almost all the other livestock in Lea County are raised in northern Lea County. Between 1929 and 1949 the value of all livestock and livestock products sold annually more than doubled. Since 1949, however, sales have steadily declined. The decline has been attributed to the redirection of effort from grazing management to farming and to the production of petroleum products.

The oil and gas industry, expanding rapidly since 1944, has become the most important segment of the northern Lea County economy. Between 1926, when the first oil well in Lea County was drilled near Maljamar, and January 1, 1955 when about 3,000 wells were in operation, more than 568 million barrels of oil and more than 939 million cubic feet of natural gas has been produced. Local plants during 1954 produced about 1½ million barrels of butane and propane, 1½ million barrels of gasoline, and 22 million pounds of carbon black from natural gas produced in southeastern New Mexico.

GEOLOGY AND GROUND WATER

Rocks of Precambrian through Cenozoic age underlie northern Lea County; however, only rocks of Mesozoic and Cenozoic age crop out in the area and only they are known to contain potable ground water. The Ogallala formation is the principle source of ground water in northern Lea County. The deposits of Quaternary age and the underlying rocks of Cretaceous and Triassic age generally yield only small amounts of water. Most of the sediments of pre-Mesozoic age contain brackish and saline water.

ROCKS OF PRE-MESOZOIC AGE

Granite and volcanic rocks of Precambrian age underlie the area at depths which range from 11,000 feet in the northwestern part to about 14,000 feet in the southeastern part (Flawn, 1956, p. 68, pl. 2). Ground water has not been reported in the rocks of Precambrian age and probably little occurs in them.

The rocks of Precambrian age are overlain unconformably (Barnes, and others, 1959, p. 25-26) by approximately 3,000 to 6,000 feet of limestone, dolomite, shale, and sandstone of Early Ordovician through Pennsylvanian age. Overlying the Pennsylvanian rocks are 8,000 feet of Permian rocks—about 5,000 feet of dolomite and limestone containing a small proportion of shale and sandstone, and about 3,000 feet of salt and anhydrite. In general, water in the rocks of Paleozoic age contains a large amount of dissolved solids and occurs with oil and gas.

Water discharges from the formations of Paleozoic age in two ways—produced with oil and as subsurface flow out of the area. The amount of subsurface flow is unknown, but records (New Mexico Oil and Gas Engineering Committee, 1952, 1954, and 1955) show that the amount of water pumped with oil from these formations was about 1,900 acre-feet in 1952 and approximately 2,400 acre-feet in 1954. By the end of 1954 about 20,500 acre-feet of water had been produced from 2,800 wells drilled since the start of oil production. Some wells did not yield any water while others produced several times the annual average of 7.35 acre-feet of water per well.

A source of recharge is the brine pumped from wells in Lea County into other wells which are bottomed in rocks of pre-Mesozoic age. In some cases this type of recharge is used primarily to repressure oil pools which thereby increases the recovery of oil and gas from the reservoir. In other cases the primary consideration is the removal of the fresh-water contamination hazard. In Lea County only a small proportion of the oil-field brines is currently (1960) artificially recharged to the rocks of pre-Mesozoic age.

ROCKS OF MESOZOIC AGE

Rocks of Mesozoic age in northern Lea County range in thickness from 1,400 to 2,100 feet and consist of shale and sandstone of Triassic age and siltstone and limestone of Cretaceous age.

The amount of water produced from rocks of Triassic and Cretaceous ages is small, but the small production does not necessarily indicate that the quantity available is insignificant. The meager production may be due in part to the general lack of exploration and development. Rocks of Mesozoic age have been penetrated by only a few water wells most of which are in the northern third of the area where the Ogallala formation is relatively thin and contains little water.

Rocks of Triassic age.—Rocks of the Dockum group of Triassic age unconformably overlie rocks of Permian age and range in thicknes from 1,400 to 2,000 feet (Nye, 1930, p. 370). The Dockum group underlies the entire area, but it is exposed only along the escarpment of the Mescalero Ridge from the southern part of T. 10 S., R. 31 E., to the northern part of T. 14 S., R. 31 E.

The Dockum group in northern Lea County comprises an upper part and a lower part that are distinctive but which grade into one another. The lower part of the group has a maximum thickness of 600 feet and consists mostly of reddish sandstone but includes a relatively small proportion of variegated shale and limestone. The upper part of the group has a maximum thickness of about 1,200 feet. This part is predominantly a reddish shale but includes minor amounts of variegated shale, sandstone, conglomerate, and limestone (Adams, 1929, p. 1051; Nye, 1932, p. 237-238).

Approximately 165 feet of the Dockum group is exposed in the SW¼ sec. 3, T. 11 S., R. 31 E. (Nye, 1932, p. 236). The lower 40 feet of the exposure consists of light-greenish-gray to grayish-green shaly sandstone that contains thin beds of chocolate-colored and greenish-colored shale and grit made up of shale pellets. Overlying the shaly sandstone is 30 feet of light-green and chocolate-colored sandy shale that includes thin beds of micaceous shaly sandstone. The sandy shale is overlain by 90 feet of poorly exposed chocolate-colored to reddish-brown shale that contains some green shale.

Silicified wood is the only fossil material reported found in the Dockum group in this area (Nye, 1932, p. 237).

The rocks of Triassic age usually can be distinguished from rocks of Permian age by the difference in color—the shale of Triassic age is deep purplish to brownish red while that of Permian age is generally brick red—and by the presence of mica flakes in the rocks of Triassic age.

The rocks of Triassic age contain some water but they are not considered to highly productive aquifers. Seven wells in northern Lea County obtain water from the upper part of the Dockum group. Several wells in southern Lea County also tap the Dockum group and it is possible that more water could be developed in the rocks of Triassic age in northern Lea County.

Rocks of Cretaceous age.—The Tucumcari shale of Cretaceous age unconformably overlies the Dockum group in the northeastern part of Lea County. A few shot-hole logs from south of Lovington record gray, blue, yellow, and green shale which may be Cretaceous in age as reported by Bates (1942, p. 269).

The fossils listed below, which were collected at North Lake in sec. 32, T. 10 S., R. 34 E., were identified: *Serpula?* sp., *Gryphaea corrugata* Say, *Exogyra texana* Roemer, *Exogyra plexa* Cragin, *Pecten (Neithea) texanus* Roemer?, and *Plicatula* cf. *incongrua* Conrad. The fossils indicate that the enclosing rocks are of Early Cretaceous age and probably are equivalent to the Tucumcari shale.

The Tucumcari shale generally consists of fossiliferous dark gray siltstone and thin beds of brownish sandy limestone, grayish limestone and sandstone. In outcrops the siltstone beds weather to yellow and the sandy limestone beds usually have the appearance of yellowish sandstone because weathering dissolves the calcium carbonate from around the sand grains.

The Tucumcari shale is about 150 feet thick in the northeast corner of Lea County but it thins southwestward and pinches out along an irregular line extending from T. 9 S., R. 33 E., to T. 14 S., R. 38 E.

The Tucumcari shale crops out along the western and northern edges of North Lake, and, reportedly, along the eastern edge of Ranger Lake (Conover and Akin, 1942, p. 286) and along the northwestern part of Middle Lake (Dane and Bachman, 1958). The greatest observed thickness of the Tucumcari shale is in a gully on the west side of North Lake where a composite section approximately 17 feet thick was measured. The Tucumcari at the exposure consists of dark gray siltstone and thin interbedded stringers of limestone. Several of the stringers wedge out laterally into siltstone. In the lower part the stringers are light brown, sandy, crystalline limestone; in the upper part they are light gray and fine grained. Here the contact between the Tucumcari shale and the overlying alluvium is exposed and is unconformable. Fragments of Lower Cretaceous fossils and of the Tucumcari shale were noted in the alluvium at this outcrop.

Limited quantities of ground water occur in the Tucumcari shale. Beds of sandstone near the base of the formation constitute the principal aquifer.

Water is pumped from several wells which penetrate the rocks of Cretaceous age. At one time some of the water in these rocks was under sufficient artesian pressure to flow at land surface, but since 1940 all the artesian wells in the area have gradually ceased to flow. Well owners generally attribute the cessation of flow to the widespread drilling of shotholes for seismic surveys. The shotholes penetrated the water-bearing stratum and since the holes were not cased the artesian water leaked into the overlying Ogallala formation and dissipated the hydraulic pressure.

The characteristics of a well in the SW¼ sec. 20, T. 12 S., R. 37 E., which produces water from rocks of Cretaceous age have been studied by the U.S. Geological Survey (Conover and Akin, 1942). The well was completed in 1940 at a total depth of 185 feet. Sediments of Cretaceous age were penetrated from 25 feet below land surface to the bottom of the well, and artesian water was found in a bed of sand at a depth of 188 to 185 feet. The well flowed about 25 gpm (gallons per minute) when first drilled and had a static head of about 14 feet above land surface; reportedly, flow ceased about 1946.

DEPOSITS OF CENOZOIC AGE

Deposits of Cenozoic age in northern Lea County range in thickness from 0 to 350 feet and consist of continental deposits of Pliocene age and sand and alluvium of Pleistocene and Recent ages. The Cenozoic formations crop out over most of the area.

The erosional surface that underlies formations of Cenozoic age was cut on rocks of Mesozoic age. The slope of the sur-

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