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Geology and Ground-Water Resources of Northern Lea County, New Mexico

Sidney R. Ash

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Most of the potable ground water is obtained from the Ogallala

formation of Tertiary age and the deposits of alluvium and sand of

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ABSTRACT

The economy of northern Lea County is dependent upon ground water; the only other source of water is the runoff from precipitation that is caught and retained in man-made or natural reservoirs, where it is used for watering stock. Irrigation utilizes most of the ground water pumped; much smaller amounts are used for stock watering and industrial, public, and rural domestic supplies. In 1958, about 107,000 acre-feet of ground water was pumped for irrigation and 19,000 acre-feet was pumped for all other uses. On the basis of present production of potable water, the economically usable supply will be depleted in certain areas within about 40 years.

Most of the potable ground water is obtained from the Ogallala formation of Tertiary age and the deposits of alluvium and sand of Quaternary age. A small amount of potable ground water is pumped from the rocks of Triassic and Cretaceous age. The rocks of Permian and older ages contain impotable water, which is produced as a by-product from many oil and gas wells in the area.

Water from wells penetrating the Ogallala formation generally contains 350 to 550 parts per million of dissolved solids and has a specific conductance ranging from 500 to 800 micromhos. The water, though generally hard, is suitable for domestic, irrigation, and many industrial uses. The deposits of Triassic, Cretaceous and Quaternary

age yield water that is generally more mineralized than water from the Ogallala but which is usable for most purposes. The water produced from formations of pre-Mesozoic age in conjunction with oil is highly mineralized and cannot be used for ordinary purposes. Generally, the brine is placed in unlined pits to evaporate.

Potable ground water in parts of northern Lea County is being contaminated by oil-field brines that have infiltrated from disposal pits to the aquifer, and, unless remedial measures are taken, much of the potable ground water will in time be contaminated by brines.

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INTRODUCTION

Northern Lea County is one of the many areas in New Mexico in which ground water is being mined; that is, more water is being withdrawn from the ground-water reservoir both by natural means and by pumping for irrigation, municipal, stock, and industrial use than is being recharged to the reservoir. The magnitude of the pumping and the volume of the water in storage are such that in places the depletion of the reservoir may be measured in a few tens of years on the basis of the rate of use of water in 1953.

The State Engineer of New Mexico declared the Lea County Underground Water Basin subject to regulation in 1931 to regulate the development of water in this area. New Mexico water policy is based on the philosophy that the withdrawal of water from an area of ground-water mining should be limited to a rate that will permit amortization of the investment in farms irrigated with ground water over a period of 40 years (Reynolds, 1960, p. 233-234). In parts of northern Lea County, the ground-water supply is considered to be fully appropriated. In these areas the users of ground water for irrigation can expect about 40 years of supply at the rate of use in 1953 and extending from that date, unless additional supplies are discovered in deeper water-bearing formations, more economical methods of irrigation are used, or there is a change in climate so that recharge increases. There

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will remain in storage at the end of the period sufficient water for stock and municipal use and, to some extent, water for industrial use for many years to come. In other parts of the declared basin water was still unappropriated in 1960.

The purpose of this thesis is to make available information on the ground-water reservoir in northern Lea County, New Mexico, an area dependent chiefly on ground water for its water supply. The saturated thickness of the principal ground-water reservoir and, indirectly, the volume of water in storage in northern Lea County is shown by means of maps. The depth to water and areas in which water levels have declined in the past several years are shown on other maps. The report was prepared as a part of the general program of ground-water investigations being made by the U. S. Geological Survey in cooperation with the State Engineer office of New Mexico. The information contained herein should lead to a better understanding of the availability of water in this important part of the State.

Escarpment of
the High Plains
Location and extent of the area

Area included
in this report

The area described contains about 2,900 square miles in southeastern New Mexico and includes northern Lea County and small parts of Chaves and Eddy Counties (fig. 1). The area is bounded on the east by the New Mexico-Texas State line, on the north by the Chaves and Roosevelt County lines and on the west and south by Mescalero Ridge.

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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.

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Generalized reports on the geology of the area have been made in connection with regional investigations concerned primarily with the suggestions and encouragement given by my co-workers in the local oil and gas-producing formations of Paleozoic age; few data have been published on the younger rocks that contain potable ground water.

Selected references pertaining to the geology and hydrology of Lea County are listed at the end of this text. A network of observation wells has been maintained on a continuing basis for a number of years by the U. S. Geological Survey in cooperation with the State Engineer Office.

Related data such as the amount of water withdrawn from the reservoir have also been collected and published in Water-Supply Papers and the Technical Report series of the State Engineer Office.

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This thesis is an outgrowth of work begun in 1952 by the U. S. Geological Survey to define the thickness of the zone of saturation of the Ogallala formation, the principal aquifer in northern Lea County. I was assigned to the project during the summer of 1957 and my report, which is in the final stages of completion, will be published as a Hydrologic Atlas by the U. S. Geological Survey.

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Shallow closed depressions, sometimes called buffalo wallows, are the most characteristic topographic features on the Llano Estacado. The floors of the depressions generally range in area from a few

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GEOGRAPHY

Topography and drainage

Northern Lea County is on the west side of the Llano Estacado, which is the southern extension of the High Plains in southeastern New Mexico and western Texas (fig. 1) (Fenneman, 1931, p. 9). The Llano Estacado, or southern High Plains, is a plateau which stands about 100 to 300 feet above the surrounding region (fig. 2). The general surface of the Llano is smooth and slopes to the southeast at 10 to 20 feet per mile. Mescalero Ridge, a steep escarpment which faces the Pecos Valley (figs. 1, 2, and 3), forms its western and southwestern boundary and is also the boundary between the High Plains and Pecos Valley sections of the Great Plains Province (Fenneman, 1931, p. 9). The steep front along the ridge from T. 9 S. to End Point in T. 19 S. is broken by broad reentrants, such as Sand Gate in the northwestern part of the area, and narrow reentrants, such as Polecat Canyon in the southern part of T. 10 S., R. 31 E., through which U. S. Highway 380 passes from the Pecos valley onto the Llano Estacado.

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Figure 4. -- A shallow closed depression which has been modified into a stock-watering tank. View looking south in sec. 28, T. 16 S., R. 31 E.

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Figure 3.--Mescalero Ridge showing the cap rock of weather-resistant caliche which is about 20 feet thick in this area. Mescalero Spring emerges at the base of the escarpment near the large trees in the foreground. View looking north in sec. 28, T 11 S., R. 31 E.

Figure 4.--A shallow closed depression which has been modified into a stock-watering tank. View looking south in sec. 28, T. 16 S., R. 33 E.

acres; the average size is probably about 1 acre. The depth of the depressions generally ranges from 1 to 50 feet. Some of the depressions have been sealed or dammed by ranchers for use as tanks for watering livestock (fig. 4). The approximate location and outline of the depressions larger than 6 acres in a part of the area are shown on figure 5. Some of the depressions contain perennial lakes, but most of them contain water only during the summer rainy season (fig. 6).

The drainage on the Llano Estacado generally is not integrated; a few of the depressions, however, are connected by shallow and superficial drainageways. Drainage into the depressions is mainly from the northwest. Much of the runoff from precipitation is caught in the depressions, where the water remains until it infiltrates, is lost by evaporation, or is consumed by plants. A shallow broad swale called Simanola Valley originates east of Sand Gate and terminates a few miles northwest of Tatum.

Six perennial lakes occur in the northern part of the area. The two largest are Lane Salt Lake (T. 10 S., R. 33 E.), 7 miles northeast of Caprock, and Ranger Lake (T. 11 S., R. 36 E.), 8 miles north of Tatum. Four Lakes (T. 11 S., R. 34 E.) is the collective name for the four small lakes about 12 miles northwest of Tatum.

Figure 5. - Map showing the distribution and form of shallow closed depressions larger than 6 acres in the vicinity of Midland, New Mexico.

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R 32 E

R 33 E

For the purpose of this report, however, they will be referred to individually as North Lake, East Lake, Middle Lake, and South Lake (fig. 2).

Springs and seeps are present in the beds or on the margins of several of the lakes. North Lake has several islands on which seeps are found (fig. 7). Water in all the perennial lakes is brackish and is derived from both surface runoff and underground inflow.

LLANO Soils

The soils in northern Lea County are loam, sandy loam, clay loam and clay (Harper and Smith, 1935). The distribution of the various soil types in most of northern Lea County is shown on Harper and Smith's map (1935). Figure 8 which is modified from their map shows the occurrence of the various soil types in T. 16 S., R. 37 E., northwest of Hobbs.

The loams, which average 3 feet in thickness, are the thickest and most productive soils. They generally occur in long, narrow, subparallel strips which vary in width and length but nearly always trend in a southeasterly direction. In places these strips have knots or ganglion-like enlargements. These enlargements seem to have a somewhat systematic distribution, a large number occur along approximately the same meridional line or belt and are perpendicular

EXPLANATION

ESCARPMENT OF THE HIGH PLAINS

SHALLOW CLOSED DEPRESSIONS

SCALE

Figure 5.--Map showing the distribution and form of shallow closed depressions larger than 6 acres in the vicinity of Maljamar, New Mexico.

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Figure 5. Map showing the distribution and form of shallow closed depressions larger than 10 acres in the vicinity of McIntosh, New Mexico.

Figure 6.--A shallow closed depression containing water a few days after a rainstorm. Oil well in right foreground. View looking northwest in sec. 26, T. 13 S., R. 31 E.

Figure 7.-- A small island in the bed of North Lake (the fence surrounds a seep on the island). View looking northeast in sec. 3, T. 11 S., R. 34 E.

to the trends of the strips. One such belt runs northeastward by the Lovington and another runs parallel to it about 7 miles east of Lovington. The two belts unite into a large irregular "ganglion" about 12 miles northeast of Lovington.

Generally only clay is found on the floors of the shallow closed depressions because coarser materials are deposited at the margins when water flows to the depressions; only very fine materials can be carried by the weak currents in the ephemeral lakes. Usually the clay is only a few inches thick and lies directly on the caprock.

Areas of sand which are characterized by sand dunes or rolling topography vary in thickness and cover the other soils along the Texas border and in the northern part of the report area. Generally the sand occurs as patches, although in places it is found in long narrow southeastward-trending strips which parallel the strips of loam.

It is characterized chiefly by a thin layer of sandy loam containing a large quantity of hard caliche fragments and directly overlies the caprock. The soil in the scrub land is too thin to be of value for cultivated crops but in most places it supports a dense growth of weeds and grass.

The northwest-southeast lineation of the strips of loam and of the sand is illustrated on the Harper and Smith soil map of the area

Figure 3. Map showing the distribution of the various soil types northwest of Hobbs, New Mexico in 1933.

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Climature

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 Tatum and Lovington the average number of frost-free days per year is 206 and at Hobbs 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.

Figure 8. -- Map showing the distribution of the various soil types northwest of Hobbs, New Mexico in T. 18 S., R. 27 E.

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EXPLANATION

Lea loam

Lea silty clay loam

Reagan fine sandy loam

Lea clay

Reagan loam

Scab land

SCALE

Figure 8. --Map showing the distribution of the various soil types northwest of Hobbs, New Mexico in T. 18 S., R. 37 E.

EXPLANATION

Figure 2. Map showing the distribution of the various soil types north of Mexico, New Mexico.

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 stock raising and dry farming to irrigated farming and the production of oil and gas.

Prior to 1929 most farmers in northern Lea County relied on precipitation. Local use of ground water for irrigation began near Lovington and Hobbs during the drought of the early thirties. The

irrigated acreage increased rapidly after 1946 and by 1954 more than 93,000 acres were under irrigation; since 1954 the expansion has continued at a reduced rate.

Most of the irrigated acreage (fig. 9) is between Tatum on the north, Hobbs on the south, the Texas border on the east, and an irregular north-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 re-defined 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 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

Figure 9.--General location of cultivated acreage in northern Lea County, New Mexico, during 1953.

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 of 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, but since 1949 sales have declined because of the change from ranching to farming and the petroleum industry.

The oil and gas industry, expanding rapidly since about 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 were produced. Local plants during 1954 also produced about 1-1/2 million barrels of butane and propane, 1-1/2 million barrels of gasoline, and 22 million pounds of carbon black from natural gas produced in southeastern New Mexico.

Foot of limestone, dolomite, shale, and sandstone of Ordovician through Pennsylvanian age. Overlying the rocks of Pennsylvanian age are about 1,000 feet of dolomite, and limestone, shale and sandstone, and about 1,000 feet of salt and anhydrite of Permian age.

acres; the average size is probably about 1 acre. The depth of the depressions generally ranges from 1 to 50 feet. Some of the depressions have been sealed or dammed by ranchers for use as tanks for watering livestock (fig. 4). The approximate location and outline of the depressions larger than 5 acres in a part of the area are shown on figure 5. Some of the depressions contain perennial lakes, but most of them contain water only during the summer rainy season (fig. 6).

The drainage on the Llano Estacado generally is not integrated; a few of the depressions, however, are connected by shallow and superficial drainageways. Drainage into the depressions is mainly from the northwest. Much of the runoff from precipitation is caught in the depressions, where the water remains until it infiltrates, is lost by evaporation, or is consumed by plants. A shallow broad waste called Simanella Valley originates east of Sand Gate and terminates a few miles northwest of Tatum.

Six perennial lakes occur in the northern part of the area. The two largest are Lane Salt Lake (T. 10 S., R. 33 E.), 7 miles northeast of Caprock, and Ranger Lake (T. 11 S., R. 36 E.), 8 miles north of Tatum. Four lakes (T. 11 S., R. 34 E.) is the collective name for the four small lakes about 12 miles northwest of Tatum.

GEOLOGY AND GROUND WATER

Rocks of Precambrian through Cenozoic age underlie northern Lea County, but only rocks of Mesozoic and Cenozoic age crop out and only they are known to contain potable ground water. The Ogallala formation of Tertiary age is the principal aquifer. Deposits of Triassic, Cretaceous and Quaternary age generally yield only small amounts of water. Most of the rocks 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 Precambrian rocks 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 Ordovician through Pennsylvanian age. Overlying the rocks of Pennsylvanian age are about 5,000 feet of dolomite, and limestone, shale and sandstone, and about 3,000 feet of salt and anhydrite of Permian age.

GEOLOGY AND GROUND WATER

Rocks of Precambrian through Cenozoic age underlie northern Lee County, but only rocks of Mesozoic and Cenozoic age crop out and only they are known to contain potable ground water. The Ogallala formation of Tertiary age is the principal aquifer. Deposits of Tertiary, Cretaceous and Quaternary age generally yield only small amounts of water. Most of the rocks of pre-Mesozoic age contain brackish and saline water.

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Water discharges from the formations of Paleozoic age in
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area. The amount of subsurface flow is unknown, but is probably
relatively small because of the low dip. 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 whereas 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 oil wells in
Lea County into other wells which are bottomed in formations of pre-
Mesozoic age. In some cases this type of recharge is used primarily
to repressure oil pools, increasing the recovery of oil and gas from
the reservoir. In other cases the primary consideration is the re-
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Mesolero Ridge from the southern part of T. 10 S., R. 31 E. to
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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 lack of exploration. Rocks of Mesozoic age have been penetrated by only a few water wells, most of them 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 thickness from 1,400 to 2,000 feet (Nye, 1930, p. 370). The Dockum group underlies the entire project area, but it is exposed only along the escarpment of Mescalero Ridge from the southern part of T. 10 S., R. 31 E. to the northern part of T. 14 S., R. 31 E. (fig. 10).

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overlie rocks of Permian age and range in thickness from 1,400 to
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entire project area, but it is exposed only along the escarpment of
Mesquero Ridge from the southern part of T. 10 S., R. 31 E. to
the northern part of T. 14 S., R. 31 E. (fig. 10).

The Dockum group in northern Lea County includes two members which are distinctive but grade into each other. The lower member has a maximum thickness of 600 feet and consists mostly of reddish sandstone and a smaller amount of variegated shale and limestone. The upper member has a maximum thickness of about 1,200 feet. It is predominantly a reddish shale but includes minor amounts of variegated shale, sandstone, conglomerate, and limestone (Adams, 1929, p. 1051; Nye, 1932, p. 236-238).

Approximately 165 feet of the upper part of the Dockum group is exposed in the SW 1/4 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 conglomerate 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 in the Dockum group in this area (Nye, 1932, p. 237).

The upper part of the Dockum group has been known for many years (Adams, 1929, p. 1051; and 1930, p. 114; Coates and Akin, 1942, p. 228-229; Nye, 1932, p. 236-238; and Fenn and Beckman, 1953), but it has not been related to the Dockum group in the subsurface.

The Dockum group in northern Lee County includes two members which are distinctive but grade into each other. The lower member has a maximum thickness of 600 feet and consists mostly of reddish sandstone and a smaller amount of variegated shale and limestone. The upper member has a maximum thickness of about 1,200 feet. It is predominantly a reddish shale but includes minor amounts of variegated shale, sandstone, conglomerate, and limestone (Adams, 1929, p. 1021; Nye, 1932, p. 236-238).

Approximately 155 feet of the upper part of the Dockum group is exposed in the SW 1/4 sec. 3, T. 11 N., R. 31 E., (Nye, 1932, p. 236). The lower 40 feet of the exposure consists of light-greenish-gray to grayish-green sandy sandstone that contains thin beds of chocolate-colored and greenish-colored shale and conglomerate made up of shale pebbles. Overlying the sandy sandstone is 30 feet of light-green and chocolate-colored sandy shale that includes thin beds of micaceous sandy sandstone. The sandy shale is overlain by 20 feet of poorly exposed chocolate-colored to reddish-brown shale that contains some green shale.

Silicified wood is the only fossil material reported in the

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Rocks of Cretaceous age reportedly crop out in two other places in

The rocks of Triassic age usually can be distinguished from the county (Conover and Akin, 1942, p. 150; Dane and Bachman, 1958), but I could not find them reported in the area of the reported outcrop at Ranger. These rocks are Triassic age actually. The rocks are brick red to brownish red while that of Permian age is generally brick red -- and by the presence of muscovite mica flakes in the rocks of Triassic age.

The rocks of Triassic age contain some water but are not highly productive. At least seven wells in northern Lea County obtain water from the upper part of the Dockum groups, as do several wells in southern Lea County. It is possible that more water could be developed in the rocks of Triassic age in northern Lea County, but since none of the wells that produce water from the Dockum group in northern Lea County have been tested, their potential yield is unknown. However, in southern Lea County comparable wells that have been tested yield from about 6 gallons per minute (gpm) to a probable maximum of 100 gpm (Nicholson and Clebsch, U.S. Geological Survey, written communication).

1938 by T. W. Stanton (written communication to C. V. Theis) of the Paleontology Branch, U. S. Geological Survey.

Rocks of Cretaceous Age

Rocks of Cretaceous age are exposed at only one locality in northern Lea County, but their subsurface distribution is extensive (fig. 11). The outcrop at North Lake has been known for many years (Theis, 1934, p. 147, and 1938, p. 124; Conover and Akin, 1942, p. 285-288; Lang, 1947, p. 1476; and Dane and Bachman, 1958), but it has not been related to the Cretaceous rocks in the subsurface.

The rocks of Triassic age usually can be distinguished from rocks of Permian age by their 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 muscovite mica flakes in the rocks of Triassic age.

The rocks of Triassic age contain some water but are not highly productive. At least seven wells in northern Lee County obtain water from the upper part of the Dockum group, as do several wells in southern Lee County. It is possible that more water could be developed in the rocks of Triassic age in northern Lee County, but since none of the wells that produce water from the Dockum group in northern Lee County have been tested, their potential yield is unknown. However, in southern Lee County comparable wells that have been tested yield from about 6 gallons per minute (gpm) to a probable maximum of 100 gpm (Nicholson and Clebsch, U.S. Geological Survey, written communication).

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Rocks of Cretaceous age reportedly crop out in two other places in the county (Conover and Akin, 1942, p. 286; Dane and Bachman, 1958), but I could not find these exposures. In the area of the reported outcrop at Ranger Lake rocks of Cretaceous age actually lie 25 to 50 feet below the surface.

Exposures

The rocks of Cretaceous age at North Lake consist of dark gray siltstone and thin interfingering stringers of limestone (fig. 12). In the lower part of the section that was measured the limestone stringers are light-brown and crystalline; in the upper part they are light gray and fine grained. Siltstone and limestone both weather yellow.

The fossils listed below were collected by C. V. Theis from the outcrop in sec. 32, T. 10 S., R. 34 E., about 500 feet north of the section that was measured, and were identified in 1935 by T. W. Stanton (written communication to C. V. Theis) of the Paleontology and Stratigraphy Branch, U. S. Geological Survey.

Figure 12. -- Composite stratigraphic section of rocks exposed on the west side of North Lake, sec. 32, T. 10 S., R. 34 E.

Gryphaea corrugata Say

Exogyra texana Roemer

Plicatula cf. incongrua Conrad

Rocks of Cretaceous age reportedly crop out in two other places in the county (Conover and Akin, 1942, p. 286; Dane and Bachman, 1958), but I could not find these exposures. In the area of the reported outcrop at Ranger Lake rocks of Cretaceous age actually lie 25 to 50 feet below the surface.

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Gryphaea corrugata Say

Enogyra texana Roemer

Phacelia cf. incognita Conrad

Figure 12.--Composite stratigraphic section of rocks exposed on the west side of North Lake, sec. 3, T. 11 S., R. 34 E.

Figure 12. - Composite stratigraphic section of rocks exposed on the west side of North Lake, section T. 11 S., R. 24 E.

Exogyra plexa Cragin

Pecten (Neithea) texanus Roemer ?

Serpula (?) sp.

These fossils indicate that the enclosing rocks are of latest Early Cretaceous age.

Exogyra texana, Gryphaea corrugata, and Plicatula sp. have been found in the Tucumcari shale in east-central New Mexico (Dobrovolsky and Summerson, 1946). On the basis of the similarity of the fossil assemblage and lithology the rocks at North Lake are correlated with the Tucumcari shale.

Subsurface occurrence

The principal criteria for determining the distribution of the Tucumcari shale in the subsurface (fig. 11) consist in references in drillers' logs to 5 or more feet of "yellow," "blue," or "gray" clay or shale, which are descriptive of other units in the area. In some places sample descriptions by geologists and fossils in drill cuttings have strengthened the interpretations. Some of the drillers' logs that were used list limestone or sandstone with the clay or shale. Many logs mention gravel or coarse sand between the recognizable Cretaceous and the Triassic rocks.

Cretaceous and the Tertiary rocks.

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Serpula (?) sp.

Pecten (Neithes) texanus Roemer ?

Exogyra flexa Cragin

Except for the sand and gravel, the drillers' logs are like the description of rocks at North Lake; therefore, the subsurface rocks are tentatively assigned to the Tucumcari shale. Although the sand and gravel may be correlatives of the lower part of the Trinity or Fredericksburg groups farther east in Texas rocks, they are referred to the Tucumcari. The Tucumcari shale lies as a continuous deposit unconformably on the eastward dipping red shales of the Dockum group of Late Triassic age. It is nearly horizontal, and is overlain unconformably by the Ogallala formation and by sand, soil, and alluvium of Quaternary age. The erosional unconformity at the base of the Tucumcari shale dips eastward at about 20 feet per mile, or a little more than the slope of the land surface, whereas the unconformity at the base of the Ogallala dips eastward at about 10 feet per mile, a little less than the slope of the land surface. Thus the Tucumcari shale in cross-section appears as a wedge, thinning to the west, between the Dockum group of Triassic age and the Ogallala formation of Tertiary age (fig. 13).

The main body of Tucumcari shale ranges in thickness from 0 to nearly 200 feet, but generally ranges between 50 and 100 feet. It is thickest in the northeastern part of the county and thins gradually to the west, pinching out along an irregular line from T. 9 S., R. 33 E., to T. 14 S., R. 38 E.

Figure 13. - Cross-section along A-A' from Mescalero Ridge to the New Mexico-Texas State line in Northern Lea County, New Mexico.

of carbon black from natural gas produced in southeastern New Mexico. and propane, 1-1/2 million barrels of gasoline, and 32 million pounds plants during 1954 also produced about 1-1/2 million barrels of butane than 939 million cubic feet of natural gas were produced. Local were in operation, more than 568 million barrels of oil and more drilled near Majanar, and January 1, 1955, when about 3,000 wells economy. Between 1950, when the first oil well in Lee County was has become the most important segment of the northern Lee County

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change from ranching to farming and the petroleum industry.

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and 1949 the value of all livestock and livestock products sold annually

stock in Lee County are raised in northern Lee County. Between 1959

About two-thirds of the cattle and almost all of the other live-

miles.

present the declared basin includes an area of about 5,180 square

vation on December 31, 1952, and on February 2, 1953. At

basin October 1, 1952. Some parts were reopened to further appro-

There are two large depressions in the surface of the main body of the Tucumcari shale north of Tatum, the southernmost of which is beneath the land surface depression containing Ranger Lake. The closed depressions in the top of the Tucumcari indicate subsidence after deposition. Incomplete data suggests that the Tucumcari shale thickens beneath the depression, and this, if true, would indicate that there was subsidence in the area before the Tucumcari shale was deposited.

The four small subsurface outliers of Tucumcari shale shown on the map, west and south of the main body are relatively thin, ranging from 0 to 50 feet in thickness and averaging about 20 feet in thickness.

South of the areas in which the Tucumcari shale can be mapped are several sporadic occurrences of the Tucumcari. The thicknesses reported range from about 5 feet to a little more than 100 feet. Most of these areas contain shot holes for which the drillers did not note the diagnostic colors or types of rock. These occurrences, however, may reflect only the wide range in accuracy and quality of the drillers' logs. Cretaceous rocks may actually be somewhat more widespread in the subsurface than shown in figure 11, but the data are too scarce to outline additional areas.

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Small quantities of ground water occur in the Tucumcari shale. The beds of coarse sand and gravel near the base of the formation constitute the principal aquifer.

Water is pumped from several wells that penetrate the rocks.

At one time some of the water was under sufficient artesian pressure

that wells flowed, but since 1944 all of the artesian wells in the

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trated the water-bearing zone and, since they were not cased, the

artesian water leaked into the overlying Ogallala formation and dis-

sipated the artesian head.

The characteristics of a well in the SW 1/4 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. Sedi-

ments 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 183 to 185 feet. The well flowed about

25 gpm when first drilled and had a static head of about 14 feet above

land surface; flow ceased in about 1946. On January 10, 1960 the

The Ogallala formation ranges in thickness from 0 to about 340 feet and averages approximately 200 feet. It is thickest near

Ground water

Small quantities of ground water occur in the Tucuman shales. The beds of coarse sand and gravel near the base of the formation constitute the principal aquifer. Water is pumped from several wells that penetrate the rocks. At one time some of the water was under sufficient artesian pressure that wells flowed, but since 1944 all of the artesian wells in the area have gradually ceased to flow. Well owners attribute this to the drilling of shot holes for seismic surveys. The shot holes penetrated the water-bearing zone and, since they were not cased, the artesian water leaked into the overlying Ogallala formation and dissipated the artesian head.

The characteristics of a well in the SW 1/4 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 183 to 185 feet. The well flowed about 25 gpm when first drilled and had a static head of about 14 feet above land surface; flow ceased in about 1946. On January 10, 1960 the

water level of this well was 25.76 feet below land surface (J. S. Havens, U.S. Geological Survey, written communication, 1960).

Deposits of Cenozoic age

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

Underlying the deposits of Cenozoic age is an erosional surface cut on rocks of Mesozoic age. The slope of the surface is generally southeastward and the relief is moderate (figs. 11 and 13). Two cycles of erosion of the bedrock surface are indicated by the contour map. Stream channels found beneath the Ogallala formation trend southeastward and probably were cut during early Tertiary time. Stream channels beneath the alluvium south of Mescalero Ridge trend southward and were cut during the Cenozoic era after the Ogallala formation had been removed by erosion.

Ogallala formation

The Ogallala formation of Pliocene age lies unconformably on rocks of Mesozoic age. It underlies the Llano Estacado everywhere except in a few small areas where it has been removed by erosion.

The Ogallala formation ranges in thickness from 0 to about 350 feet and averages approximately 200 feet. It is thickest near

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Ogallala formation

The Ogallala formation of Pliocene age lies unconformably on rocks of Mesozoic age. It underlies the Llano Estacado everywhere except in a few small areas where it has been removed by erosion. The Ogallala formation ranges in thickness from 0 to about 350 feet and averages approximately 500 feet. It is thickest near

Mescalero Ridge in Tps. 14 and 15 S., Rs. 31 and 32 E. Near Lovington and McDonald it ranges from 75 to 225 feet and averages about 150 feet. Most of the variation in thickness is due to irregularities of the unconformity on which the Ogallala formation was deposited rather than to post-Ogallala erosion (Nye, 1930, p. 369).

The Ogallala is a continental deposit of fine to very fine sand and minor quantities of clay, silt, coarse sand, and gravel. Its lower one-quarter contains a higher proportion of coarse sediments than the upper three-quarters. Usually the coarse sediments occur as lenticular beds in the finer material. Extensive beds of coarse sand and gravel are found in some of the buried stream channels cut into the Mesozoic bedrock.

The Ogallala has generally been interpreted as a fluvial apron that was deposited east of the Rocky Mountain front. The probable source areas for the Ogallala formation in northern Lea County were the Sierra Blanca, Jicarilla, Capitan, Sacramento and Guadalupe mountains to the west. It is generally believed that the formation extended west to these ranges in southern New Mexico prior to the northward advance of the Pecos River in Quaternary time. The southeasterly slope of the Llano appears to be the original depositional slope of the formation and the present surface of the Llano can be correlated with a cut surface which truncates the structure on the north slope of the Sacramento Range.

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are found in some of the buried stream channels cut into the Mesozoic beds in the finer material. Extensive beds of coarse sand and gravel upper three-quarters. Usually the coarse sediments occur as lenticular one-quarter contains a higher proportion of coarse sediments than the and minor quantities of clay, silt, coarse sand, and gravel. Its lower The Ogallala is a continental deposit of fine to very fine sand rather than to post-Ogallala erosion (Wye, 1930, p. 369).

ties of the unconformity on which the Ogallala formation was deposited about 150 feet. Most of the variation in thickness is due to irregular- Lovington and McDonald it ranges from 75 to 225 feet and averages Mescalero Ridge in Tps. 14 and 15 S., R. 31 and 32 E., Near

Figure 14. --A house with outer walls made of blocks of caliche. View looking west in sec. 31, T. 12 S., R. 38 E.

J Harlan Bretz and Leland Horberg (1949a, p. 478) describe the deposition of the Ogallala formation as follows:

"The deposit...originated as a great alluvial plain or bajada on which various mountain-born streams debouched, deposited, wandered, divided into shifting distributaries, probably provided the fines for associated wind transportation and deposition in the changing interstream areas."

Most of the formation is unconsolidated, although near the top, and locally lower, the sediments have been cemented by calcium carbonate to form beds of caliche. The degree of cementation of the caliche varies greatly. In general, the Ogallala is most firmly cemented near the top of the formation and where the sediments are fine and contain much silt.

The bed of caliche at the top of the formation forms topographic prominences because of its resistance to erosion. It occurs at the top of most plateaus in the southern High Plains and is called the cap rock. There is no sharp break between the caliche and the underlying sediments because the amount of cement decreases gradually. In some places the cap rock is so dense that it breaks with a semiconchoidal fracture; elsewhere it may be soft and chalk-like. Usually it is not stratified, but locally it is flaggy and used as building material (fig. 14). The partially cemented material beneath the cap rock is used as road metal, particularly in the oil and gas fields. Sand and gravel from the Ogallala formation is used in construction and road building.

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The origin of the caliche cap rock has been a subject of much discussion and considerable controversy. The principal hypotheses are summarized below.

Elias (1931) described it as "Algal" limestone and reported its occurrence at the top of the Ogallala in Kansas. More recent work (Price, Elias, and Frye, 1946, p. 1744) has shown that algal limestone is also found in southeastern New Mexico in the same stratigraphic position. According to Elias (1931, p. 141) "...This rock was deposited on the nearly flat bottom of a very large and very shallow lake at the close of Ogallala time." However it is difficult to explain the origin of the extensive ponding on the surface of the High Plains which would be necessary to substantiate this hypothesis. Theis' (1936, p. 391) proposal that the lakes were small and discontinuous makes the basic algal-limestone hypothesis more tenable. If the structures attributed to algae were actually formed by algal growths they were of very minor importance according to Bretz and Horberg (1949b, p. 508) and did not form much of the cap rock.

It has been suggested that ascending ground water formed the cap rock. Bretz and Horberg (1949b, p. 508-509) dismiss this theory because of the downward penetration of caliche into impervious shales and its occurrence "...on slopes where solutions could never be brought to the surface by capillarity."

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A third hypothesis attributes the cap rock to a soil-forming process which Bretz and Horberg (1949b, p. 509) describe as follows:

"The caliche profile development is believed to be best explained by conditions of alternating saturation and desiccation in a relatively dry climate with periodic rains. Solution occurred as the soil waters moved downward during a rainy period, and precipitation took place with the capillary rise of saturated alkaline solutions as the soil dried out."

This theory is substantiated by the abrupt climatic change toward aridity that occurred in the Great Plains at the end of Pliocene time as indicated by geomorphological, stratigraphic and organic evidence (Frye and Leonard, 1957, p. 8).

In the southern High Plains of Texas the Ogallala group has been divided into two formations on the basis of lithology and fossil content (Evans, 1956, p. 17-22). The older member is the Couch formation of early Pliocene age. It consists of cross-bedded sands and gravels at the base, overlain by well-sorted slightly consolidated calcareous and clayey sands. The Birdwell formation unconformably overlies the Couch formation. It is of middle Pliocene age and consists of bedded unconsolidated sands and clays. A thick channel deposit of sand and gravel is usually present at the base. The upper part of the formation has been cemented by calcium carbonate to form the characteristic caliche cap rock.

Ground water of Pliocene age and the alluvium, sand, and sand of Pleistocene and Recent ages form one hydrologic unit and in this report their hydrologic characteristics will be discussed together.

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No one has subdivided the Ogallala group in northern Lea County, probably because no distinctive marker beds are known. The stratigraphic sections on figure 10 illustrate this. Fossils also are scarce, and consequently the Ogallala group has not been subdivided on a faunal basis. Detailed geologic mapping in south-eastern New Mexico might result in subdivision of the Ogallala group in the area.

Alluvium

Ground water in the deposits of Cenozoic age is unconfined and occurs mainly in the unconsolidated or poorly consolidated sand and gravel.

Sand, soil, and alluvium of Pleistocene and Recent ages unconformably overlie the Ogallala formation on the Llano Estacado, and the Dockum group west and south of Mescalero Ridge. The thickness of the sediments ranges from 0 to about 30 feet on the Llano Estacado and from 0 to about 40 feet on rocks of the Dockum group.

The material overlying the Ogallala formation is off-white to light brown and is derived from the Ogallala formation; the material overlying the Dockum group is mostly red because it has been derived from the red beds of Triassic age.

The cementation are due to variations in the coarseness and degree of sorting of the particles.

Ground water

The yield of wells ranges widely throughout the area. The

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Ground water

The Ogallala formation of Pliocene age and the alluvium, silt,

and sand of Pleistocene and Recent ages form one hydrologic unit and

in this report their hydrologic characteristics will be discussed together.

Some potable ground water is found in the sand, and alluvium, particularly south of Mescalero Ridge in Tps. 19 and 20 S., where these deposits are the thickest. Usually the deposits on the Llano Estacado are too thin to contain appreciable quantities of ground water and are above the water table. The water available in the Ogallala formation constitutes the most important source of water in the area.

Ground water in the deposits of Cenozoic age is unconfined and occurs mainly in the unconsolidated or poorly consolidated sand and gravel of the Ogallala formation beneath the caliche cap rock. The water-bearing properties of the formation vary vertically and horizontally. The vertical variation is due chiefly to the amount of calcium carbonate cement in the Ogallala formation. As a rule, the amount of calcium carbonate decreases downward and is practically negligible at depths of 35 to 50 feet below the surface. The porosity and permeability increase downward as the amount of cement decreases. Lateral variations in the water-bearing properties of the sand and gravel below the zones of cementation are due to variations in the coarseness and degree of sorting of the particles.

The yield of wells ranges widely throughout the area. The maximum yield recorded in normal operation of the pumps in 1953 was about 1,700 gpm. Some wells used for irrigation pump as little as

A

SECTION LINE

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Great ...
Side ...
in ...

200 gpm but wells yielding less than about 300 gpm are considered unsatisfactory for irrigation. The yields of wells differ greatly in relatively short distances and this may be attributed either to formation differences or differences in well construction. The low yield in some wells may be due in part to poor development or construction, inasmuch as wells of higher yield have been developed nearby.

Perched ground water occurs in beds of caliche that have a honeycomb-like structure. These beds have bedding planes enlarged by solution and are locally referred to as "honeycombed rock" or "water rock" (Nye, 1930, p. 372). The quantity of ground water derived from this type of reservoir is small.

Irrigation wells tap the alluvium in the area south of Mescalero Ridge, in the vicinity of Nadine and Monument. Stock wells have been constructed in alluvium at Sand Gate, but no large-production wells have been drilled so the potential of the aquifer there is unknown.

The Water Table In Deposits Of Cenozoic Age

The shape and approximate altitude of the water table are shown (fig. 15) by contour lines based on water-level measurements made mostly during 1952. A few measurements in Tps. 9 and 10 S. were made later; 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

Figure 16. --Map showing the water-level changes in east-central Lea County, New Mexico between January 1950 and January 1960.

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 by 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 relatively slight pumpage and because of average to above average precipitation. Above average precipitation from January 1940 to January 1950 caused the water table to rise generally, except near McDonald, Lovington, Humble City, and Hobbs, where pumpage increased appreciably during 1947 to 1950. 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 below average rainfall (fig. 16). 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

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 by heavy pumping in certain areas.

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Depth to Water and Saturated Thickness of the Deposits of Cenozoic Age

The depth to water ranges from a little less than 15 feet in an area about 13 miles east of Caprock to almost 300 feet along the

Mescalero Ridge northwest of Maljamar (fig. 17). When the Lea County Underground Water Basin was declared in 1931, it included about 1,080 square miles where the depth to water was known to be 50 feet or less. By 1952 the area where the depth to water was 50 feet or less had been reduced to about 1,040 square miles.

Discharge of Ground Water from the Deposits of Cenozoic Age

The saturated thickness in the deposits of Cenozoic age ranges from less than 25 feet to about 250 feet (fig. 18). The average was about 100 feet in 1952. The zone of saturation is thinnest in the northeastern portion of the County, where the Ogallala formation is thin and is underlain by sediments of Cretaceous age. The zone of saturation is thickest where the Ogallala formation is thickest and where there has been little use of ground water. It has locally become thinner as water has been withdrawn for irrigation.

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Movement of Ground Water in the Deposits of Cenozoic Age

and the rocks of Triassic age is covered by Quaternary alluvium.

Ground water moves southeastward down the slope of the water table throughout most of the area. The rate of movement in the deposits of Cenozoic age is controlled by the gradient of the water table and the permeability of the saturated material. The rate varies because of variations in grain size, degree of sorting, and the extent of cementation, especially near the base of the Ogallala formation, where water moves more rapidly through stringers of coarse sand

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and gravel than through fine sand and clay. The average rate of movement of ground water in the Ogallala formation is on the order of 150 feet per year (H. O. Reeder, 1960, U.S. Geological Survey, oral communication).

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: - Most natural discharge of ground water from northern Lea County is by subsurface outflow at the New Mexico-Texas State line. More moves out 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 because there are few areas where the water table is shallow.

Evaporation from the zone of saturation takes place only where the water table is within 10 feet of the surface, as around the perennial lakes, along Mescalero Ridge, and south of Mescalero Ridge from Rgs. 35-38 E. It is estimated that the amount of water lost is about 10,000 acre-feet.

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Discharge of Ground Water from the Deposits of Cenozoic Age

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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 subsequently lost by transpiration.

Flow from springs and seeps is small compared to total discharge from the Ogallala formation. Some springs and seeps discharge along the contact between the sediments 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; especially Ranger Lake and North Lake.

Artificial discharge: - Ground water discharged through wells from the formations 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 in 1952 was about 185,000 acre-feet; of this 166,000 acre-feet were used for irrigation. Almost the same quantities were pumped each year during the period 1953-57. Because of above-average precipitation during the growing season of 1958, the amount of water pumped for irrigation decreased to about 107,000 acre-feet; the use for other purposes remained the same -- 19,000 acre-feet.

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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	3,200	1952	166,000
1941	1,500	1953	165,000
1942	3,500	1954	163,000
1943	6,000	1955	170,000
1944	3,500	1956	160,000
1945	6,500	1957	140,000
1946	3,500	1958	107,000
1947	19,000		
1948	39,000		

Recharge of the Deposits of Cenozoic Age

The deposits of Cenozoic age are recharged by two natural means -- precipitation and subsurface flow into the area, -- and by three artificial means -- irrigation return, seepage from brine

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1940	3,200	1952	166,000
1941	1,500	1953	168,000
1942	3,500	1954	163,000
1943	6,000	1955	170,000
1944	3,800	1956	160,000
1945	6,500	1957	140,000
1946	3,800	1958	107,000
1947	19,000		
1948	29,000		

Recharge of the Deposits of Cenozoic Age

The deposits of Cenozoic age are recharged by two natural means -- precipitation and subsurface flow into the area, -- and by three artificial means -- irrigation return, seepage from ditches

the water reaches the water table by infiltration, although most is disposal pits, and fresh water recharge installations. At present the probably lost by transpiration of plants and by evaporation.

largest amount of recharge is from precipitation.

Ground water in the Ogallala formation in adjacent areas in

Natural recharge: - The average annual recharge from precipitation to the zone of saturation in the southern High Plains is between direction and a small amount enters Lea County as subsurface flow 1/4 and 1/2 inch per year, depending on the amount of precipitation along its northern boundary.

(Theis, 1937). The area of northern Lea County is about 1,800,000

Artificial recharge: - 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.

Underground Water basin is approximately 29,000 to 58,000 acre-feet. It may be called return discharge, but it does not constitute an as the basin has an area of 1,400,000 acres.

Most of the natural recharge from precipitation occurs in the net discharge and should be considered a form of artificial recharge. the areas covered by dune sand and where shallow closed depressions

Brine-disposal pits for oil-field water are another source of are most numerous. Recharge takes place easily in the depressions artificial recharge. Nicholson and Clebsch, U.S. Geological Survey, because the caliche cap rock is thin or absent as observed by White,

(written communication, 1961) calculated that about 96 percent of the Broadhurst and Lang (1946) in Texas and by John Havens of the U.S. brine discharged to disposal pits supposedly to evaporate, actually Geological Survey in Lea County, New Mexico (written communication,

1961). of brine were produced with oil and gas at an average ratio of

A small amount of recharge comes from surface inflow 1 barrel of water to 5 barrels of oil (New Mexico Oil and Gas Engineer- derived from precipitation falling on the Llano Estacado in Chaves and ing Committee, 1959), and approximately 18,200,000 barrels (2,300 Roosevelt County, near the northern boundary of Lea County. The acre-feet) probably seeped into the ground. Over the years an enormous southeast-trending stream channel carry runoff into the northern Lea amount of brine will infiltrate the fresh water reservoir unless the acc County, where it is caught in shallow closed depressions. Some of of disposal pits is discontinued.

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(Theis, 1937). The area of northern Las County is about 1,500,000

acres; therefore, the annual recharge probably varies between 35,000

and 75,000 acre-feet. The average annual recharge to the Las County

Underground Water basin is approximately 29,000 to 58,000 acre-feet,

as the basin has an area of 1,400,000 acres.

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Roosevelt County, near the northern boundary of Las County. The

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County, where it is caught in shallow closed depressions. Some of

the water reaches the water table by infiltration, although most is probably lost by transpiration of plants and by evaporation.

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 Lea County as subsurface flow along its northern boundary.

Artificial recharge: - 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 and should be considered a form of artificial recharge.

Brine-disposal pits for oil-field water are another source of artificial recharge. Nicholson and Clebsch, U.S. Geological Survey, (written communication, 1961) calculated that about 96 percent of the brine discharged to disposal pits supposedly to evaporate, actually seeped to the water table. In 1954, 18,960,000 barrels (2,400 acre-feet) of brine were produced with oil and gas at an average ratio of 1 barrel of water to 3 barrels of oil (New Mexico Oil and Gas Engineering Committee, 1955), and approximately 18,200,000 barrels (2,300 acre-feet) probably seeped into the ground. Over the years an enormous amount of brine will infiltrate the fresh water reservoir unless the use of disposal pits is discontinued.

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Artificial recharge: - 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 and should be considered a form of artificial recharge.

Brine-disposal pits for oil-field water are another source of artificial recharge. Nicholson and Clebach, U.S. Geological Survey, (written communication, 1961) calculated that about 96 percent of the brine discharged to disposal pits supposedly to evaporate, actually seeped to the water table. In 1954, 18,960,000 barrels (2,400 acre-feet) of brine were produced with oil and gas at an average ratio of 1 barrel of water to 3 barrels of oil (New Mexico Oil and Gas Engineering Committee, 1955), and approximately 18,200,000 barrels (2,300 acre-feet) probably seeped into the ground. Over the years an enormous amount of brine will infiltrate the fresh water reservoir unless the use of disposal pits is discontinued.

A third source of artificial recharge is the injection of runoff from precipitation by some artificial means. At present a small amount of this type of recharge is being practiced, as an experiment, in northern Lea County by the U.S. Geological Survey. The project site is on the Llano Estacado, a few miles north of Maljamar. Here, water that has accumulated in a shallow closed depression flows by gravity through a gravel filter and a recharge well into the Ogallala formation. The project was begun in 1956 by the Lea County Commissioners, but, because of expense involved, it is now being run as a cooperative project with the U.S. Geological Survey, the Lea County Soil Conservation District, and the New Mexico State Engineer under the supervision of John Havens (White, 1960). It has two major objectives: (1) to determine the amount of water that is available for artificial recharge and (2) to determine what methods can be used for recharge.

It now appears that artificial recharge of fresh water from precipitation offers the best means of increasing the amount of ground water in storage, because only 1/30 to 1/60 of precipitation naturally recharges the aquifer. Practically all precipitation that does not recharge the reservoir in the Cenozoic formations evaporates or is consumed by plants, because only a slight quantity moves out of the area as surface water.

(Whetstone, 1956, p. 3).

Some potable ground water is found in the sand, and alluvium, particularly south of Mesasero Ridge in Tps. 19 and 20 S., where these deposits are the thickest. Usually the deposits on the Llano Estacado are too thin to contain appreciable quantities of ground water and are above the water table. The water available in the Ogallala formation constitutes the most important source of water in the area.

Ground water in the deposits of Cenozoic age is unconfined and occurs mainly in the unconsolidated or poorly consolidated sand and gravel of the Ogallala formation beneath the caliche cap rock. The water-bearing properties of the formation vary vertically and horizontally. The vertical variation is due chiefly to the amount of calcium carbonate cement in the Ogallala formation. As a rule, the amount of calcium carbonate decreases downward and is practically negligible at depths of 35 to 50 feet below the surface. The porosity and permeability increase downward as the amount of cement decreases. Lateral variations in the water-bearing properties of the sand and gravel below the zones of cementation are due to variations in the coarseness and degree of sorting of the particles.

The yield of wells ranges widely throughout the area. The maximum yield recorded in normal operation of the pumps in 1953 was about 1,700 gpm. Some wells used for irrigation pump as little as

The subject of artificial recharge is complex, but an extensive annotated bibliography has been compiled by Todd (1959). In northern Lea County the most practical method is the collection of runoff from precipitation in shallow-closed depressions, where either it will infiltrate by natural means through the floors or where it can be fed into the reservoir through recharge wells. In either case, an evaporation retardant should be placed on the surface of the water to reduce the amount of water lost by evaporation. Cruse and Harbeck (1960) have published the results of their research on evaporation control in Texas and their conclusions should be applicable in northern Lea County. (Cruse and Harbeck, 1960). One Recommendation, Separates AP33,

reduced If a recharge well is not used, the caliche beneath the floor of the collecting pond must be broken so that the water can infiltrate. Eventually silt and clay brought in by runoff will reduce the permeability of the floor, and it will be necessary to break the floor periodically. Probably the most economical method of recharge would be by means of specially constructed recharge wells used near collecting ponds. The water which has accumulated in a collecting pond is either allowed to flow by gravity or is pumped through a recharge well into the ground-water reservoir. Recharge wells of both types are being successfully operated in many parts of the world, including a number of places in the southern High Plains of Texas (Whetstone, 1956, p. 3).

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including a number of places in the southern High Plains of Texas both types are being successfully operated in many parts of the world, recharge well into the ground-water reservoir. Recharge wells at pond is either allowed to flow by gravity or is pumped through a collecting ponds. The water which has accumulated in a collecting be by means of specially constructed recharge wells used near periodically. Probably the most economical method of recharge would ability of the floor, and it will be necessary to break the floor. Eventually silt and clay brought in by runoff will reduce the permeability of the collecting pond must be broken so that the water can infiltrate. If a recharge well is not used, the silt will collect beneath the floor able in northern Lea County.

evaporation control in Texas and their conclusions should be applicable and Harbeck (1950) have published the results of their research on the water to reduce the amount of water lost by evaporation. Cross case, an evaporation retardant should be placed on the surface of it can be fed into the reservoir through recharge wells. In either either it will infiltrate by natural means through the floor or where runoff from precipitation in shallow closed depressions, where northern Lea County the most practical method is the collection of alive annotated bibliography has been compiled by Todd (1957). In The subject of artificial recharge is complex, but an exten-

periods, for a recharge installation costing \$2,000 are summarized. Injection wells are simple to build, maintain, and operate,

in figure 19. It shows that, in general, the cost of water per acre-foot injected decreases up to about 30 years and from then on increases but may become inoperable after a time. The aquifer will eventually become clogged around the recharge well if large quantities of silt and clay are suspended in the water. Clogging can be reduced by crops in the southern High Plains as a guide, "...recharged water passing the water through a filter before it enters the formation and can be the source of an attractive return on investment." by surging the recharge well occasionally (Cullinan, 1960). Experi-

ments in Texas have shown that, even though both these preventive

measures are taken, clay and silt in the reservoir may become a

serious problem (Jensen and Clyma, 1959). If chemicals are used

to flocculate the silt and clay in the collecting basin, clogging will

be reduced considerably (Winn, 1960). One flocculant, Separan AP30,

where V is the quantity of water in storage, A is the surface area of reduced the suspended solids in a shallow closed depression in Texas,

the aquifer, p is the porosity of aquifer, and m is the saturated thick-

during one day, from 1,280 parts per million (ppm) to 157 ppm

ness of the aquifer. The area (A) of the Lee County Underground Water Basin is about 1,400,000 acres; the average porosity (p) is about 35

well or the formation unless they are killed before the water enters per cent; and in 1952, the saturated thickness (m) averaged about 100

the injection well. feet. On the basis of the above figures, it is estimated that about

The initial cost of a recharge installation is high, but over 49,000,000 acre-feet of water were in storage in the aquifer at the

the years it is not prohibitive. The cost can be reduced by using end of 1952. However, not all of the water in storage in the reservoir

the well both as recharge well and as a production well. can be recovered for large scale irrigation development because of two

The cost of recharge water has been determined by Billingsley principal factors. First, it usually is not economically feasible to

(1960). His findings concerning the costs per acre-foot of water pump large quantities of water in areas where the zone of saturation

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recharged for various sized collecting ponds and for various times (1960). His findings concerning the costs per acre-foot of water The cost of recharge water has been determined by Billingsley the well both as recharge well and as a production well.

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well or the formation unless they are killed before the water enters (Kistner, 1959). Anaerobic bacteria and algae sometimes clog the during one day, from 1,580 parts per million (ppm) to 187 ppm reduced the suspended solids in a shallow closed depression in Texas, be reduced considerably (Winn, 1960). One flocculant, Sagarin AP30, to flocculate the silt and clay in the collecting basin, clogging will serious problem (Jensen and Glynn, 1959). If chemicals are used measures are taken, clay and silt in the reservoir may become a means in Texas have shown that, even though both these preventive by surging the recharge well occasionally (Cullinan, 1960). Expert- passing the water through a filter before it enters the formation and and clay are suspended in the water. Clogging can be reduced by become clogged around the recharge well if large quantities of silt but may become inseparable after a time. The silt will eventually injection wells are simple to build, maintain, and operate.

periods, for a recharge installation costing \$2,000 are summarized in figure 19. It shows that, in general, the cost of water per acre-foot injected decreases up to about 20 years and from then on increases slightly. He concluded that, using present returns from irrigated crops in the southern High Plains as a guide, "...recharged water can be the source of an attractive return on investment."

Ground Water in Storage

The 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 per cent; 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,

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Figure 19. --Graph showing the costs per acre-foot of water recharged at various rates and for various time periods for a recharge installation costing \$2,000. (Adapted from Billingsley, 1960).

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

Generally is harder and has a higher dissolved-solids content than most uses. Water from the Triassic and Cretaceous formations in the northern Las County Underground Water Basin can be recovered of the total amount of water in storage in the deposits of Cenozoic age to be 0.5 of the volume of saturated sediment. Thus about 40 percent up the reservoir. The yield of water from the sediments is estimated will be retained by adhesion on the surfaces of the grains which make as available for large scale pumping. Secondly, much of the water only the water in the upper 70 feet of the reservoir can be considered extensive local development. supply will be exhausted in 40 years or less, from 1925, because of farming and will not be used for this purpose while in other areas the use. But some of the water underlies areas that are unsuited for in storage would last approximately 100 years at the present rate of water pumping was distributed evenly throughout the Basin, the amount for large-scale irrigation, or about 20,000,000 acre-feet. If ground in the northern Las County Underground Water Basin can be recovered of the total amount of water in storage in the deposits of Cenozoic age to be 0.5 of the volume of saturated sediment. Thus about 40 percent up the reservoir. The yield of water from the sediments is estimated will be retained by adhesion on the surfaces of the grains which make as available for large scale pumping. Secondly, much of the water only the water in the upper 70 feet of the reservoir can be considered

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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 20 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 11 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 sulfate; 250 ppm of chloride; and 1.5 ppm of fluoride. The preferred limits for one or more substances were exceeded in 8 of the 52 analyses of water from the Cenozoic deposits. They were exceeded in the three analyses of

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 water is indicated by the analyses in figure 29 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.

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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 shows (salinity hazard) ranges from medium to high; however, it is necessary to determine its suitability for drinking. The New Mexico quantity of exchangeable sodium (alkali hazard) is low. (Richards, 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.

concentration of sodium lessens the alkali hazard. Boron is not known to occur in

Water for Industrial Use

growth.

Water from deposits of Cenozoic age may be considered satisfactory for most industrial uses, even though the water is hard. 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 rocks. Water from the rocks of pre-Mesozoic age generally is of such poor quality that it is suitable for most use only where quality of water is of little or no importance, such as drilling shot holes and

water-flooding of oil and gas fields.

Potable water in the Ogallala formation in southeastern

New Mexico is being contaminated with water containing a high

water from the Tecumcari shales, 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 most use only where quality of water is of little or no importance, such as drilling shot holes 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

Potable water in the Ogallala formation in southeastern New Mexico is being contaminated with water containing a high concentration of salts. When the quality of the water from a well begins to deteriorate, it is usually too late for

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

Potable water in the Ogallala formation in southeastern New Mexico is being contaminated with water containing a high

concentration of chloride, calcium, magnesium, and other dissolved solids. A well in NW 1/4 SE 1/4 NE 1/4 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 SW 1/4 SW 1/4 SW 1/4 sec. 31, T. 14 S., R. 37 E., and a well in NW 1/4 NW 1/4 NW 1/4 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

concentration of chloride, calcium, magnesium, and other dissolved solids. A well in NW 1/4 SE 1/4 NE 1/4 sec. 12, T. 15 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 329 ppm since 1954, and the concentration of chloride had increased to 329 ppm. The hardness (as CaCO₃) had increased from 290 ppm to 615 ppm during the 7-year period and the SAR (sodium adsorption ratio) had increased from 1.3 to about 5.4. The water had become impotable according to the U.S. Public Health Service standards (1945).

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 SW 1/4 SW 1/4 NW 1/4 sec. 31, T. 14 S., R. 37 E., and a well in NW 1/4 NW 1/4 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:

2 figs.

(1) Line the disposal pits with impervious material,

Barnes, V. W., and others, 1957, Stratigraphy of the pre-Santonian Paleozoic of the Permian Basin, New Mexico: Bureau of Economic Geology, Texas Univ. Pub. 5724, 836 p. such as concrete, so that the brine does not seep downward.

Bates, R. L., 1942, The oil and gas resources of New Mexico:

N. M. and Mineral Res. Div. Bull. 16, 383 p., 35 pls., 23 figs. (2) Return the brine to deep-lying formations either by using the brine to repressure oil pools or by

Berkstresser, C. F., Jr., 1959, Tatum-Leighton-Hobbs area, Lea County, New Mexico: water-level measurements in observation wells, 1951-55, and atlas of (3) Demineralize the brine. This method would

from beginning of record through 1954, New Mexico: N. Mex. State Eng. Rept., 1954, 44-55. significantly improve the water situation by removing a contamination hazard and would

Billingsley, Ray, 1963, How much does recharge water cost? The Cross Section, v. 4, no. 2, p. 2-3. increase the supplies of potable water.

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It now appears that artificial recharge of fresh water from
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amount of water that is available for artificial recharge and (2) to
(White, 1960). It has two major objectives: (1) to determine the
the New Mexico State Engineer under the supervision of John Havens
Geological Survey, the Las County Soil Conservation District, and
involved, it is now being run as a cooperative project with the U.S.
in 1955 by the Las County Commissioners, but, because of expense
recharge well into the Ogallala formation. The project was begun
closed depression flows by gravity through a gravel filter and a
north of Majumdar. Here, water that has accumulated in a shallow
Survey. The project site is on the Llano Estacado, a few miles
experiment, in northern Las County by the U.S. Geological
small amount of this type of recharge is being practiced, as an
tunnel from precipitation by some artificial means. At present a
A third source of artificial recharge is the injection of

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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,

such as concrete, so that the brine does not

seep downward.

(2) Return the brine to deep-lying formations either by

using the brine to regenerate 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.