Recharge Studies on the High Plains in Northern Lea County, New Mexico

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1819-F

Prepared in cooperation with the New Mexico State Engineer and the Lea County Soil and Water Conservation District

RECHARGE STUDIES ON THE HIGH PLAINS IN NORTHERN LEA COUNTY, NEW MEXICO

Aerial view looking east-southeast at a depression in the SW¼ sec. 20, T. 16 S., R. 32 E., showing the apparent alinement of chains of depressions. Rainfall in July 1960 filled the depressions.

Recharge Studies on the High Plains in Northern Lea County, New Mexico

By JOHN S. HAVENS

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1819-F

Prepared in cooperation with the New Mexico State Engineer and the Lea County Soil and Water Conservation District

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1966

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

RECHARGE STUDIES ON THE HIGH PLAINS IN NORTHERN LEA COUNTY, NEW MEXICO

By John S. Havens

ABSTRACT

The area described in this report is that part of the southern High Plains principally within northern Lea County, N. Mex.; it comprises about 1,400,000 acres. Hydrologic boundaries isolate the main aquifer of the area, the Ogallala Formation, from outside sources of natural recharge other than precipitation on the area. Natural recharge to this aquifer from the 15-inch average annual precipitation for the period 1949–60 is estimated to be about 95,000 acre-ft (acre-feet) which is between the 59,000 and 118,000 acre-ft a year obtained from the Theis estimate (1934) of ½ to 1 inch a year. About one-sixth of the water pumped for irrigation, or an average of about 23,000 acre-ft a year in the period 1949–60, returns to the aquifer. The estimated long-term (1939–60) average annual recharge to the aquifer is about 77,000 acre-ft.

Discharge from the aquifer is by pumping and underflow from the area. Gross pumpage averaged about 151,000 acre-ft a year in the period 1949–60. Underflow from the area is estimated to have been about 36,000 acre-ft a year. Thus, the estimated average annual discharge from the aquifer was about 187,000 acre-ft a year, and this exceeded recharge by about 69,000 acre-ft a year. This overdraft is reflected in a general net decline of the water table of 10 ft in the period 1950–60 and net declines of as much as 30 feet in local areas.

Data obtained during this study indicate that about 100,000 acre-ft of water collects in closed depressions on the surface of the High Plains in years when precipitation is normal. Studies of water losses from ponds in selected depressions indicate that between 20 and 80 percent of this loss recharges the ground-water body and the balance is lost to evapotranspiration, principally evaporation. Artificial recharge facilities constructed in the depressions could put at least 50,000 acre-ft of water underground annually that otherwise would be lost to evaporation. Recharging through pits or spreading ponds would cost less per unit volume of water than recharge through wells.

INTRODUCTION

The Ogallala Formation of Tertiary age underlies the southern High Plains of southeastern New Mexico and is an aquifer heavily pumped for irrigation, commercial, industrial, and domestic uses. The amount of water pumped annually from this aquifer, chiefly for irrigation, plus the natural discharge exceeds the natural recharge to the aquifer and has caused ground-water levels to decline. In the

1,400,000-acre area described in this report, principally northern Lea County (fig. 1), the average net decline during 1950–60 was about 10 feet, and maximum net declines in areas of extremely heavy pumping were as much as 30 feet.

Natural hydrologic boundaries—such as the Mescalero Ridge escarpment on the south and west, bedrock highs of impermeable rocks of Cretaceous age on the north, and the southeast gradient of the water table at the New Mexico-Texas State line—prevent water outside the area from recharging the aquifer. The precipitation that falls on the land surface is the only new water reaching the area, and it is many times greater than the amount that eventually reaches the water table. If a part of storm runoff now lost by evapotranspiration could be introduced into the aquifer by means of artificial recharge, the decline of the ground-water level would be slowed, and the economic life of the aquifer would be prolonged.

This investigation was made to determine the amount of water from runoff that might be available annually for recharge to the main aquifer and to study possible methods of artificial recharge that would be applicable in the southern High Plains.

The possibility of increasing the supply of ground water by artificial recharge was recognized by the Board of County Commissioners of Lea County when they established the Lea County Underground Water Recharge Project in 1955. The project was under the direction of E. G. Minton, Jr., who supervised the installation of four recharge wells, nine observation wells, and climatological equipment about 3 miles east of Lovington, N. Mex. In April 1959 the recharge facilities were made available to the U.S. Geological Survey and the State Engineer of New Mexico, who, in cooperation with the Lea County Soil and Water Conservation District, maintained and operated the facilities until the summer of 1962.

Data about artificial recharge operations, precipitation, and ground-water levels were collected and analyzed. Statistics on frequency and intensity of precipitation in northern Lea County obtained from records of the U.S. Weather Bureau were tabulated and examined. Information about the material flooring and beneath several natural surface depressions in the area was obtained by tests with rotary-drilling equipment provided by the New Mexico State Engineer.

PREVIOUS INVESTIGATIONS

Previous investigations of ground-water conditions in the area were made by Nye (1930, 1932), Theis (1934, 1937, 1939), Hale and Nicholson (1953), Conover and Akin (1942), Berkstresser (1959), Cronin (1961), Nicholson and Clebsch (1961), and Ash (1963). Of these

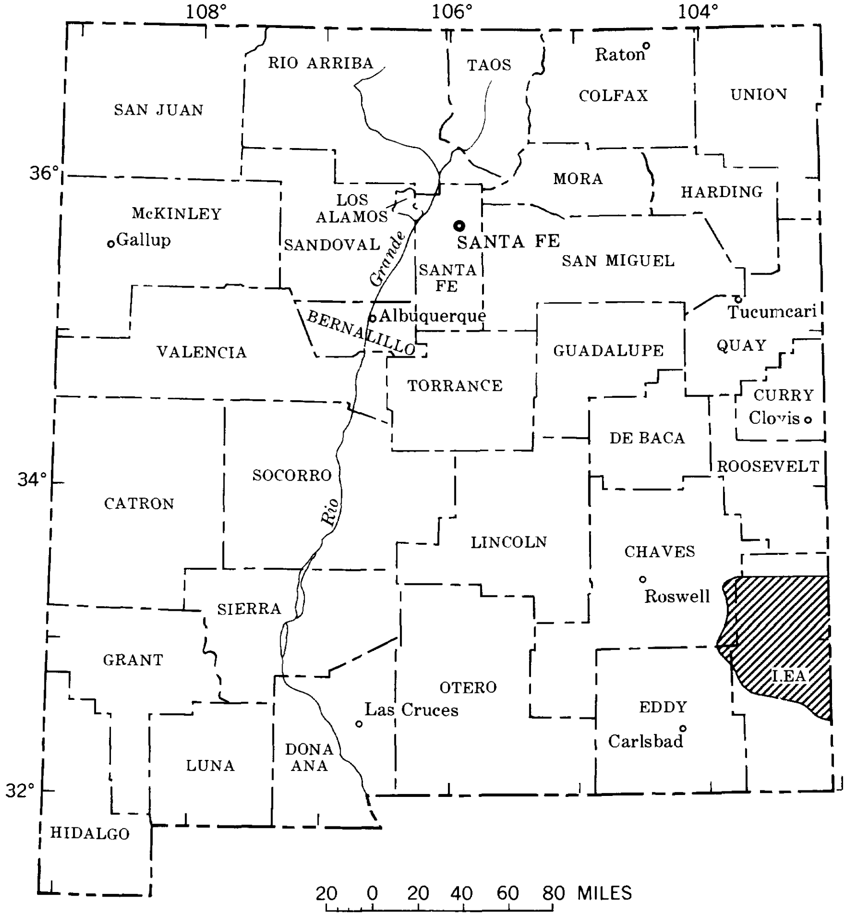


FIGURE 1.—Area of investigation (shaded).

only Theis (1934, 1937) attempted to arrive at an estimate of annual recharge to the aquifer. Most geologic investigations are primarily of conditions related to oil and gas production.

SYSTEM OF NUMBERING WELLS IN NEW MEXICO

All wells referred to in this report are identified by a location number used by the Geological Survey for numbering water wells in New Mexico. The well number is a description of the geographic location of the well and is based on the system of public land surveys. It indicates the location of the well to the nearest 10-acre tract in places where the well can be located that accurately. The well number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order (fig. 2). If a well has

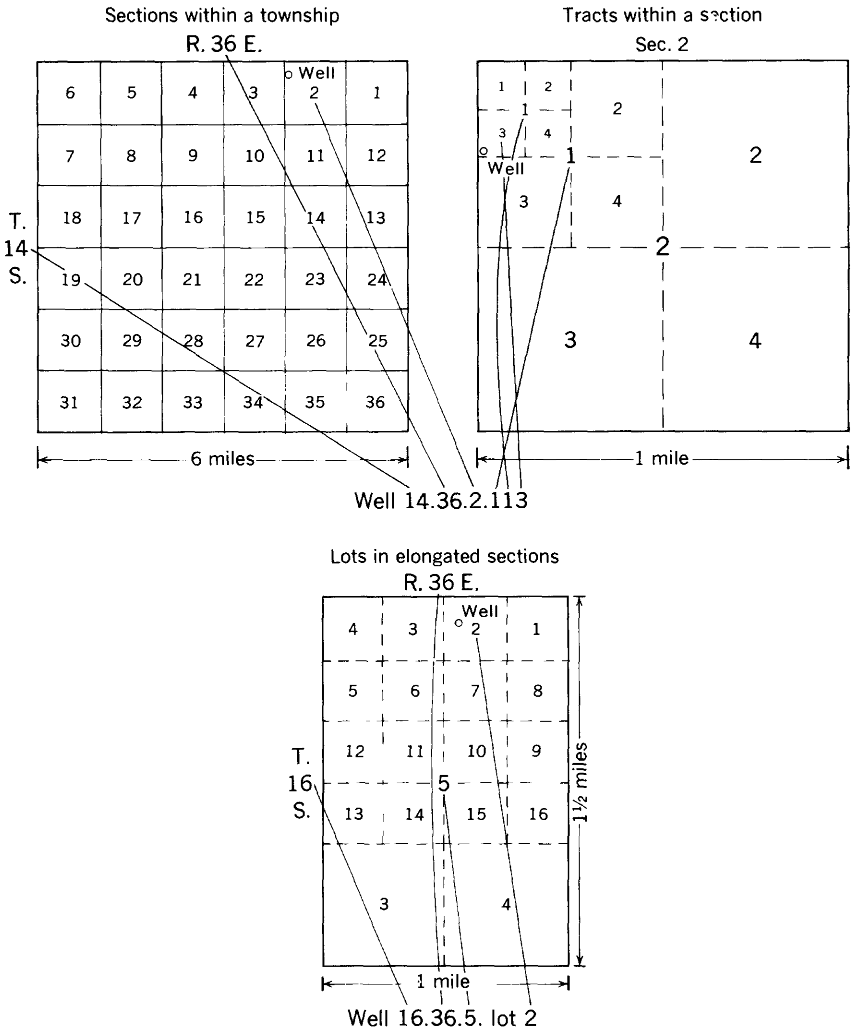


FIGURE 2.—System of numbering wells in New Mexico.

not been located closely enough to be placed within a tract smaller than 160 acres within a section, a zero is used for that part of the number. All wells in the area covered by this report are south of the New Mexico base line and east of the New Mexico principal meridian. Letters a, b, c, and so forth are added to the last segment of the well number to designate the second, third, fourth, and succeeding wells in the same 10-acre tract.

The third standard parallel south passes through Lea County just north of Lovington. The sections of land that abut the correction line on the south are elongated and are approximately 1½ miles in length.

These elongated sections are divided into 2 quarter sections in the southern third of the sections and into 16 lots in the northern two-thirds (fig. 2). The system used in this report for numbering wells in these elongated sections is the same as that described for numbering wells in a standard section except that, when the well is in a lot, the fourth segment of the well number consists of the word "lot" followed by the lot number. Letters a, b, c, and so forth are added to the fourth segment to designate the second, third, fourth, and succeeding wells in the same lot.

The well-numbering system is used also in this report to identify the location of test holes and sites where soil samples were collected.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to the numerous well owners whose information and cooperation made possible the gathering of many of the basic data for this report. In particular, the writer thanks the landowners who so generously permitted test drilling and continued observations in depressions on their lands: Kyle Taylor, Jr., and Cecil Holeman, Warren M. Snyder, R. E. Hilburn, Johnny Etcheverry, and George Sumruld. Special thanks are given to John T. Easley, who contributed the land upon which the artificial recharge facilities are located and whose cooperation during their operation by the Geological Survey contributed greatly to the success of this project.

City and county officials were most helpful in furnishing information. The members of the Lovington office of the Soil Conservation Service contributed materially by information, suggestions, and liaison with landowners.

PHYSIOGRAPHY

The High Plains in New Mexico are a subdivision of the Great Plains physiographic province (Fenneman, 1931, p. 11). The southern part of the High Plains lies in New Mexico and Texas, separated from the northern part of the High Plains by the Canadian River, which flows eastward in New Mexico and Texas. The plains in northern Lea County are almost flat, broken only by subdued hills, swales, and many elongate depressions. The surface slopes southeastward 10 to 15 feet per mile. The southeastward-trending drainage system is poorly formed, and runoff from precipitation is to the depressions, where it remains until the water infiltrates or is lost by evapotranspiration. A few of the depressions contain perennial lakes.

The area investigated is principally in northern Lea County and is that part of the southern High Plains in southeastern New Mexico south of the bedrock high area of Ash (1963), east of the Mescalero

Ridge, west of the New Mexico-Texas State line, and north of a line from End Point on Mescalero Ridge extending east-southeast to the State line.

The depressions that pock the surface of the High Plains have probably been forming since the beginning of Pleistocene time. In several places along the Mescalero Ridge, these depressions have been breached by recent erosion. Present-day erosion is confined to the upper surface of the Ogallala Formation and exposures of older sediments along Mescalero Ridge. Erosion may have been accelerated by removal of protective grass cover through overgrazing. Unstabilized and partially stabilized dune sands cover some areas.

Most of the irrigated farmland is in the east half of Lea County, and ranching dominates in the west half.

DRAINAGE FEATURES

In this report, the High Plains in northern Lea County are divided in four physiographic zones based on drainage, topography, and surficial materials (pl. 1). The boundaries of these zones are arbitrary.

ZONE 1

The surface of zone 1 is flat except for depressions, which number about 1,900. The bottoms of about 60 percent of the depressions are 10 acres or less in area; in about 35 percent they are 10 to 50 acres, and in about 5 percent they are larger than 50 acres. The predominant drainage is to the depressions. Groups of depressions are alined in a general southeasterly direction. Although some are connected by shallow drainage channels, surface flow between depressions occurs only after extremely heavy precipitation.

ZONE 2

Zone 2 is characterized in the central and eastern part by very broad, low, elongated hills alternating with poorly defined swales that trend southeastward. The swales become more distinct and abruptly change direction to the east-southeast at the east boundary of zone 2. This change in direction corresponds closely to a buried valley (Ash, 1963). Depressions are numerous in this zone near the west boundary.

ZONE 3

Zone 3 is characterized by broad, elongated swales trending east-southeast, separated by low hills. The swales and hills pass directly into dune areas and sandier soils near the New Mexico-Texas State line. A few depressions, most of which have bottom areas of less than 5 acres, are in zone 3. Approximately 10 percent of the land consists of low caliche-capped hills, and about 90 percent of broad, elongated swales.

ZONE 4

Zone 4 consists of dune areas and sandy soils. Many of the broad swales of zone 3 terminate in the sandy areas of zone 4. Several clearly defined swales, however, continue eastward into Texas; Seminole Draw, which heads northeast of Hobbs, is very distinct. Infiltration of surface water is relatively rapid compared with that in other zones. Storm runoff from Hobbs drains to Seminole Draw and disappears within a few miles.

GENERAL CHARACTERISTICS AND DESCRIPTION OF DEPRESSIONS

Depressions are the most characteristic surface feature of the High Plains. The depressions are playas and may contain water following greater than normal summer rainfall. The water is generally dissipated through evapotranspiration and infiltration within a few months.

Depressions on the High Plains range in size from a few inches in depth and a few yards in diameter to more than 50 feet in depth and more than a mile in diameter. The depressions in the New Mexico part of the southern High Plains, however, are generally not more than about 40 feet deep and a quarter of a mile in diameter.

The depressions are generally elongate downslope to the southeast, and groups, or chains, of depressions trend in that direction. In zones 1 and 2 this alinement is most evident (frontispiece).

Depressions and their origins have been the subject of much discussion in geologic literature (Judson, 1950, p. 254). Differential solution and collapse of evaporite sections in pre-Ogallala rocks may have caused the depressions and, by extension, may account for the alinement. Solution within the Ogallala may also be considered as a cause of the alinement.

Channeling in the post-Mesozoic erosional surface and subsequent deposition of sediments of Pliocene to Recent age on the erosional surface could account for the pattern of alinement. Several breached depressions along Mescalero Ridge, however, have no features that would be present if irregular bedding or solution and collapse were the cause of the alinement of the depressions. Bedding appears to be horizontally continuous, and no rubble zone or recemented rubble is evident beneath the depressions.

The alinement of the depressions may have been caused by jointing in the caliche and underlying sediments, but such a joint pattern has not been proved definitely.

The simplest and most probable hypothesis for alinement of the groups of depressions is that they occur along poorly formed drainageways. Solution of caliche along these drainageways would entrench the drainage and lead to enlargement of the depressions. This succession seems to have happened in zone 3 in eastern Lea County where groups, or chains, of depressions may have coalesced to form broad swales.

Exploratory holes were drilled to obtain data on the origin of eight depressions (pl. 1)—depressions D–1, –2, –6, and –7 just west of Lovington; depressions D–4 and –5 about midway between Lovington and Maljamar; and depressions D–8 and –9 about 3 miles north-northwest of Maljamar. Samples of materials obtained by drilling were collected, identified, and described. Geologic sections were drawn which show obvious correlations between test holes (pls. 2, 3; figs. 3–5).

Geologic sections across depressions D–1 (pl. 2) and D–2 (fig. 3) show that caliche may be continuous beneath these two small depressions. Although the depressions could have been caused by subsurface irregularities in the caliche, it is more likely that the hard caliche penetrated by the test hole in the center of D–2 is either a boulder or a layer of caliche formed by the precipitation of calcareous salts in the formation. In a caliche pit (figs. 7, 8) only 800 feet east of D–2, caliche boulders are present 10 to 15 feet below the general land surface.

Beneath depressions D–1, –7, –8, and –9 caliche thins toward or is absent beneath the central part of the depressions (pls. 2, 3; figs. 3–5). Solution and removal of calcium carbonate by percolating water is almost certainly the mechanism for removal of most of the caliche. Toward the low points of the depressions calcareous material is present in the underlying sand of the Ogallala Formation. Part of the caliche may have been removed by wind action or animals.

In addition to a thinning of the caliche in depressions D–8 and –9, the surface of the underlying sand has been lowered beneath the depressions (pl. 3, fig. 5), but this lowering is probably not due to slumping. In this part of the Southwest, winds may reach velocities of 60 miles per hour for as long as 24 hours, and winds of lesser velocities may blow for several days. These winds generally blow during the spring when the depressions are least likely to contain water. Deflation during earlier arid climatic cycles could easily account for removal of the sand from the depressions. Judson (1950, p. 265) mentioned finding large dune areas on the leeward sides of similar depressions on the north border of the southern High Plains. Such dune areas have not been definitely observed in Lea County, but windblown material removed from the depressions may have been dissipated too rapidly to form dunes.

The dip of the caliche toward the centers of some depressions may

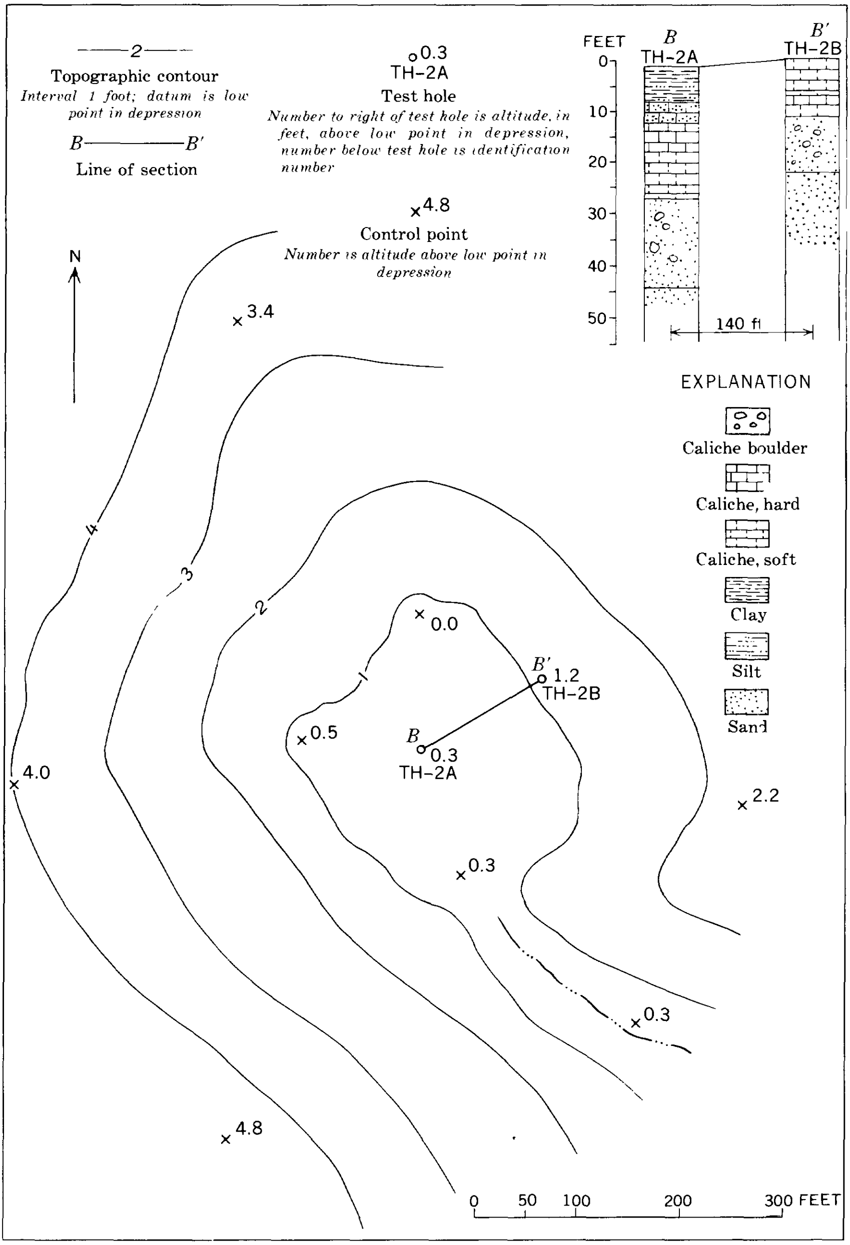


FIGURE 3.—Topographic map of depression D-2 (lot 13, sec. 6, T. 16 S., R. 36 E.) showing test holes and section *B–B′*

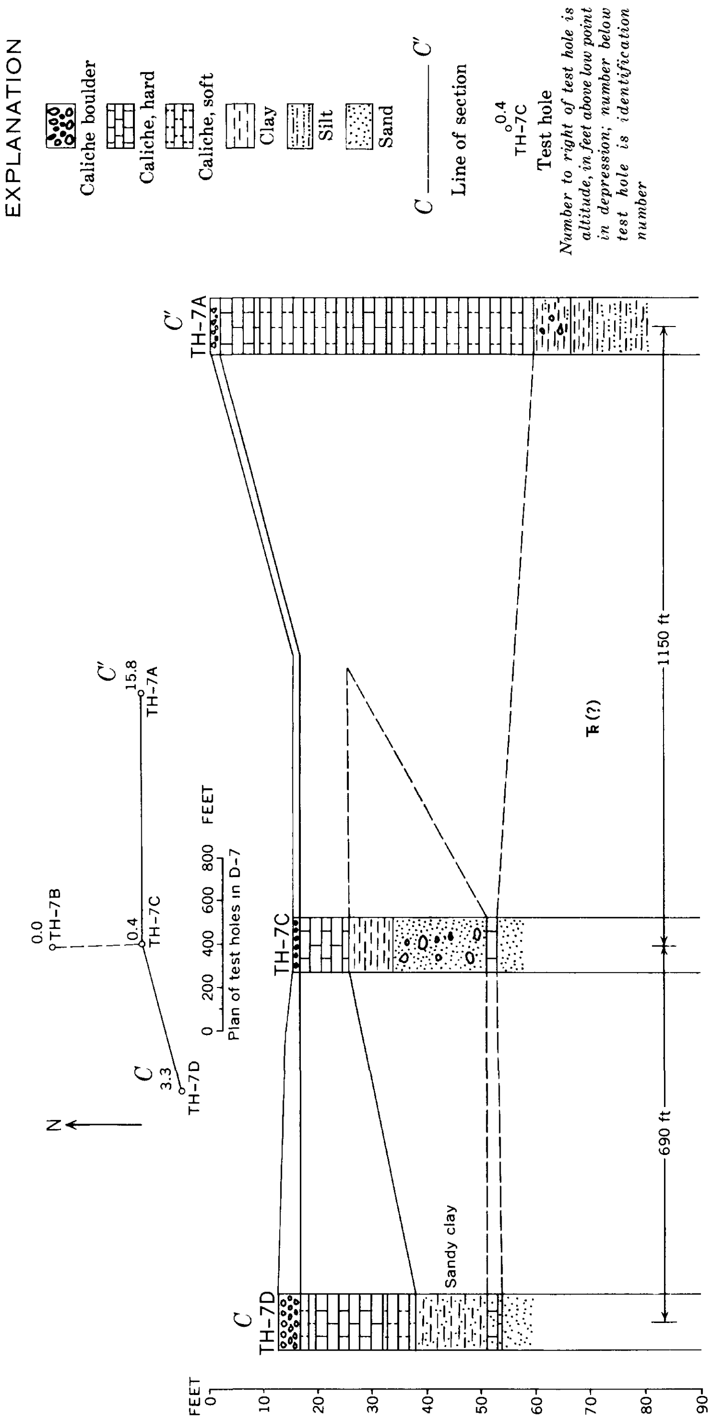


FIGURE 4.—Section C–C′ across depression D-7 (SW¼ sec. 24, T. 16 S., R. 35 E.).

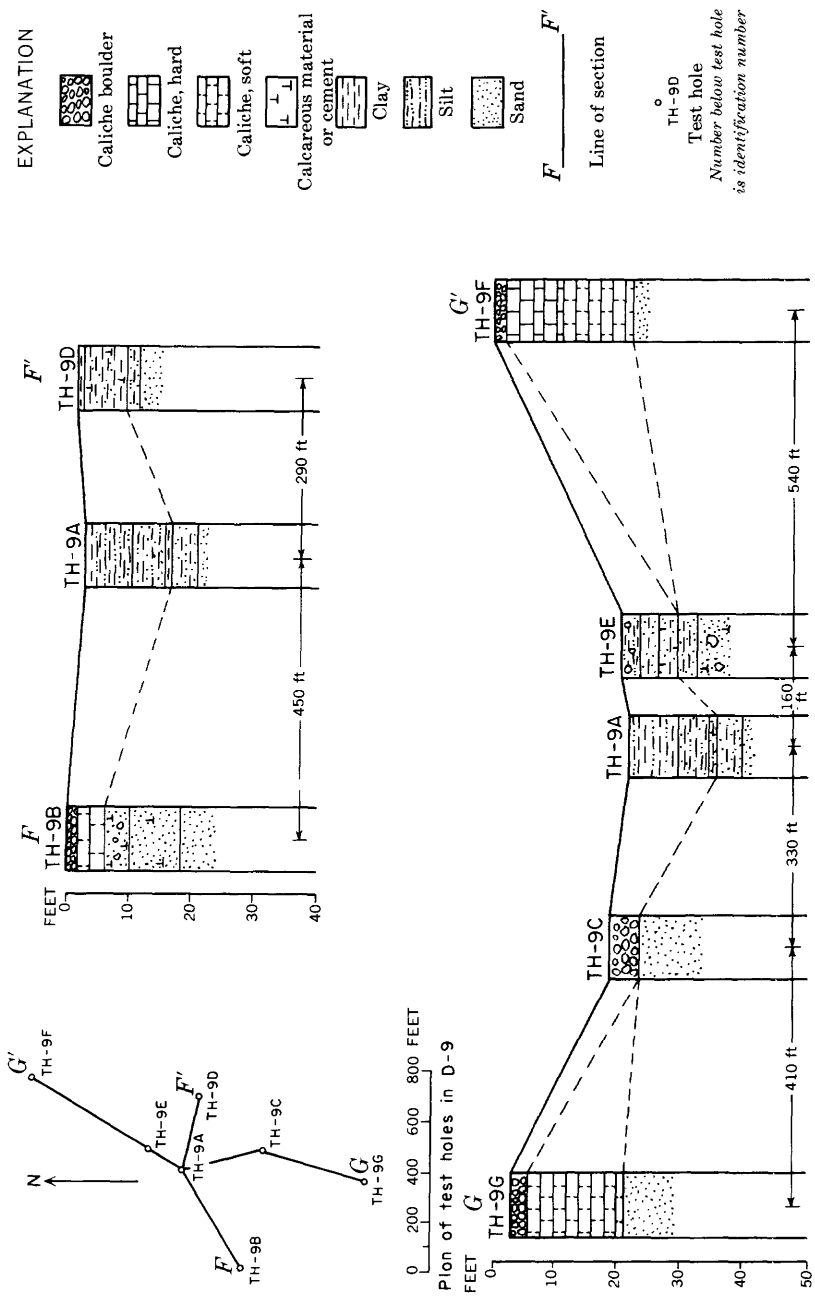


FIGURE 5.—Sections *F–F'* and *G–G'* across depression D-9 (NE¼ sec. 29, T. 16 S., R. 32 E.).

have been caused by the removal of sandy material and the consequent slumping of parts of the caliche. Redeposition of soluble carbonates could produce the same effect.

Materials on the floors of the depressions are silt, sand, and clay in varying proportions. These materials may have been washed in from the southeastward-trending drainage systems or they may represent insoluble materials released by the solution of caliche. Some of these materials may be Pleistocene lakebed sediments; several fossil gastropod assemblages were found during test drilling in depression D–6 (pl. 1).

The depressions are Pleistocene to Recent in age. The Diamond A-Mescalero plain of Pleistocene age, on the west boundary of the Llano Estacado, has breached several depressions, a condition which indicates that the depressions had been forming prior to the degradation of that erosional surface. Depressions are still forming on the southern High Plains of New Mexico.

In summation, data obtained during the investigation indicate that the depressions are the result of (1) solution of the caliche caprock along zones of weakness parallel or coincident with a poorly formed drainage pattern and (2) removal of underlying sand by wind action. The depressions have been partly filled by fine sediments brought in by runoff following greater than normal precipitation.

CLIMATE

Northern Lea County has a semiarid climate (Thornthwaite, 1941, p. 4, pl. 3). In winter the temperatures are generally moderate, but occasional short periods of severe cold weather may occur. In summer, temperatures are high during the day but generally low at night. The precipitation at times exceeds losses by evapotranspiration and results in accretion to ground water. Irrigation is generally necessary for successful crop growth.

Precipitation in northern Lea County is about 14 inches per year, according to the following data:

Station	Years of complete record	To year—	Arithmetic average of precipitation for years of complete record (inches)
Caprock	12	1958	12. 87
Hobbs	39	1961	14. 96
Lovington	42	1961	15. 14
Maljamar	15	1961	13. 02
Pearl	33	1961	13. 13
Tatum	32	1961	16. 44
Unweighted yearly average			14. 26

Records at these six stations were used in a Theissen-polygon network to calculate the amount of precipitation that reached the land surface in northern Lea County in the period 1949–61. This period included a drought in the early 1950's and greater than average rainfall in 1959–60 (table 1). Isohyets on plate 4 show that the average amount of precipitation decreases westward across northern Lea County, N. Mex.

TABLE 1.—*Annual precipitation, 1949–61, at weather stations in northern Lea County, N. Mex.*

[From Annual Summaries, Climatological Data, New Mexico, U.S. Weather Bureau. Asterisk indicates estimated data]

Year	Caprock	Hobbs	Lovington	Maljamar	Pearl	Tatum
1949		20.29	25.06	17.87	*18.64	22.27
1950		20.34	12.72	16.96	11.04	18.66
1951		8.14	11.14	11.31	*11.78	8.70
1952	9.76	8.38	9.28	7.93	4.47	10.19
1953	8.18	10.09	9.37	10.17	8.82	16.15
1954	14.52	16.08	14.29	7.73	11.33	10.91
1955	*13.65	12.30	13.73	*13.83	11.87	16.37
1956	*3.74	8.63	10.73	7.38	5.79	10.29
1957	*13.94	19.20	12.79	9.98	*15.36	18.04
1958	*18.60	18.98	22.58	20.06	18.85	23.94
1959		14.64	12.99	10.00	9.60	11.34
1960		20.41	23.13	25.66	18.34	22.85
1961		9.76	15.89	12.49	11.82	*17.30

A Theissen network drawn around the six weather stations in northern Lea County (pl. 4) shows areas which are assumed to receive the same rainfall as the weather station (Linsley and others, 1949, p. 78). The areas and percentages of the entire area for each Theissen polygon are as follows:

Weather station	Area (sq mi)	Percent of total area
Caprock	462	20.9
Tatum	497	22.5
Lovington	543	24.6
Maljamar	295	13.4
Pearl	144	6.5
Hobbs	267	12.1
Total	2,208	100.0

Precipitation for 1949–61, weighted and adjusted by the Theissen network, was as follows:

Year	Precipitation (inches)	Year	Precipitation (inches)
1949	[1]21.78	1956	8.15
1950	[1]16.15	1957	14.78
1951	[1]10.07	1958	21.05
1952	8.97	1959	[1]11.98
1953	10.80	1960	[1]22.66
1954	12.73	1961	[1]14.43
1955	14.02		

[1] Record from Caprock station not included; other values adjusted to 100 percent.

Soil-moisture content, air temperature, humidity, intensity of precipitation, and slope of the land surface influence the amount of runoff from precipitation. In northern Lea County, soil-moisture content, air temperature, and humidity can probably be treated as though they were constants. Slope and intensity are the variables. When soil moisture is at a minimum, air temperature is high and humidity is low, and the amount of runoff will probably be low. Runoff will be high from steeper slopes of depressions, but water may stand on level areas atop hills.

Intensity of rainfall can be studied from published precipitation records. Hourly precipitation records from the Caprock weather station show that most rains of 1 inch or more in a 24-hour period fell within 2 to 3 hours. Precipitation patterns at other stations in northern Lea County are similar.

Precipitation of less than 1 inch per 24 hours will result in runoff if the rate of precipitation, in inches, is as follows:

1st day	2d day	3d day
0.1–0.3	0.1–0.3 or 0.3–0.6	0.6–1.0
.3– .6	0.6–1.0	------------
.6–1.0	>0.5	------------

Much of the intense rainfall in the High Plains, particularly during the summer and early autumn, falls as isolated thundershowers or cloudbursts. Storms common to three or more stations probably are regional or areawide, rather than limited local events.

The storms that yielded more than 1 inch of precipitation and the instances in which such a storm was common to three or more stations are listed in table 2. During the period studied, an average of three storms a year was common to three stations. Hobbs and Tatum have the greatest average number of heavy storms, about four a year, and Caprock the fewest, about two a year.

TABLE 2.—*Number of storms having 1 inch or more of precipitation, 1949–61, northern Lea County, N. Mex.*

[Column 1 refers to storms lasting 1 day; column 2 refers to storms lasting more than 1 day]

Year	Weather station												Total number of storms		Storms common to 3 or more stations		Storms lasting 1 or more days common to 3 or more stations
	Caprock		Hobbs		Lovington		Maljamar		Pearl		Tatum						
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	
1949	0	0	9	4	6	2	4	2	4	3	4	3	27	14	2	3	4
1950	1	2	8	3	3	2	4	4	2	1	5	5	23	17	1	2	3
1951	4	1	2	2	3	0	3	2	4	0	1	0	17	5	2	1	3
1952	1	0	2	2	3	3	0	0	1	0	2	1	9	6	0	0	1
1953	1	2	3	1	1	0	3	2	1	1	3	3	12	9	1	1	1
1954	4	3	5	3	6	0	3	3	2	2	3	1	23	12	2	1	4
1955	2	1	3	3	2	2	2	1	4	3	3	2	16	12	1	2	3
1956	0	0	2	1	2	2	2	1	0	1	3	3	9	8	1	2	3
1957	2	[2] 1	5	2	2	3	3	3	3	2	3	3	18	[2] 14	1	[2] 2	4
1958	5	3	2	3	4	5	6	3	4	3	8	6	29	23	4	3	5
1959	3	2	3	4	1	2	2	1	1	2	3	1	13	12	1	0	2
1960	(1)	(1)	5	3	7	6	7	6	6	3	8	5	[2] 33	[2] 23	[2] 5	[2] 4	5
1961	(1)	(1)	1	1	2	3	3	2	3	3	6	2	[2] 15	[2] 11	[2] 2	[2] 1	4
Average	2	1	4	2	3	2	3	2	3	2	4	3	------	------	2	2	3

[1] Records not available.
[2] Partial record for year.

In this report, excess precipitation is defined as more then 1 inch of rainfall in 24 hours. The first inch of rainfall presumably satisfies soil-moisture deficits or evaporates; larger amounts appear as in runoff. Field observations of rainfall and runoff indicate that this figure is a reasonable estimate.

The precipitation data for northern Lea County were used in estimating the amount of excess precipitation. The excess precipitation estimated for each year from 1949 through 1960 and the average for that period follow:

Year	*Estimated excess precipitation (inches)*	*Year*	*Estimated excess precipitation (inches)*
1949	4.14	1956	1.61
1950	3.25	1957	2.65
1951	1.74	1958	6.13
1952	.25	1959	1.66
1953	1.19	1960	12.34
1954	5.08		
1955	3.84	Average	3.66

The number of days between the last killing frost in the spring and the first killing frost in the fall and the amount of precipitation during this growing season for the Hobbs, Lovington, Maljamar, Pearl, and Tatum weather stations for 1949–61 follow:

Weather station	Average dates		Average length (days)	Average precipitation during growing season, 1949–61	
	From—	To—		Inches	Percent of yearly precipitation
Hobbs	May 10	Nov. 8	214	12.81	84.8
Lovington	May 15	Oct. 28	196	12.06	79.7
Maljamar	Apr. 10	Oct. 31	204	11.70	89.6
Pearl	Apr. 7	Nov. 4	211	10.18	77.3
Tatum	Apr. 21	Oct. 25	194	12.62	76.9
Overall average	Apr. 13	Oct. 31	204	11.87	83.1

An evaporation station was operated approximately 3 miles east of Lovington from January 1960 through March 1961. For that period, evaporation averaged 0.09 inch per day. Average daily evaporation from May through August 1960 was 0.36 inch. The monthly evaporation for 1960 and part of 1961 is compared with that from the Lake Avalon, N. Mex., evaporation pan, listed in table 3. Lake Avalon is about 4 miles north of Carlsbad and about 40 miles west of the study area. Total wind movement in miles measured at Lovington is compared with that at Lake Avalon in table 3. The altitude at Lake Avalon is 3,208 feet and at the Lovington evaporation pan, approximately 3,870 feet. The lower altitude and higher mean temperature at Lake Avalon may account for the higher evaporation rate there despite the greater wind movement at Lovington, but differences in exposure are frequently of greater significance.

TABLE 3.—*Comparison of monthly evaporation and wind movement, 1960–61, Lovington and Lake Avalon, N. Mex.*

Date	Lake Avalon		Near Lovington		Ratio, Lake Avalon to Lovington	
	Evaporation (inches)	Wind movement (miles)	Evaporation (inches)	Wind movement (miles)	Evaporation (inches)	Wind movement (miles)
1960						
Jan	[1] 2. 94	2154	2. 42	--------	1. 21:1	--------
Feb	[1] 6. 04	3315	3. 64	--------	1. 66:1	--------
Mar	[1] 8. 04	2860	7. 15	--------	1. 12:1	--------
Apr	12. 19	2981	9. 79	--------	1. 22:1	--------
May	15. 11	3046	14. 57	--------	1. 04:1	--------
June	13. 41	1928	11. 93	--------	1. 12:1	--------
July	[1] 10. 99	1282	7. 98	--------	1. 38:1	--------
Aug	12. 60	2347	10. 15	--------	1. 24:1	--------
Sept	9. 67	1693	9. 22	2208	1. 05:1	0. 78:1
Oct	[1] 6. 71	1710	6. 02	2610	1. 12:1	0. 58:1
Nov	4. 54	1752	4. 64	2955	0. 98:1	0. 59:1
Dec	[2] 1. 45	1580	[2] 1. 04	2683	--------	0. 59:1
1961						
Jan	[1] 2. 71	1860	2. 41	2727	[2] 1. 12:1	0. 68:1
Feb	4. 56	2346	[2] 3. 06	3242	[2] 1. 49:1	0. 72:1
Mar	[1] 8. 55	3272	6. 62	3976	1. 29:1	0. 82:1

[1] Adjusted to a full month.
[2] Partial record.

GENERAL GEOLOGY

Nearly all the sedimentary rocks exposed in northern Lea County are of Tertiary or Quaternary age. Older rocks crop out in only two places—rocks of Late Triassic age along Mescalero Ridge and rocks of Early Cretaceous age on the west side of the northernmost of the Four Lakes. Rocks of Precambrian and Paleozoic age are present only in the subsurface and reportedly do not contain potable water. The only formations of importance to this study are the Ogallala Formation of Tertiary (Pliocene) age, the principal aquifer in northern Lea County, and the underlying formations which retard greatly or prevent the downward movement of water from the Ogallala Formation.

ROCKS OF TERTIARY AND QUATERNARY AGE

The Ogallala Formation of Tertiary age underlies most of the High Plains. Most authors consider it to be of Pliocene age (Cronin, 1961, p. 35), probably deposited by meandering streams. According to Bretz and Horberg (1949, p. 477), "The Ogallala formation * * * has been universally interpreted as a fluviatile apron deposited east of the Rocky Mountain front * * *."

The Ogallala is as much as 350 feet thick near Mescalero Ridge (Ash, 1963), but it wedges out in the northern part of Lea County where it laps against Cretaceous rocks. The Ogallala probably was deposited by aggrading streams flowing across a post-Mesozoic erosional surface. The surface of the High Plains is correlated by Horberg (1949, p. 464) with the Sacramento plain, possibly of Pliocene age, which truncates the Sacramento Range west of the Pecos River.

The sediments of the Ogallala Formation generally are fine to very fine sand, poorly to moderately well cemented by calcium carbonate. Silt and clay predominate in some sections. The test-hole logs penetrating the upper few feet of the formation could not be correlated where the distance between holes was more than 300 yards (pls. 2, 3; figs. 3–5). Lithologic sections of the Ogallala are given by Theis (1934, p. 131–135), Ash (1963), and Nicholson and Clebsch (1961, fig. 15).

The Ogallala Formation is the principal aquifer of the High Plains. The hydrology of the aquifer is discussed in the section on aquifer characteristics.

Quaternary lakebed sediments consisting of clay, silty sand, and silt have been dated from a fossil snail assemblage collected during test drilling in a depression northwest of Lovington in lot 5, sec. 1, T. 16 S., R. 35 E. These fossils have been identified by D. W. Taylor (written commun., 1962), of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey. Two suites of fresh-water and land snails gathered from 5 to 12 feet below the depression floor contain a single fossil (*Dinoceras laeve*) not known earlier than in the Illinoian Glaciation of Late Pleistocene age; the other snails occur in Pliocene, Pleistocene, or Recent deposits.

Several fragments of what appear to be algal limestones were also present in this section. These sediments were probably deposited in shallow-water lakes.

These Quaternary lakebed sediments in this part of the High Plains probably are not capable of transmitting more than small quantities of water. Because they are confined to depressions, the total area occupied by these sediments is not great.

Sediments of Recent age mantle much of the surface of Lea County. These sediments consist of sandy to silty or clayey loams containing calcareous and organic material, underlain at shallow to moderate depths by caliche.

Much of the surficial material on the High Plains probably is eolian. This hypothesis is not at all unreasonable because winds attain velocities of 50 to 60 miles per hour for sustained periods during some seasons of the year. Another source of surface material is the breakdown of caliche containing sand and silt of eolian origin (Brown, 1956, p. 14–15).

Caliche is at or near the surface throughout most of the High Plains. Its contact with the underlying sand of the Ogallala Formation is generally gradational. Caliche from 0 to 22 feet thick has been measured in outcrops.

The age of the caliche has not been determined, but the gradational contact between the caliche and the Ogallala Formation indicates that little if any hiatus occurred between the final deposition of the Ogallala and formation of the caliche. Formation of caliche has probably continued to the present.

Many attempts have been made to account for the origin of the thick deposits of caliche over the High Plains region. Most authors theorize that the caliche has been precipitated by ascending or descending water in a soil profile. Others suggest chemical or organic precipitation in shallow lakes as the origin. Most present evidence seems to support the theory of a precipitate around plant roots in an eolian, aggrading soil (Brown, 1956, p. 14–15).

The caliche is predominantly calcium carbonate with minor amounts of sand and finer materials, although siliceous cement and cracks filled with opal or chalcedony have been observed. Near the surface, the caliche commonly is a hard, well-indurated limestone, blocky and slabby in exposure; it grades at depth to a soft, friable, chalky material. In borrow pits, from which caliche has been removed for use as road metal, near-surface slabs 2 to 3 feet long and 4 to 6 inches thick are separated from adjoining slabs by open joints half an inch or more wide. The slabs lie in planes parallel to the general slope of the land surface. The size of the slabs decreases downward, and the caliche grades into softer, more porous material which extends to the top of the Ogallala Formation. (See fig. 6.)

Masses of concentrically banded caliche as much as 8 feet in diameter and 4 feet in thickness are present in many places within the softer caliche in the lower part of the caliche section (fig. 7). These caliche masses have a well-indurated inner part of irregularly shaped fractured or rounded fragments or of banded caliche (fig. 8). Similar features occur in the slabby caliche at the top of the section.

The color of the hard caliche at a new break varies from very dark brown or black to very light pink or nearly colorless. Softer caliche is a light yellowish gray, light greenish gray, or light brown. Caliche

FIGURE 6.—Caliche exposed in borrow pit (lot 13, sec. 6, T. 16 S., R. 36 E.) showing blocky and slabby character and gradation to finer material at depth (1-foot rule indicates scale).

FIGURE 7.—Rounded caliche boulders in borrow pit west of Lovington. These boulders have been moved; hammer rests on a boulder that probably is in place.

FIGURE 8.—Exterior banding and heterogeneous interior features of caliche boulders.

weathers from a light gray or tan on horizontal surface exposures to a medium dark brown on exposures along the cliff faces of Mescalero Ridge.

Several reports have been made about water-bearing caliche on the High Plains outside Lea County (Cronin, 1961, p. 41). Cavernous caliche is reported in Lea County (Nye, 1930, p. 12). In northern Lea County, however, the caliche is well above the water table and is not a water-bearing formation.

GROUND WATER IN THE OGALLALA FORMATION

The principal source of water to wells in northern Lea County is the Ogallala Formation. Prior to the extensive drilling of geophysical prospect holes, two water-bearing zones were reported in parts of the area. A stratum containing "windmill water" is reported to be at shallow depths near Lovington. Northwest of Tatum, in the vicinity of well 11.33.25.442, one rancher indicated that in 1917 and later an artesian aquifer was a few feet below a water-table aquifer at shallow depth (R. W. Epperson, oral commun., 1961). These aquifers at shallow depth probably were perched-water zones overlying clayey materials or indurated caliche in the Ogallala Formation that have since been drained through geophysical prospect holes.

According to Ash (1963), depths to water in the Ogallala range from less than 12 feet a few miles east of Caprock to almost 300 feet along Mescalero Ridge. The saturated thickness of the formation ranges from less than 25 feet to about 250 feet. The zone of saturation is thinnest in the northeastern part of Lea County where the Ogallala Formation is thin.

HYDROLOGIC CHARACTERISTICS OF THE OGALLALA FORMATION

The yield of a properly constructed well depends primarily on the hydraulic properties of the aquifer tapped by the well. These properties include permeability, transmissibility, and storage or specific yield. The coefficient of permeability commonly is expressed as the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at a temperature of 60° F. Viscosity of fluid contained in an aquifer is a function of temperature, and the range of temperature in most aquifers is small; therefore, the correction for temperature variance commonly is disregarded. The coefficient of permeability in terms of prevailing temperature is referred to as the field coefficient of permeability. Laboratory determinations of permeability are corrected to 60° F.

The coefficient of transmissibility is expressed as the rate of flow of water, at the prevailing water temperature, in gallons per day through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent. The coefficient of transmissibility may be considered equal to the product of the field coefficient of permeability and the saturated thickness of the aquifer.

The coefficient of storage is defined as the volume of water that is released from or taken into storage in a vertical prism of the aquifer with a base 1 foot square as the water level declines or rises 1 foot. For unconfined aquifers the coefficient of storage is approximately the same as the specific yield, which may be expressed as the ratio of the volume of water that saturated material will yield by gravity to its own volume.

The field coefficients of permeability, transmissibility, and storage can be determined by controlled pumping tests. These coefficients are used in formulas to compute the quantity of water that a well or wells might be expected to yield with specified drawdown in the pumped wells and in other wells. Quantitative estimates, therefore, may be made of the amount of water that an aquifer will yield if the following conditions can be satisfied or accounted for mathematically: (1) The aquifer is equally permeable in all directions, (2) the aquifer is of infinite extent, (3) the wells penetrate the full thickness of the aquifer, (4) the coefficient of transmissibility is constant throughout the aquifer, and (5) the aquifer releases water from storage instantly with a decline in water level. Some variance from the above idealized conditions can be accommodated mathematically without undue distortion of the quantitative estimate.

Nye (1932, p. 249) reported a pumping test at well 17.37.26.400 in Lea County. On the basis of Nye's report, Theis (1934, p. 137) estimated the coefficient of permeability of the aquifer at this well to be 306 to 356 gpd per ft per ft (gallons per day per foot per foot) and the coefficient of transmissibility to be 53,550 to 62,300 gpd per ft (gallons per day per foot).

Moulder and Frazor (1957, p. 15) concluded that coefficients of transmissibility ranged from 6,000 to 7,000 gpd per ft in the McDonald well field near Amarillo, Tex. The coefficient of permeability would be between 160 and 190 gpd per ft per ft. Cronin and Wells (1960, p. 35) conducted a 120-day pumping test of the Ogallala Formation near Plainview, Tex., and estimated that the coefficient of transmissibility was between 24,000 and 38,000 gpd per ft and the coefficient of permeability between 100 and 170 gpd per ft per ft.

Coefficients of transmissibility ranging from 109,000 to 325,000 gpd per ft were computed from data obtained by recharging the aquifer through recharge well 2 in sec. 5, T. 16 S., R. 37 E. These values are inconclusive because of their large range. The large range in coefficients is attributed to poor test conditions arising from fluctuating recharge rates caused by variations in the degree of screen clogging.

Analysis by the U.S. Geological Survey hydrologic laboratory of recompacted samples of sand from a Lovington city well (16.36.10.241) gave the following hydrologic characteristics:

Specific gravity	2.68
Dry unit weight g per cc	1.46
Specific retention percent	7.1
Porosity do	45.5
Specific yield do	38.4
Coefficient of permeability gpd per ft per ft	100

Laboratory determinations of permeability of sediments from above the saturated section of the aquifer along Mescalero Ridge are given by Theis (1934, p. 133). The highest coefficient of permeability is 125 gpd per ft per ft, the lowest 15, and the average 60.

For administration of the Lea County Underground Water Basin, the New Mexico State Engineer uses a coefficient of transmissibility of 100,000 gpd per ft as an average transmissibility for the Ogallala Formation.

The specific yield of a few samples of the Ogallala Formation from northern Lea County have been determined by laboratory methods. The average specific yield of samples collected by Theis (1934) was 27.8 percent. The recompacted sample of sand pumped from a Lovington city well in 1961 had a specific yield of 38.4 percent. Tertiary sand from the southern High Plains in Texas (Barnes and others, 1949, p. 40–41) had an average of 29.2 percent for 8 samples. Data from pumping and recharging tests and laboratory determinations indicate that the specific yield of the Ogallala Formation in the southern High Plains is about 15 percent (Cronin, 1961, p. 46).

From 1930 through January 1955 a net of about 936,000 acre-ft (acre-feet) of ground water was pumped in northern Lea County. Annual water-level-change maps prepared by the Geological Survey indicate that this pumpage dewatered 3,879,000 acre-ft of sediments. On the basis of the preceding figures and if recharge other than irrigation return was negligible, the specific yield of the Ogallala Formation is 24 percent.

The New Mexico State Engineer uses a specific yield of 20 percent in administering the ground-water rights in the Lea County Underground Water Basin, and this figure will be used in this report. This figure of 20 percent has been questioned in hearings before the State Engineer, and most witnesses have agreed that it is reasonable.

The porosity of 23 samples of the Ogallala as reported by Theis (1934, p. 133) ranged from 33.4 to 47.4 percent and averaged 36.2 percent. The porosity of a sample from a well in Lovington was 45.5 percent. An average porosity of 40 percent possibly would not be an unreasonable assumption for the purposes of this report.

HYDROLOGIC CHARACTERISTICS OF PLEISTOCENE AND RECENT SEDIMENTS

Overlying materials directly affect recharge to the Ogallala Formation. Permeabilities of caliche core samples obtained by test drilling in 1959 were low (analyses by New Mexico State Engineer Office):

Test hole	Location	Interval sampled (feet below land surface)	Coefficient of permeability (gpd per ft per ft)
TH-4D	15. 33. 2. 100	12 to 14	0. 00062
TH-5A	15. 34. 6. 300	22 to 23	. 00139
TH-7A	16. 36. 24. 300	22 to 30	2. 94
TH-9G	16. 32. 29. 200	14 to 18	. 0198

Permeabilities in table 4 are for Pleistocene or Recent sediments from the slopes and bottoms of selected depressions. Samples from the floors of depressions have very low permeabilities, while materials below the surface and on the slopes of the depressions have slightly higher permeabilities.

TABLE 4.—*Hydrologic characteristics of Pleistocene and Recent sediments from northern Lea County, N. Mex.*

[Determined in U.S. Geol. Survey hydrol. lab.]

Location	Depth (feet)	Specific gravity	Dry unit weight (g per cc)	Specific retention (percent)	Porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd per ft per ft)	Remarks
16.37.6.lot 15	0. 1–0. 25						0. 0004	Bottom of depression.
6.lot 6	. 2– . 3	2. 67	1. 37	46. 0	48. 7	2. 7	. 0001	Do.
6.lot 6	2. 9–3. 2	2. 70	1. 54	32. 4	43. 0	10. 6	70	Do.
6.lot 7	. 3– . 5						. 02	Do.
5.lot 15	. 25– . 4						26	Side of depression.
5.lot 15	5. 1–5. 3	2. 71	1. 44	27. 8	46. 9	19. 1	. 2	Bottom of depression.
5.414	. 2– . 4						. 2	Do.
16.32.20.334	. 25– . 4						. 02	Do.
20.334	2. 2–2. 4	2. 66	1. 49	45. 2	45. 2	. 0	. 0003	Do.

NATURAL DISCHARGE

Most of the natural discharge of the main aquifer in northern Lea County is underflow from the area. A small amount of underflow moves to the south half of Lea County through continuous hydrologic connections with Quaternary aquifers (Nicholson and Clebsch, 1961, pl. 2), but most of the underflow moves eastward through the Ogallala Formation into Texas.

Underflow (table 6) may be computed by using the formula

$$Q=P_f\, I\, mw$$

where

Q= quantity of underflow, in gpd,
P_f= field coefficient of permeability, gpd per ft per ft,
I= hydraulic gradient, in feet per mile,
m= thickness of saturated section, in feet, and
w= width of section of flow in miles.

In 1952, a 47.5-mile section near the Texas-New Mexico State line had an average saturated thickness of 130 feet. The hydraulic gradient, the slope of the water table to the southeast, ranged from 4.6 to 21.7 feet per mile, averaging 15 feet per mile along this saturated section. Three estimates of field permeability were used to compute underflow. Theis (1934, p. 151) used P_f values of 60 and 325 gpd per ft per ft in computing underflow in northern Lea County. The New Mexico State Engineer office uses a transmissibility of 100,000 gpd per ft for administration of the Lea County basin. Transmissibility is the product of field permeability and the saturated thickness; therefore, the 130-foot-thick saturated section along the State line has a field permeability of about 770 gpd per ft per ft if the transmissibility is 100,000 gpd per ft.

Underflow to Texas would be about 7,000 acre-ft per year if P_f=60 gpd per ft per ft; about 36,000 if P_f=325; and about 84,000 if P_f=770. This author believes that a P_f of 325 gpd per ft per ft is a reasonable estimate of permeability of the Ogallala in Lea County and that underflow is about 36,000 acre-ft per year.

Springs and seeps discharge small amounts of water along Mescalero Ridge. A few small lakes intersect the water table in the northern part of Lea County, and water is discharged from the lake surface by evaporation.

The water table in much of Lea County lies below the depth at which evapotranspiration can discharge ground water. Transpiration by vegetation is confined generally to the vicinity of springs and seeps. and natural discharge from these areas is not great. Deeply penetrating roots of phreatophytes such as mesquite may reach the water table in some areas (Robinson, 1958, p. 14); however, this transpiration potential is small in Lea County.

ARTIFICIAL DISCHARGE

About 1,650 wells were yielding water for industrial, municipal, irrigation, and secondary-oil-recovery uses in northern Lea County in 1962. The amount of ground water pumped each year in the area is computed from electric-power records and pump ratings for selected wells. Pump ratings consist of determinations of the amount of water pumped from a well per unit of power consumed. A tabulation of the estimated acre-feet of water pumped in northern Lea County during 1930–60 is given in table 5.

TABLE 5.—*Estimated pumpage, in acre-feet, in northern Lea County, N. Mex., 1930–60*

[Adapted from U.S. Geol. Survey Water-Supply Papers "Water Levels and Artesian Pressures in Observation Wells in the United States" for various years and biennial reports and technical reports of the New Mexico State Engineer. Net pumpage for irrigation is five-sixths of gross pumpage; one-sixth of irrigation pumpage returns to the aquifer by deep percolation]

Year	Pumpage for irrigation		Pumpage for other uses	Total pumpage	
	Gross	Net		Gross	Net
1930	500	400	5, 600	6, 100	6, 000
1931	800	700	5, 400	6, 200	6, 100
1932	900	700	5, 700	6, 600	6, 400
1933	1, 200	1, 000	5, 800	7, 000	6, 800
1934	1, 500	1, 200	5, 800	7, 300	7, 000
1935	1, 500	1, 200	5, 800	7, 300	7, 000
1936	1, 500	1, 200	5, 700	7, 200	6, 900
1937	1, 800	1, 500	5, 700	7, 500	7, 200
1938	1, 700	1, 400	7, 000	8, 700	8, 400
1939	2, 200	1, 800	7, 000	9, 200	8, 800
1940	3, 200	2, 700	6, 400	9, 600	9, 100
1941	1, 600	1, 300	6, 000	7, 600	7, 300
1942	3, 500	2, 900	6, 000	9, 500	8, 900
1943	6, 000	5, 000	6, 500	12, 500	11, 500
1944	3, 500	2, 900	7, 000	10, 500	9, 900
1945	6, 500	5, 400	7, 000	13, 500	12, 400
1946	3, 500	2, 900	7, 000	10, 500	9, 900
1947	19, 000	15, 800	8, 000	27, 000	23, 800
1948	39, 000	32, 500	8, 000	47, 000	40, 500
1949	60, 000	50, 000	8, 000	68, 000	58, 000
1950	95, 000	79, 000	9, 000	104, 000	88, 000
1951	153, 000	127, 000	10, 000	163, 000	137, 000
1952	166, 000	138, 000	10, 000	176, 000	148, 000
1953	165, 000	137, 000	14, 000	179, 000	151, 000
1954	163, 000	136, 000	14, 000	177, 000	150, 000
1955	170, 000	142, 000	15, 300	185, 300	157, 300
1956	160, 000	133, 000	18, 600	178, 600	151, 600
1957	140, 000	117, 000	18, 600	158, 600	135, 600
1958	107, 000	89, 000	18, 800	125, 800	107, 800
1959	149, 000	124, 000	18, 800	167, 800	142, 800
1960	105, 000	87, 000	18, 800	123, 800	105, 800
Total	1, 732, 400	1, 441, 500	295, 300	2, 027, 700	1, 736, 800

RECHARGE TO THE AQUIFER

Recharge to the aquifer in the Ogallala is from precipitation and seepage from irrigation (return irrigation water). Water entering the aquifer from precipitation is "new water" because it has not been in the ground-water system; seepage from irrigation is "old water" because it is the return to the aquifer of water that was temporarily withdrawn.

The quantity of return irrigation water varies greatly from field to field within northern Lea County. Accurate determinations of the percentage of return to the aquifer have not been made. The New Mexico State Engineer's office estimates return irrigation water as 0.5 acre-ft for every 3.0 acre-ft of water pumped—an amount equivalent to 16⅔ percent of the pumpage for irrigation (J. R. Yates, written commun., 1952). Deep percolation losses from fields may be as high as 25 percent in very sandy soils; possibly 12½ percent of this loss may recharge the aquifer (J. I. Wright, oral commun., 1963). An estimate of 16⅔ percent may be too high in northern Lea County, because much of the soil is silty and clayey and would inhibit deep percolation. Irrigation water returned as recharge to the aquifer in the Ogallala is probably 5 to 20 percent of the estimated irrigation pumpage. A return of 16⅔ percent of the total irrigation pumpage, as estimated by the State Engineer, was used in computing return irrigation water shown in table 5. It is estimated that in the period 1949–60, the average annual recharge from pumpage for irrigation amounted to about 23,000 acre-ft.

Several investigators have attempted to determine the amount of recharge that is derived from precipitation. C. V. Theis (1934, p. 152) used water-level fluctuations in wells, measurement of flow of ground water, permeability data from a pumping test, and comparison of hydrologic data from the Portales Valley (about 50 miles north of Lea County) to estimate annual recharge in Lea County. According to Theis (1934, p. 152), "no plausible method of estimating the recharge from the data available can be made to indicate more than 1 inch of recharge a year, and * * * independent methods of approach to the problem converge on a recharge of half an inch a year or less." White, Broadhurst, and Lang (1946, p. 381) estimated that a small fraction of an inch replenishes the aquifer yearly. Barnes and others (1949, p. 26–27) and Cronin (1961, p. 65) agree that annual recharge is probably of the order of magnitude given by Theis.

Additional data on pumpage, water-level changes, and precipitation gathered in northern Lea County since the estimate by Theis make possible another method of estimating the annual recharge. This method uses the relation:

$$\text{Recharge} = \text{net withdrawal} + \text{change in ground-water storage} + \text{natural discharge (underflow)}.$$

Estimates of the recharge that is attributed to precipitation are summarized in table 6. The net charge in ground-water storage was computed by the use of water-level-change maps and a specific yield

TABLE 6.—*Estimated recharge to the Ogallala Formation from precipitation, northern Lea County, N. Mex.*

Period	Net pumpage (acre-ft)	Decrease (−) or increase in ground-water storage (acre-ft)	Net pumpage plus storage change		Summation of recharge equivalents, in inches per year, if underflow recharge equivalent is—		
			Sum (acre-ft)	Recharge equivalent (inches per year)	0.06 inch per year [1]	0.31 inch per year [2]	0.72 inch per year [3]
1930–39	71,000	0	71,000	0.06	0.12	0.37	0.78
1940–49	191,000	96,000	287,000	.24	.30	.55	.96
1950–60	1,475,000	−772,000	703,000	.55	.61	.86	1.27
1930–49	262,000	96,000	358,000	.15	.21	.46	.87
1930–60	1,737,000	−675,000	1,062,000	.30	.36	.61	1.02
1948	40,000	−78,000	−38,000	−.32	−.26	−.01	.40
1949	58,000	−46,000	12,000	.10	.16	.41	.82
1950	88,000	−79,000	9,000	.08	.14	.39	.80
1951	137,000	−112,000	25,000	.21	.27	.52	.93
1952	148,000	−162,000	−14,000	−.12	−.06	.19	.60
1953	151,000	−142,000	9,000	.08	.14	.39	.80
1954	150,000	−77,000	73,000	.62	.68	.93	1.34
1955	157,000	46,000	203,000	1.74	1.80	2.05	2.46
1956	152,000	−124,000	28,000	.24	.30	.55	.96
1957	135,000	−78,000	57,000	.49	.55	.80	1.21
1958	108,000	−41,000	67,000	.57	.63	.88	1.29
1959	143,000	−98,000	45,000	.38	.44	.69	1.10
1960	106,000	97,000	203,000	1.74	1.80	2.05	2.46

[1] Underflow computed as 7,000 acre-ft per year from $P_f=60$ gpd per ft per ft.
[2] Underflow computed as 36,000 acre-ft per year from $P_f=325$ gpd per ft per ft.
[3] Underflow computed as 84,000 acre-ft per year from $P_f=770$ gpd per ft per ft.

of 20 percent as used by the State Engineer. The amount of recharge that would be necessary to equal the sum of net withdrawal and storage change is termed equivalent recharge. Similarly, the amount of underflow also is considered in terms of equivalent recharge.

The amount of underflow will fluctuate slightly from year to year according to the relative thickness of the saturated section and the hydraluic gradient. Continued pumping at the present (1962) rate, or unrestricted pumping near the State line, will decrease the amount of underflow, but it probably has not been greatly reduced during the period of record.

The various amounts of underflow per year, as described in the section on natural discharge, when reduced to equivalent recharge are 0.06, 0.31, and 0.72 inch per year. The author believes that 0.31 is closest to the true value. The total recharge from precipitation computed from the average equivalent of 0.82 inches per year for the period 1949–60 amounts to about 95,000 acre-ft per year. (See table 9.)

FACTORS THAT INFLUENCE RECHARGE FROM PRECIPITATION

The factors that influence recharge from precipitation include the intensity, duration, and distribution of precipitation, the soil-moisture content, the permeability of the material through which recharge water must move, and evapotranspiration opportunity.

In northern Lea County about 80 percent of the precipitation is during the growing season. In many areas the precipitation for a

24-hour period may take place in 2 to 3 hours with the result that not all the water infiltrates the ground where it falls, but some runs off. About 25 percent of the excess precipitation is runoff to the depressions.

Materials of low permeability at the land surface prevent or greatly retard infiltration and promote runoff to the depressions. The hard, dense caliche that covers large areas in Lea County has a very low permeability. Cracks as wide as half an inch may form between large slabs of dense caliche and increase the permeability locally. In gross the permeability of the dense caliche is estimated to be as high as 20 gpd per sq ft. Material of low permeability (silt and clay) is also present in the bottoms of most of the swales and depressions (table 4).

About 75 percent of the precipitation that infiltrates the soil either is discharged by evapotranspiration in the upper part of the soil profile or percolates to depths beyond the reach of plants and evaporation. The opportunity for evapotranspiration is high where water is intercepted by a vegetative cover; however, the vegetation will retard runoff and give the water an opportunity to enter the ground near the point where it hits the earth. In some places recharge would be greater under a vegetative cover than upon barren ground.

Some of the water en route to the zone of saturation may be retained in the unsaturated section by capillary or molecular attraction. Less permeable zones within the Ogallala Formation will inhibit the downward movement of water, and extensive, flat-lying layers of silty or clayey sediments may perch small bodies of water above the main water table.

Sand dune areas offer the best opportunity for natural recharge because they are highly permeable and quickly absorb precipitation.

Some of the water that ponds in a depression is discharged by evaporation before it can infiltrate the bottom of the depression. No studies were made during the project to determine the rate of evaporation from pond surfaces; however, the rate of evaporation can be estimated from the evaporation rate from a class A land pan. The results of other investigators (Linsley, Kohler, and Paulhus, 1949, p. 163) who have studied evaporation rates generally show that evaporation rates from pond and lake surfaces are between 0.6 and 0.8 (referred to as pan coefficients) of that from class A land pans. Evaporation rates from water surfaces in the broad shallow depressions of Lea County may be about equal to that of the land pan, or have a pan coefficient of about 1.0. A pan coefficient of about 0.8 is probably a reasonable one to use as an average for estimating evaporation from water surfaces in the depressions of northern Lea County.

NATURAL RECHARGE IN SELECTED DEPRESSIONS

After a rainfall in July 1960, water ponded in six depressions that had been selected for studies of natural recharge. Most of the water in these depressions dissipates naturally by evaporation and infiltration. Transpiration by vegetation in the bottoms of some depressions may account for some water loss. Some of the infiltrating water percolates to the water table and causes temporary mounding of the water table beneath the depressions.

The volume of water in depression 2–RP and amount of water loss are shown in table 7 for July 7–22, 1960. The total loss of water less the evaporation loss is the loss from other causes, which is assumed to be the loss by infiltration through the side and bottom of the depression. Water levels rose about 1 foot in observation well 2–E (16.37.5.lot 10) and about 1.8 feet in well 2–F (16.37.5.lot 15; fig. 9). Water loss from the depression during the period of record was 6.6 acre-ft, of which 1.0 acre-ft is attributed to evaporation and 5.6 acre-ft to infiltration.

In July and October 1960 rainfall filled many depressions in Lea County. Observations of water levels in depression 2–RP, depression

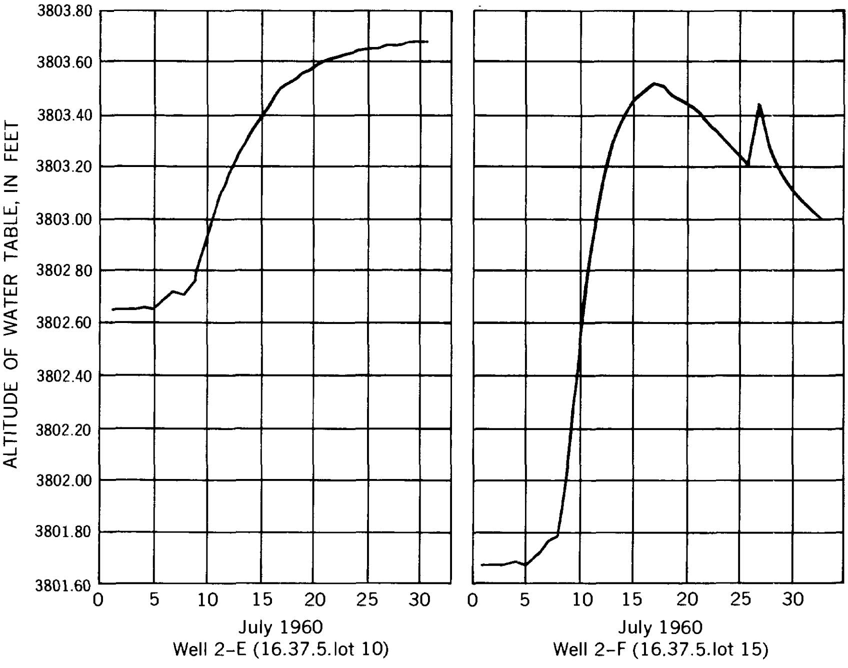


FIGURE 9.—Water-level fluctuations in wells 2–E (16.37.5.lot 10) and 2–F (16.37.5.lot 15) that was caused by natural infiltration after precipitation in July 1960, Lea County recharge project. Datum is mean sea level.

TABLE 7.—*Computed loss of water, July 7–22, 1960, from depression 2–RP (lot 15, sec. 5, T. 16 S., R. 37 E.) Lea County recharge project*

Date in July 1960	Staff gage reading (feet above datum)	Volume in storage (acre-ft)	Loss since preceding date		
			Computed total loss (acre-ft)	Total evaporation using pan coefficient of 0.8 (acre-ft)	Apparent infiltration (acre-ft)
7	3. 60	9. 5			
11	2. 85	6. 3	3. 2	0. 3	2. 9
13	2. 53	5. 1	1. 2	. 1	1. 1
14	2. 40	4. 5	. 6	. 05	. 55
16	2. 26	4. 1	. 4	. 08	. 32
18	2. 10	3. 6	. 5	. 13	. 37
19	2. 05	3. 4	. 2	. 12	. 08
20	2. 00	3. 2	. 2	. 08	. 12
21	1. 93	3. 0	. 2	. 08	. 12
22	1. 89	2. 9	. 1	. 07	. 03
Total			6. 6	1. 01	5. 59

3–RP, and depression 4–RP (fig. 13), evaporation from a class A land pan, and rainfall are shown in figure 10.

From July 12 to August 1, 1960, about 1 foot of water was lost from depression 2–RP. Evaporation was about 0.75 foot with a pan coefficient of 1.0, or about 0.6 foot with 0.8 coefficient. Thus, losses to other than evaporation (principally infiltration) were 0.25 to 0.40 foot. For this 19-day period infiltration in depression 2–RP amounted to 0.013 to 0.021 foot per day, or 0.097 to 0.157 gpd per sq ft.

For the period October 17–December 5, 1960, two rates of loss from depression 2–RP apply (fig. 9). From October 17–28 about 180,000 gal. (gallons) of water was artifically recharged through recharge well 2–RP, and the apparent loss was 0.031 to 0.034 foot per day. From October 28 through December 5 the apparent loss was 0.004 to 0.007 foot per day.

In addition to draining the pond for artificial recharging, two other factors may have caused this change in apparent rate of loss on October 28: (1) the water level may have receded to less permeable sediments on the sides of the depression or (2) freezing temperatures on or after October 31 may have killed vegetation in the pond area and eliminated transpiration losses. If transpiration losses have been eliminated from the readings of October 28 to December 5, a rate of 0.004 to 0.007 foot per day may closely approximate the true infiltration rates at this elevation in the depression. (See table 4).

Water losses from other depressions in northern Lea County are summarized in table 8. Losses from other than evaporation range from 0.09 foot per day to 0.01 foot per day at a 0.8 pan coefficient, or 0.08 to 0.01 foot per day at 1.0 pan coefficient.

TABLE 8.—*Water loss from selected depressions in northern Lea County, N. Mex.*

Depression	Observation period in 1960	Elapsed time in period (days)	Gage height above datum at start of period (feet)	Decline of water surface in period (feet)	Evaporation		Apparent infiltration rate at evaporation ratio of pond to class A land pan of—					
					Class A land pan (feet)	0.8 of class A land pan (feet)	1.0			0.8		
							In period (feet)	Average per day (feet)	Average per day (gal per sq ft)	In period (feet)	Average per day (feet)	Average per day (gal per sq ft)
2-RP [1]	July 25-Sept. 12	49	1.94	1.74	1.29	1.03	0.45	0.01	0.07	0.71	0.01	0.07
3-RP [1]	July 25-Aug. 17	23	1.46	1.09	.62	.50	.47	.02	.15	.59	.02	.15
3-RP [1]	Oct. 17-Nov. 15	29	1.48	1.05	.37	.30	.68	.02	.15	.75	.03	.22
4-RP [1]	July 25-Aug. 5	11	.85	.57	.30	.24	.27	.02	.15	.33	.03	.22
4-RP [1]	Oct. 26-Oct. 31	5	.75	.18	.08	.06	.10	.02	.15	.12	.02	.15
D-1	June 12-June 22	10	1.60	.80	.37	.30	.43	.04	.30	.50	.05	.37
D-1	July 25-Aug. 3	9	1.39	.37	.24	.19	.13	.01	.07	.18	.02	.15
D-1	Oct. 19-Nov. 23	35	1.70	1.26	.44	.35	.82	.02	.15	.91	.03	.22
D-2	June 12-June 17	5	.56	.50	.18	.14	.32	.06	.44	.36	.07	.52
D-2	Oct. 19-Oct. 31	12	.74	.70	.17	.14	.53	.04	.30	.56	.05	.37
D-8	June 13-June 27	14	.80	.64	.52	.42	.12	.01	.07	.22	.02	.15
D-8	July 21-Aug. 9	19	6.0	2.0	.4	.3	1.6	.08	.59	1.7	.09	.67
D-8	Aug. 16-Oct. 12	57	3.8	3.1	1.4	1.1	1.7	.03	.22	2.0	.04	.30
D-8	Oct. 26-Nov. 23	28	3.4	1.5	.4	.3	1.1	.04	.30	1.2	.04	.30

[1] In the depression complex that is part of the Lea County recharge project in secs. 5 and 6, T. 17 S., R. 37 E. See figure 13.

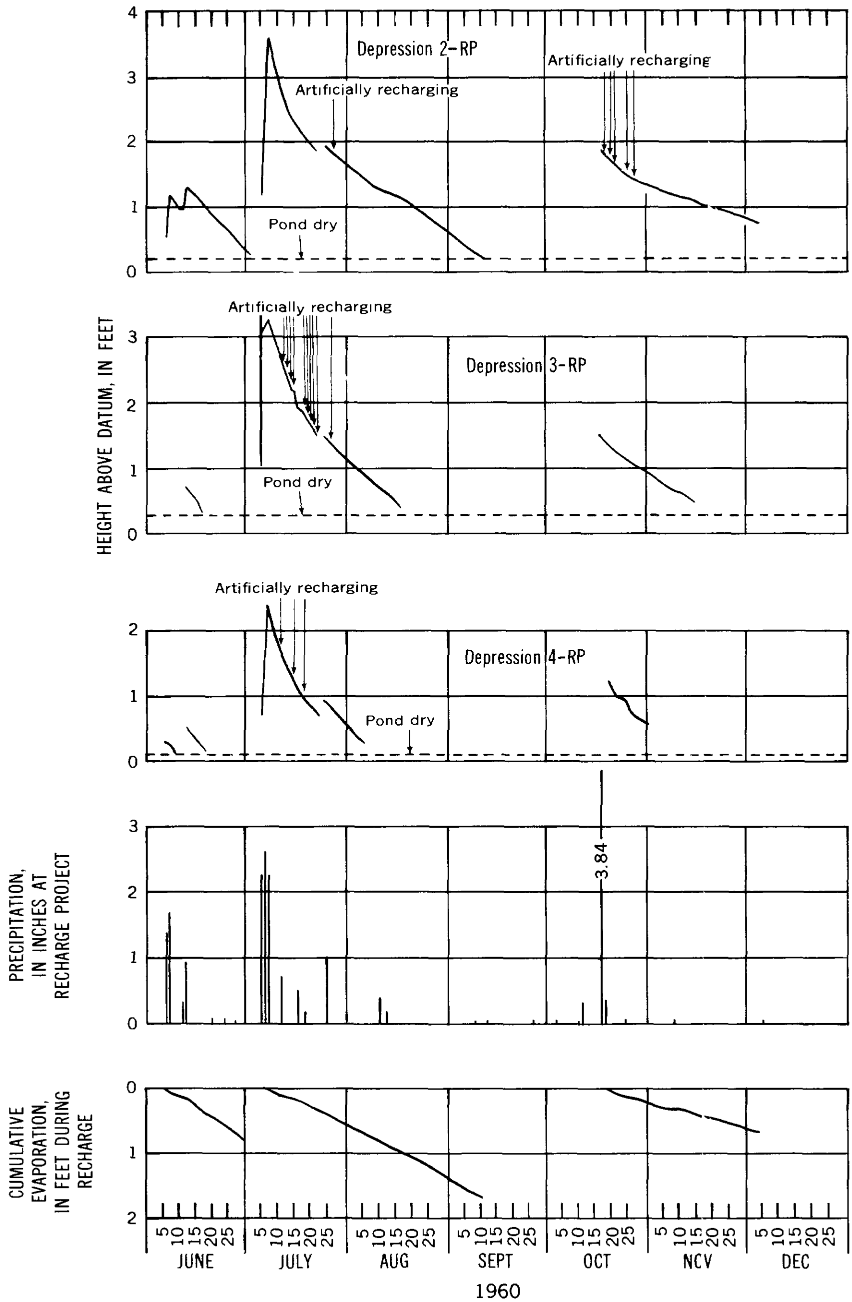


FIGURE 10.—Water-level declines in selected depressions, precipitation, and evaporation from class A land pan, June through December 1960, Lea County recharge project.

Although natural recharge through depressions will return large quantities of water to the aquifer, the process is slow and inefficient. More than 80 percent of the water in shallow ponds may be lost by evapotranspiration at a pan coefficient of unity. In depression 8 (NE¼ sec. 20, T. 16 S., R. 32 E., table 8) evaporation loss was 81 percent of the losses when the water level was less than 1 foot above the depression floor—a loss of about 3 acre-ft. When the level was 4 to 6 feet above the floor, losses were about 20 percent of the total—a loss of about 11 acre-ft. Even though the percentage of loss at the higher elevations is less, these losses are greater than the increased percentage at lower water levels.

SOURCES OF WATER FOR ARTIFICIAL RECHARGE

Sources of water other than precipitation are not readily available for artificial recharge in northern Lea County. Possibilities for increasing the amount of water available for artificial recharge in this area include the salvage of industrial waste waters and purified sewage effluents, importation of water from the Pecos or Canadian River basins, and redistribution of ground water in storage.

PRECIPITATION

The precipitation that is available for artificial recharging is the runoff from excess precipitation that collects in or can be diverted to the depressions. A comparison of the graphs in figure 11 indicates a correlation between estimated yearly recharge and excess precipitation. Two years, 1955 and 1960, are notable for recharge; in both these years precipitation was more than 4 inches above normal. In 1954, another year of greater than normal precipitation, a storm in May centered northwest of Lovington caused extensive runoff and flooding throughout the city. The Lovington weather station recorded 4.40 inches of precipitation from May 16 through 18 and an additional 1.27 inches on May 22.

About 30 percent of the excess precipitation probably recharged the aquifer during 1949–60 (table 9). Although the spread about any median value of excess precipitation as effective recharge is wide, an average of about one-third of the excess precipitation probably will recharge the ground-water reservoir; a part of the remaining two-thirds will be available for artificial recharge.

Estimated excess precipitation multiplied by 1,400,000 (acres in study area) gives the estimated potential runoff. The yearly average potential runoff for 1949–60 is approximately 400,000 acre-ft (table 9).

The approximate percentage of potential runoff which reached selected depressions during study periods is shown in table 10. Drain-

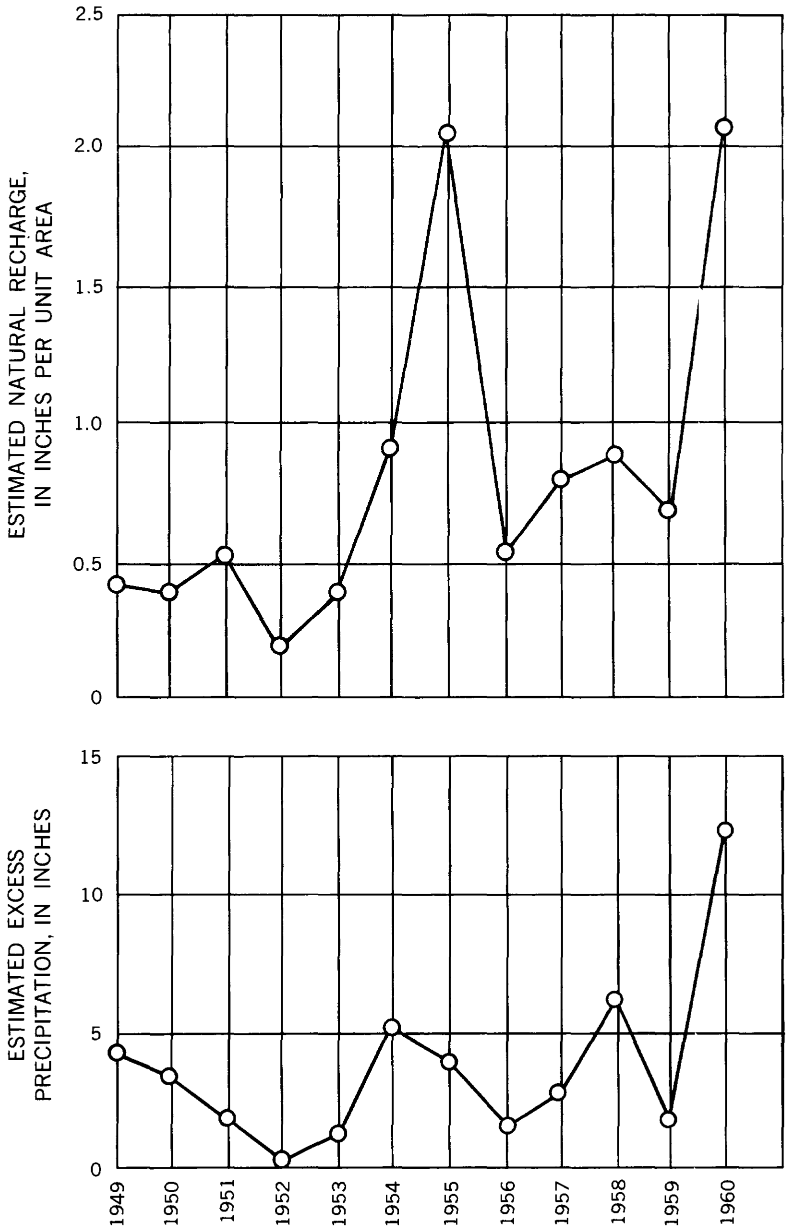


FIGURE 11.—Graphic comparison of excess precipitation and estimated recharge in northern Lea County, N. Mex., 1949–60.

TABLE 9.—*Estimated excess precipitation, natural recharge, and potential runoff 1949–60, northern Lea County, N. Mex.*

Year	Estimated excess precipitation; see page F16 (inches)	Estimated natural recharge; see table 6 (inches)	Ratio of natural recharge to excess precipitation (percent)	Estimated potential runoff (acre-ft)
1949	4.14	0.41	10	483,000
1950	3.25	.39	12	379,000
1951	1.74	.52	30	203,000
1952	.25	.19	76	29,100
1953	1.19	.39	33	139,000
1954	5.08	.93	18	593,000
1955	3.84	2.05	53	448,000
1956	1.61	.55	34	188,000
1957	2.65	.80	30	309,000
1958	6.13	.88	14	715,000
1959	1.66	.69	42	194,000
1960	12.34	2.05	17	1,440,000
Average	3.66	0.82	31	427,000

TABLE 10.—*Estimated excess precipitation, runoff, storage increase, and ratio of storage increase to runoff in selected depressions in northern Lea County, N. Mex.*

Depression	Observation date in 1960	Estimated excess precipitation (feet)	Estimated potential runoff (acre-ft)	Estimated increase in storage (acre-ft)	Ratio of storage increase to runoff (percent)
1–RP	July 5–6	0.321	73.6	10.2	13.8
1–RP	July 5–7	.505	115.8	21.0	18.1
2–RP	July 5	.104	6.5	1.3	20.0
2–RP	July 5–7	.505	31.3	9.7	31.0
2–RP	Oct. 17	.236	14.6	2.8	19.2
2–RP	Oct. 17–18	.288	17.8	2.8	15.7
3–RP	July 5	.127	9.8	1.0	10.2
3–RP	July 5–7	.510	39.2	11.8	30.1
3–RP	Oct. 17	.233	17.9	2.4	13.4
3–RP	Oct. 17–18	[1] .248	[1] 19.1	[2] 1.9	[2] 9.9
4–RP	July 5	.127	5.0	2.4	48.0
4–RP	July 5–7	.510	19.9	9.7	48.7
4–RP	Oct. 17	.233	9.1	3.9	42.9
D–1	June 12	.096	2.8	.5	17.9
D–1	July 6	.275	8.0	5.5	68.8
D–1	Oct. 19	.248	7.2	.7	9.7
D–2	June 12	.086	1.6	.2	12.5
D–2	July 6	.234	4.2	.5	11.9
D–2	Oct. 19	.258	4.6	.3	6.5
Average					24.4

[1] Precipitation data may be erroneous.
[2] Amount of storage increase may be too low by the amount of infiltration that occurred. Figures not included in average.

age areas for these depressions were taken from topographic maps and aerial photographs. The amount of water actually appearing in selected depressions compared to the estimated amount of potential runoff to those depressions ranges from 6 to 69 percent and averages about 25 percent.

Some of the variation in these figures probably can be attributed to water unaccounted for because of infiltration. The degree of accuracy in delimiting the boundaries of the drainage tributary to each depression studied also affected the accuracy of the results.

On the basis that approximately 25 percent of the potential runoff reaches the depressions throughout northern Lea County, the figures given below show the probable amounts of water in depressions in the period 1949–60.

Year	*Estimated runoff reaching depressions (acre-ft)*
1949	121,000
1950	95,000
1951	51,000
1952	7,000
1953	35,000
1954	148,000
1955	112,000
1956	47,000
1957	77,000
1958	179,000
1959	48,000
1960	360,000
Total	1,280,000
Average	107,000

OTHER SOURCES OF WATER

Precipitation is the principal source of water for artificial recharge in northern Lea County, but other sources could furnish relatively small quantities of water. Industrial- or municipal-waste-water could be returned to the aquifer if its purity, both chemical and bacteriological, were satisfactory. Water used by industries for cooling could be injected into the aquifer; but if its temperature were higher than that of the ground water, it would raise the temperature of the ground water (Suter and Harmeson, 1960, p. 31–35). The quantity of industrial water having a temperature higher than that of ground water would be too small, however, to make an undesirable temperature change in Lea County ground water.

Sewage effluent might be used for recharging the aquifer. Experimental injection of raw sewage by the University of California Sanitary Engineering Research Project showed that bacteria traveled 100 feet in 33 hours but no farther thereafter ([California] State Water Pollution Control Board, 1954, p. 165). Treated and purified effluents from sewage-disposal plants in northern Lea County would be better than raw sewage for recharging; however, chlorination probably would be necessary to meet State Health Department requirements. Frequent checks should be made to guard against pollution if sewage is used in recharging the aquifer.

The sewage-disposal plant serving the city of Hobbs discharges 2 to 4 mgd (million gallons per day) and the plant at Lovington 0.4 to 0.6 mgd. The effluent from these plants is appropriated for year-round agricultural use.

Only small quantities of waste water from industries are available for recharge in northern Lea County. Two electric-power-generation plants dispose of several thousand gallons per day of boiler-feed water into surface pits. Other sources of waste water of satisfactory purity are not known at present.

Importation of water from areas outside the High Plains could be considered either for direct use or for artificial recharge facilities. The Canadian River and the Pecos River and their tributaries are the nearest stream systems. All the water in the Pecos River is fully appropriated.

The aquifer in local areas where the water level has declined more than normal for the basin can be replenished with water obtained elsewhere within the ground-water basin. Such redistribution probably would be feasible only under the most urgent economic need, such as the threatened total depletion of a municipal-well field. Some of the water brought from distant areas could be used immediately, and any excess could be injected into the depleted part of the aquifer for later use. This process would utilize underground rather than surface storage. Experimental artificial recharging of a city-well field near Amarillo, Tex., showed that during the winter sufficient water could be injected from a more distant well field to provide for peak demands during the summer and that approximately 80 percent of the water injected was recovered (Moulder and Frazor, 1957, p. 1).

POTENTIAL RECHARGE IN THE PHYSIOGRAPHIC ZONES

ZONE 1

Zone 1, the western physiographic zone, contains about 975 square miles or about 44 percent of northern Lea County. About 1,900 depressions of various sizes, including most of the larger, better formed depressions, are in this zone. Drainage is toward the depressions. After a heavy rainfall, such as that in July 1960, most of the depressions contain water (frontispiece). When pond levels are high, water loss by natural infiltration through the more permeable materials on the slopes of the depressions is rapid, and the ratio of infiltration rate to evaporation loss is high. After the pond surface has fallen to a level where the only wetted areas are the less permeable bottoms or floors of the depressions, the infiltration rate decreases, and more is lost through evapotranspiration than through infiltration. This level generally is reached when about 1 foot of water is left, and the total amount of water remaining in all depressions below the 1-foot level in zone 1 would approximate 24,000 acre-ft. Most of this water could be drained to the ground-water reservoir by small inexpensive recharge pits or recharge wells with filtration units in the bottoms of the depressions in zone 1.

The water table in zone 1 slopes southeast toward heavily pumped areas in zones 3 and 4. Water recharged to the ground-water reservoir in zone 1, if not used in that zone, would move southeastward and would eventually be available to wells in zones 3 and 4.

If an average aquifer permeability of 325 gpd per ft per ft, a hydraulic gradient of 15 feet per mile (0.0028 ft per ft), and a porosity of 40 percent are assumed in zone 1, ground-water velocity would be about 110 feet per year. Based upon a transmissibility of 100,000 gpd per ft, an average saturated thickness of 100 feet, the same gradient, and the same porosity, the ground-water velocity may be as high as 340 feet per year. The true velocity probably lies somewhere between these two estimates.

Injection of water will increase hydraulic gradients away from the point of injection and thus increase flow velocities. Water already in the aquifer will be affected by the injected water and, although water injected in zone 1 may take several years to reach more heavily pumped areas in zones 3 and 4, its hydraulic effects will be observed much sooner.

Ground water is pumped in zone 1 primarily for industrial or commercial use, but the demand is not as large as in the areas pumped for irrigation. Additional withdrawals are generally for stock and domestic use.

ZONE 2

Zone 2 contains 409 square miles, about 19 percent of northern Lea County. Depressions similar to those in zone 1 predominate in the western part of zone 2. Use of these depressions for recharging would be the same as that suggested for zone 1.

In the central and eastern parts of zone 2, broad elongated swales trending southeastward are conspicuous drainage features. After precipitation has satisfied soil-moisture requirements, runoff flows in these channels. Artificial recharging would conserve part of this water which might otherwise be lost by evapotranspiration. Small dams and diversion structures could be built for diversion, storage, or temporary detention of floodflows. Pits or wells could be placed at or upstream from the dams for artificial recharge. Floodflows might be diverted by channels and dikes to nearby depressions containing artificial-recharge facilities.

Zone 2 contains much irrigated farmland in the eastern part and only minor amounts in the central and western parts. Pumping in the farmland causes an annual net decline in water level because the rate of ground-water discharge exceeds the rate of recharge. Artificial recharge in this area might be sufficient to increase the gross recharge to equal or partly offset the discharge. The degree of equality would depend on the amount of water available for artificial recharge and the rate of injection. A balance between recharge and discharge would result in no net change in water levels; a partial balance would decrease the rate of water-level decline.

Water injected into the aquifer will move downgradient; therefore, the best site for artificial recharge is upgradient from the area to be benefited. As the water table slopes southeast across zone 2, the most favorable place for artificial recharge to zone 2 would be northwest of pumped areas.

ZONE 3

Zone 3 occupies about 468 square miles, or about 21 percent of northern Lea County. The predominant surface features of zone 3 are elongated shallow swales in the plain. Relatively few depressions are within the zone. Runoff from excess precipitation collects in the swales and, if precipitation is intense, flows to the southeast (fig. 12).

Most of the intensive cultivation in northern Lea County is in zone 3. Water-level declines, caused by irrigation and municipal pumping, generally are large during the growing season.

Floodflows through the swales could be diverted by dikes, dams, or channels to recharge facilities. Recharging of the underground reservoir near heavily pumped areas will prolong the life expectancy of the well fields.

ZONE 4

Zone 4 has an area of approximately 355 square miles, about 16 percent of northern Lea County. Many of the swales, originating in zones 2 and 3 terminate in zone 4. Most of the precipitation in zone 4 enters sandy surface materials; infiltration rates are high—about 3 inches per hour—and runoff from precipitation is low.

The high infiltration and natural recharge in zone 4 seem to obviate the general use of artificial recharge facilities. Selected recharge installations near the more heavily pumped areas, however, might be desirable. The hydraulic gradient is to the southeast; hence, the general use of recharge facilities in zone 4 would contribute to the underflow from the State.

FIGURE 12.—Shallow stream flowing east-southeast through a swale, July 1960. Road in foreground marks New Mexico-Texas State line. View is to the west-northwest about 1 mile north of State Highway 83.

SUMMARY OF RECHARGE POTENTIAL IN THE PHYSIOGRAPHIC ZONES

Artificial recharging in zone 1 would add to ground-water storage which, because of the southeast hydraulic gradient, would be available to other zones in northern Lea County. The saturated section beneath zone 1 could be thought of as a storage tank that would contribute water to the other zones over a period of years. Additions to the ground-water reservoir in zone 1 would have a less noticeable immediate effect on the water table in the heavily pumped area than recharging in zones 2 and 3.

In zones 2 and 3 most of the artificial recharge probably would go to make up deficiencies caused by pumping. Additional recharge would increase the life of well fields.

Recharging in zone 4 probably would give localized benefits. Water injected and not recovered by pumping would discharge as underflow from the State.

Extreme variability in rainfall frequency and distribution makes difficult any estimate of amounts of runoff available in the zones. In a general way, the isohyetal lines of plate 4 indicate that precipitation is greater in the northeastern part of northern Lea County, but it is here, in the sandy areas of zone 4, that the need is least for recharge facilities. Plate 4 shows that rainfall is progressively less toward Mescalero Ridge. Recharge facilities should probably be placed throughout the northwestern and central parts of northern Lea County. Facilities along the south boundary of the study area would probably be of little benefit to the High Plains except in the vicinity of Hobbs.

ARTIFICIAL RECHARGE

Artificial-recharge facilities should be ready for recharge operations before the season of heavy rainfall and should be capable of storing large quantities of water and injecting them in a short time to minimize evaporation losses. In addition, these installations should be self-contained or self-functioning and should be inexpensive to build and maintain.

ARTIFICIAL RECHARGE METHODS

Artificial recharge of the aquifer in the Ogallala Formation can be accomplished by two methods—by injecting water into the aquifer through wells and by spreading water on permeable areas of the land surface where it will percolate downward to the aquifer.

RECHARGE THROUGH WELLS

Water can be put into a recharge well either under pressure or by gravity flow. Pressure may be necessary where the depth to water is too shallow for the buildup of a column of water of sufficient height in the well to force water into the aquifer at a reasonable rate. The depth to the water table is great enough in Lea County to insure that gravity feed of water into the well will be satisfactory.

Water for recharge through wells generally needs some treatment to reduce suspended-sediment load, air content, temperature, algae, and bacteria. Solid particles carried in suspension, algal and bacterial growths, and entrained air in the recharge water may eventually clog the pore spaces in the aquifer around the well and greatly reduce or stop the recharging activity. Filtration and chlorination facilities as well as means of keeping air bubbles from being entrained in the recharge water must be provided.

There are various means of removing sediment from the recharge water. Commercial flocculants can be used. Filtration through rapid-sand filters, cotton-gin trash, pea gravel, or other filter material will reduce the suspended-sediment load.

Clogged pore spaces in the aquifer around the recharge well can, under certain conditions, be reopened by pumping the well if the well is finished in the aquifer. Rehabilitation of the well by pumping will be expensive if the pump must be installed in the well for each pumping period. Not all the solids drained into a well can be pumped out again; therefore, the recharge efficiency of a well may decrease in time.

The advantage of being able to pump the well is a good reason for completing the well in the aquifer rather than in permeable beds in the zone of aeration. Naturally, a recharge well completed in the aquifer must be deeper and consequently is more expensive to construct than a shallower well in the zone of aeration. A recharge well finished in the aquifer in the High Plains would be preferred, as the difference in cost would be small there, where the water table is at a shallow depth.

Air bubbles trapped in the recharge water can plug the aquifer around the well as effectively as silt and clay. Minute air bubbles caught and held in the pore spaces of the aquifer create an airlock. Air bubbles enter the water if the water falls into the well through a column of air. The recharging water could be put into the well without entraining air by extending the lower end of an inductor pipe below the water level in the well and using a pipe large enough to accommodate the designed rate of injection without an airspace in the pipe. Price (1961, p. A28–A29) suggests deaeration of the water and use of a foot valve on the bottom of the inductor pipe to help overcome the air-lock hazard.

Artificial recharge through wells may change the temperature of the water contained in the aquifer (Brashears, 1946, p. 504; Suter and Harmeson, 1960, p. 31–35). Injection of water during the summer when surface-water temperatures are higher than ground-water temperatures will raise water temperatures in the vicinity of the recharge well. Conversely, water at a lower temperature injected during the winter will lower water temperatures. Although at first this effect is local, over several years the ground-water temperature will change under a wide area, particularly down the hydraulic gradient from the injection site (Suter and Harmeson, p. 35).

Rises in ground-water temperatures from injection of water can be minimized, even though the most likely times for runoff coincide with the hottest months of the year—June, July, and August. During these months, precipitation should be injected into the aquifer as soon as it collects at the recharging points to take advantage of the lower temperature of the water immediately after rainfall. Injection of water will probably not raise water temperatures much in northern Lea County.

Algal and bacterial growth may be present in any well (Cotey, 1959, p. 1–3). Although there have been no reports of bacterial or algal growth in wells in Lea County, this possibility must not be overlooked. Water injected through a well might carry bacteria and algae whose growth could lead to the eventual clogging of the aquifer near the well. Proper chlorination and periodic cleaning of the well will reduce the likelihood of algal or bacterial plugging.

Chlorination of the recharge water probably will be necessary to gain approval of the State Public Health Department. Periodic chemical and bacteriological analyses of water from the aquifer near the recharge well should be made to insure that artificial recharge is not causing pollution.

EXPERIMENTS IN RECHARGING THE AQUIFER THROUGH WELLS

Three operative recharge wells with filters are in the bottoms of depressions east of Lovington, N. Mex., in secs. 5 and 6, T. 16 S., R. 37 E. (fig. 13). A cross-sectional view of a filter and recharge well is shown in figure 14. Flow into the well is by gravity. Pumps were not provided for cleaning the wells, and provision was not made for automatic chlorination of recharge water.

In October 1960, water was injected by gravity flow into the aquifer through recharge well 2. The initial metered flow ranged from 600 to 750 gpm (gallons per minute). Within 2 minutes the water level rose nearly 0.6 foot in an observation well 196 feet southeast of the injection well (fig. 15). As injection continued at lessened rates, the water level in the observation well reflected these changes but continued to rise. When the flow of water into the injection well was stopped, the water level in the observation well declined within a few hours to a level about 0.2 foot above that observed before recharging was started. Because several days were required for the water level in the observation well to decline to that observed before injection began, the buildup and gradual dissipation of a mound of water around the recharge well was indicated.

The operation of the gravel-packed filters was not satisfactory, as the gravel became clogged with fine materials, and the slots on the outside of the filter were clogged by shrimp and tadpoles. It was necessary to scrape the slots and to hammer on the filter to loosen accumulated sand, silt, and clay in the filter pack. These operations increased the flow temporarily but allowed fine materials to enter the well. Flow through the filters after a period of several hours was very small, and the recharge well had to be shut down overnight so that the accumulated organisms could be scavenged from the slots. A finer screen than the ¼-inch mesh that was used might have prevented clogging of the slots.

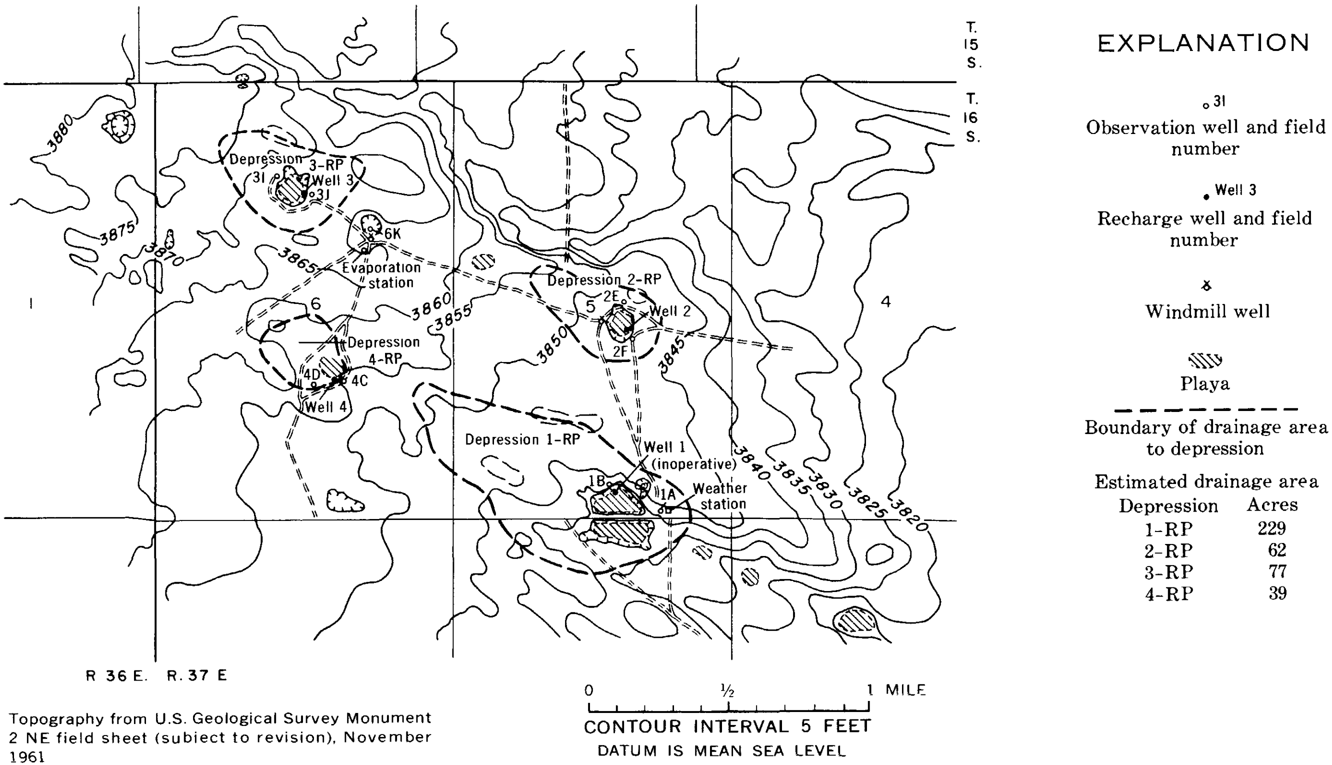


FIGURE 13.—Topographic map of depression complex in the Lea County recharge project showing approximate drainage areas to depressions.

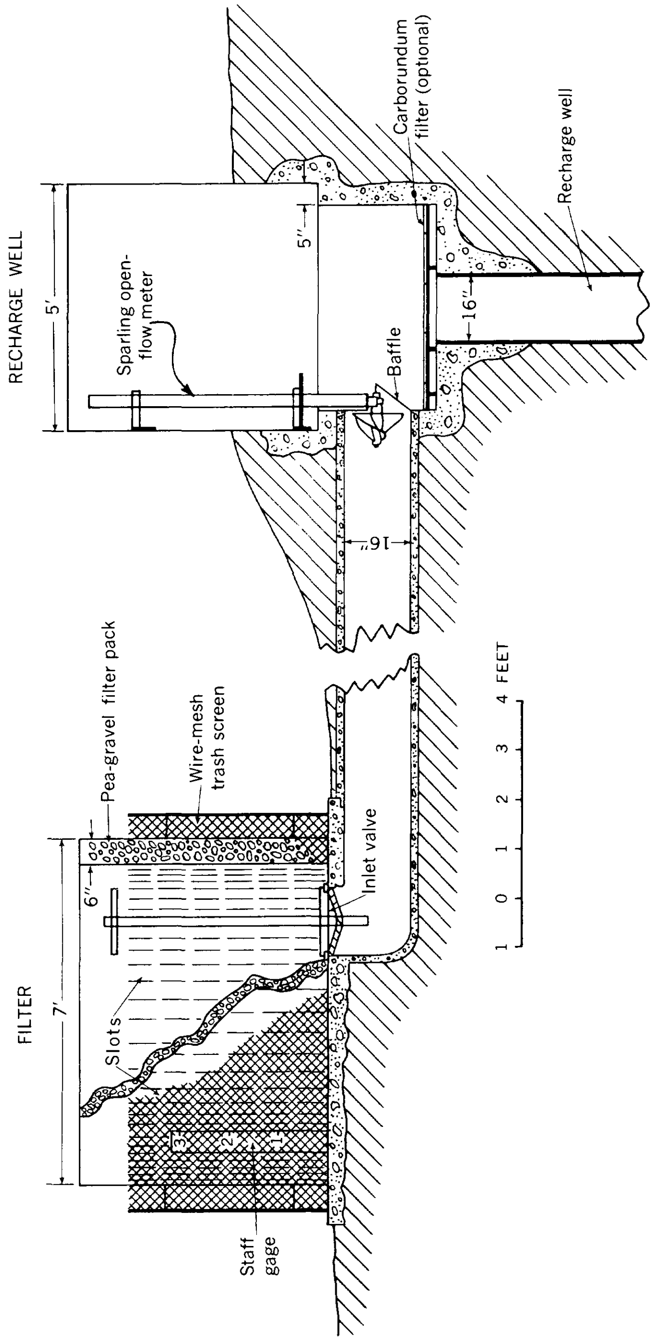


FIGURE 14.—Filter and recharge well in Lea County recharge project.

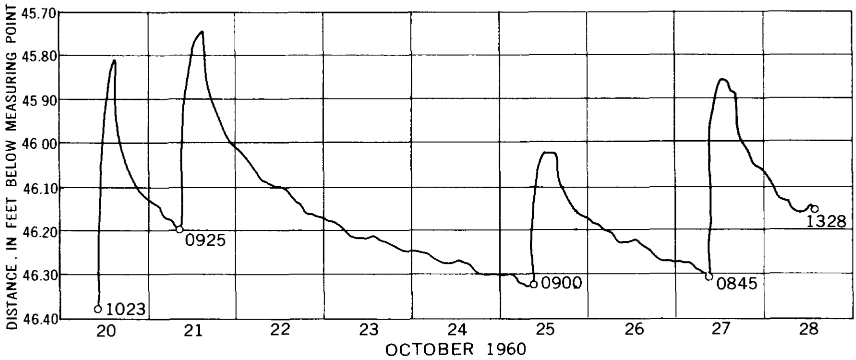


FIGURE 15.—Water-level fluctuation in well 2–F (16.37.5.lot 15) during artificial recharge through well 2 (16.37.5.lot 15a), Oct. 20–28, 1960, Lea County recharge project.

Complete cleaning annually of the gravel pack and the slots would eliminate much of the difficulty from sediment clogging. Covering the filter to prevent filling by windblown sediments would reduce maintenance care.

The low-flow conditions imposed by impeded filtration prevented the open-flow meter installed in the inlet pipe (fig. 14) from measuring the flow of water correctly, and the accuracy of the metered rates of flow is questionable. Information from the manufacturer indicates that, even with a full pipe of water, at rates of less than 350 gpm (0.0011 acre-ft per min.) accuracy might be as low as 70 percent. The total estimated flow was about 180,000 gal (70 percent of the metered flow of 260,000 gal).

The New Mexico Department of Public Health required that 2 parts per million of chlorine be added during recharging to prevent possible bacterial contamination in stock and domestic wells. High-test hypochlorite powder or solution was added by hand to maintain this concentration at the metered flow. Bacteriological analyses of samples taken by the Lea County Sanitarian showed no pollution after recharging.

RECHARGE THROUGH SPREADING PONDS OR PITS

In northern Lea County permeable sand of the Ogallala Formation is present at depths generally less than 25 to 30 feet. In and near depressions where this depth is lessened by solution of caliche overlying the Ogallala Formation, construction of spreading pits or ponds in the depressions would be advantageous. Water spreading has several advantages, principally ease and cheapness of construction and accessibility to points where trouble might occur. In northern

Lea County ground water occupies only part of the Ogallala Formation, and the zone of aeration provides natural filtration. Entrained air would be largely, if not entirely, eliminated; bacterial pollution would be reduced to a safe minimum; silt and clay would be filtered out before reaching the aquifer.

Permeable material, constituting a natural filter for removal of sediment carried in recharge waters, is at a shallow depth beneath depressions. If the thickness of less permeable materials does not exceed 5 feet, they could be removed by bulldozing. Silt and finer materials will probably be held in the upper 2 or 3 inches of a fine to very fine sand filter. In some places a layer of filtering material might be laid on the cleared floor of depressions. A 6-inch pea-gravel filter can trap most of the finer material carried in waters available for recharge in northern Lea County (Suter and Harmeson, 1960, p.23).

Water for recharging will probably not be available for more than 2 or 3 weeks each year in northern Lea County. After the season for recharging is over and the depressions are dry, clay and trash should be removed from the surface, and the surface should be scarified. Care should be exercised in using heavy equipment in the depressions because compaction of the floor could greatly reduce the permeability of the sand and thus reduce the infiltration rate.

Alinement of pits or spreading ponds with the prevailing southwesterly winds would take advantage of the scouring action of wind and would aid in keeping the pits free of debris and sediments.

The disadvantage of recharge pits and spreading ponds is their slow recharge rate per unit area; however, their gross area is large compared to that of a recharge well.

Water spreading over a large area results in a large evaporation loss. Artificially accelerating the recharge rate through ponds would, however, reduce the evaporation loss.

A typical spreading pond in northern Lea County might consist of a bulldozed trench along the outside edge of the flat bottom of a depression. Placement along the edge would take advantage of the lesser thickness of low permeability sediments. The trench should be alined to the southwest to take advantage of the scouring and cleaning action of the prevailing winds. The trench should be deep enough to expose either soft caliche or sand of the underlying Ogallala Formation.

COMPARISON OF PROBABLE RECHARGE VOLUMES

The volume of water that could be recharged to the aquifer in the Ogallala in a 24-hour period in northern Lea County is estimated to range from about 150 gpm (0.7 acre-ft per day) to 1,200 gpm (5.3

acre-ft per day) when recharge is through a well and to range from 5 inches per hour (10 acre-ft per day) to 20 inches per hour (40 acre-ft per day) for infiltration of water through a 1-acre spreading pond.

SUMMARY AND CONCLUSIONS

Physical boundaries isolate the southern High Plains of Lea, Chaves, and Eddy Counties, N. Mex., from outside sources of natural recharge. The present rate of ground-water discharge by pumping and underflow from the area exceeds the natural recharge rate, and the ground-water reserves of the area are being reduced.

The average annual natural recharge in the period 1949–60 is computed to be about 30 percent of the excess precipitation, or about 95,000 acre-ft. Approximately one-sixth of the water pumped for irrigation is returned to the aquifer by seepage; therefore, the average annual recharge from this source in the period 1949–60 probably was about 23,000 acre-ft. Thus the average annual recharge amounts to about 118,000 acre-ft.

The average annual discharge from the aquifer in the period 1949–60 probably amounted to 151,000 acre-ft as gross pumpage and about 36,000 acre-ft as underflow, or a total of about 187,000 acre-ft.

The average annual difference between recharge and discharge amounted to about 69,000 acre-ft. This annual deficit is reflected in a general net decline of about 10 feet in the High Plains of northern Lea County and local net declines of as much as 30 feet in the period 1950–60.

At least 50,000 acre-ft of water a year could be added to the aquifer by artificial recharge. In the period 1949–60 an average of 107,000 acre-ft a year entered depressions within the 1,400,000-acre study area. Observations of natural recharge indicated that 20 to 80 percent of the water reaching the depressions probably infiltrated to the aquifer; the remainder was discharged by evapotranspiration, principally by evaporation from pond surfaces.

Artificial recharging in northern Lea County could be accomplished either by injection of water through wells or by water spreading in pits or ponds. Water used for injection through wells must be low in suspended sediment, should not entrain air while being injected because it might air lock the aquifer near the well, and should be free from chemical or bacterial contamination. Water spreading, which hastens the process of natural recharge, would require water of moderate to low turbidity to prevent sealing of the floor of the pits and ponds too rapidly. Filtration through the unsaturated section above the aquifer will probably remove most bacterial contamination, but it will not remove chemical contaminants.

Rates of recharge through a well in northern Lea County may range from less than 1 to more than 5 acre-ft per day; rates of recharge per acre of pits or spreadinng ponds may range from 10 to 40 acre-ft per day. Recharging through pits or spreading ponds probably would have a lower cost of installation and maintenance per unit of water recharged than recharging through wells. Recharging through pits or ponds has been successful for long periods, whereas recharging through wells has been plagued by many operational difficulties.

SELECTED REFERENCES

Ash, S. R., 1963, Ground-water conditions in northern Lea County, New Mexico: U.S. Geol. Survey Hydrol. Inv. Atlas HA-62.

Barnes, J. R., and others, 1949, Geology and ground water in the irrigated region of the Southern High Plains in Texas: Texas Board Water Engineers Prog. Rept. 7, 51 p., 7 pls., 32 figs., 20 tables.

Berkstresser, C. F., Jr., 1959, Tatum-Lovington-Hobbs area, Lea County, *in* Reeder, H. O., and others, Annual water-level measurements in observation wells, 1951-55, and atlas of maps showing changes in water level for various periods from beginning of record through 1954, New Mexico: New Mexico State Engineer Tech. Rept. 13, p. 91–115, tables 6–7, figs. 46–55.

Brashears, M. L., Jr., 1946, Artificial recharge of ground water on Long Island, New York: Econ. Geology, v. 41, no. 5, p. 503–516.

Bretz, J. H., and Horberg, C. L., 1949, The Ogallala Formation west of the Llano Estacado [New Mexico]: Jour. Geology, 1. 57, no. 5, p. 477–490.

Brown, C. N., 1956, Origin of caliche on the northeastern Llano Estacado, Texas: Jour. Geology, v. 64, no. 1, 15 p.

[California] State Water Pollution Control Board, 1954, Report on the investigation of travel of pollution: Pub. no. 11, 218 p.

Clyma, Wayne, and Jensen, M. E., 1960, Flocculent used to remove sediments from playa lake water used for ground-water recharge: Texas Agr. Expt. Sta. Prog. Rept. 2144, 7 p.

Conover, C. S., and Akin, P. D., 1942, Progress report on the ground-water supply of northern Lea County, New Mexico: New Mexico State Engineer 14th and 15th Bienn. Rept., 1938–42, p. 285–309.

Cotey, Brad, 1959, Texas wells threatened by strange growth: Water Well Jour., v. 13, no. 7, 4 p.

Cronin, J. G., 1961, A summary of the occurrence and development of ground water in the Southern High Plains of Texas: Texas Board Water Engineers Bull. 6107, 104 p.

Cronin, J. G., and Wells, L. C., 1960, Geology and ground-water resources of Hale County, Texas: Texas Board Water Engineers Bull. 6010, 146 p

Dane, C. H., and Bachman, G. O., 1958, Preliminary geologic map of the southeastern part of New Mexico: U.S. Geol. Survey Misc. Geol. Inv. Map I–256.

Fenneman, N. M., 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., 534 p.

Frye, J. C., and Leonard, A. B., 1957, Studies of Cenozoic geology along the eastern margin of the Texas High Plains, Armstrong to Howard Counties: Texas Univer., Bur. Econ. Geology, Rept. Inv. no. 32, 62 p.

Hale, W. E., and Nicholson, Alexander, Jr., 1953, Three maps of a portion of Lea County, New Mexico: (1) Contour map of the bottom of the Ogallala Formation, (2) Contour map showing elevation of the water table, and (3) Map showing the thickness of the zone of saturation in the Ogallala Formation: U.S. Geol. Survey open-file report, 3 figs.

Horberg, Leland, 1949, Geomorphic history of the Carlsbad Caverns area, New Mexico: Jour. Geology, v. 57, no. 5, p. 464–476.

Judson, S. S., Jr., 1950, Depressions of the northern portion of the southern High Plains of eastern New Mexico: Geol. Soc. America Bull., v. 61, no. 3, p. 253–274.

Linsley, R. K., Jr., Kohler, M. A., and Paulhus, J. L. H., 1949, Applied hydrology: New York, McGraw-Hill Book Co., Inc., 689 p.

Moulder, E. A., and Frazor, D. R., 1957, Artificial-recharge experiments at McDonald well field, Amarillo, Texas: Texas Board Water Engineers Bull. 5701, 34 p.

Nicholson, Alexander, Jr., and Clebsch, Alfred, Jr., 1961, Geology and ground-water conditions in southern Lea County, New Mexico: New Mexico State Bur. Mines and Mineral Resources Ground-Water Rept. 6, 123 p., 2 pls., 30 figs.

Nye, S. S., 1930, Shallow ground-water supplies in northern Lea County, New Mexico: New Mexico State Engineer Bull. 2, 26 p.

——— 1932, Progress report on the ground-water supply of northern Lea County, New Mexico: New Mexico State Engineer 10th Bienn. Rept., 1930–32, p. 229–251.

Price, C. E., 1961, Artificial recharge through a well tapping basalt aquifers, Walla Walla area, Washington: U.S. Geol. Survey Water-Supply Paper 1594–A, 33 p., 4 figs.

Robinson, T. W., 1958, Phreatophytes: U.S. Geol. Survey Water-Supply Paper 1423, 84 p., 32 figs.

Suter, Max, and Harmeson, R. H., 1960, Artificial ground-water recharge at Peoria, Illinois: Illinois State Water Survey Bull. 48, 48 p., 42 figs.

Theis, C. V., 1934, Progress report on the ground-water supply of Lea County, New Mexico: New Mexico State Engineer 11th Bienn. Rept., 1932–34, p. 127–153.

——— 1937, Amount of ground-water recharge in the southern High Plains: Am. Geophys. Union Trans., v. 18, p. 564–568, 3 figs.

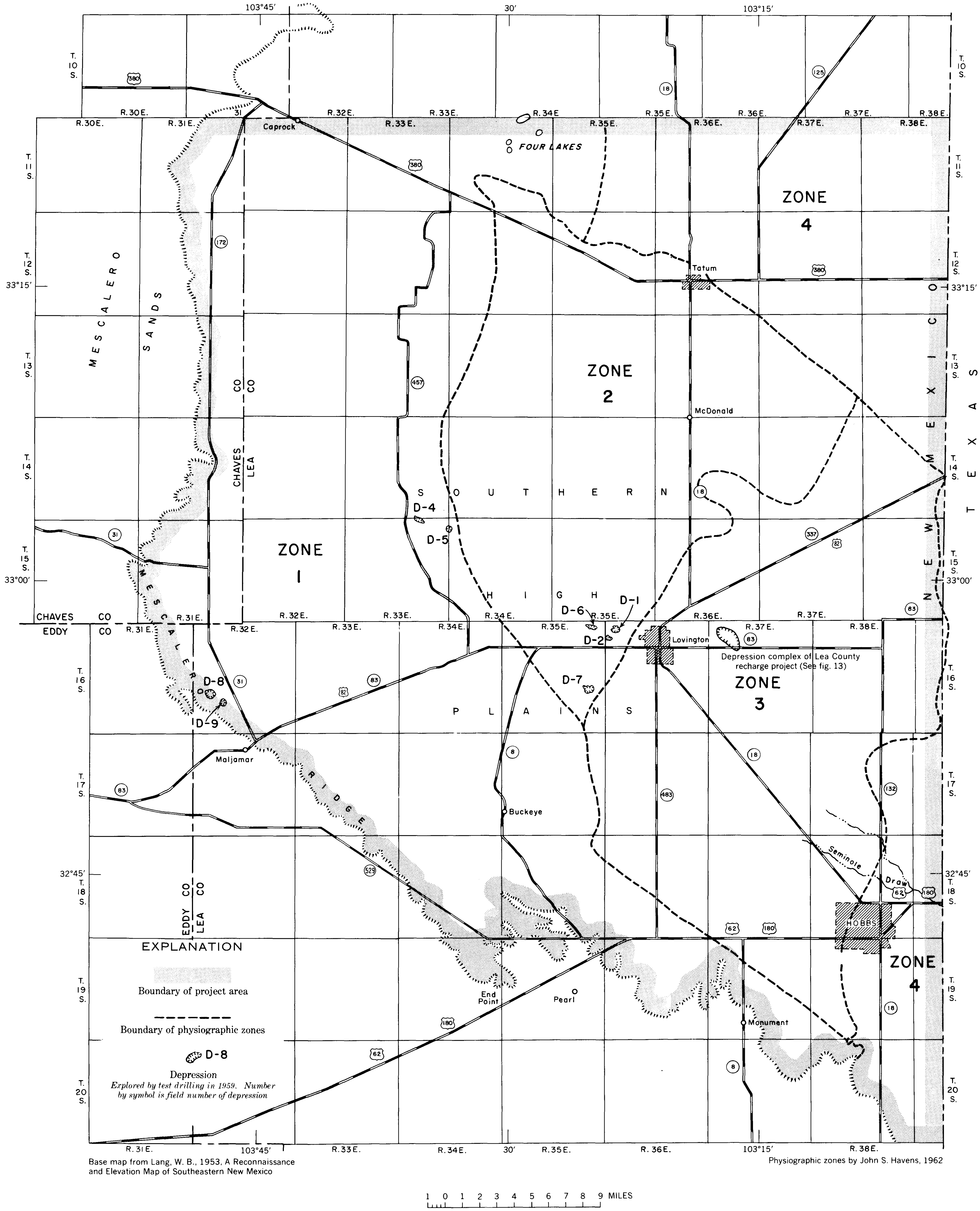
——— 1939, Progress report on the ground-water supply of Lea County, New Mexico: New Mexico State Engineer 12th and 13th Bienn. Repts., 1934–38, p. 121–134.

Thornthwaite, C. W., 1941, Atlas of climatic types in the United States, 1900–1936: U.S. Dept. Agriculture Misc. Pub. 421, 7 p., 96 pls.

U.S. Weather Bureau, 1949–61, Climatological data, New Mexico: v. 53–65, nos. 1–13.

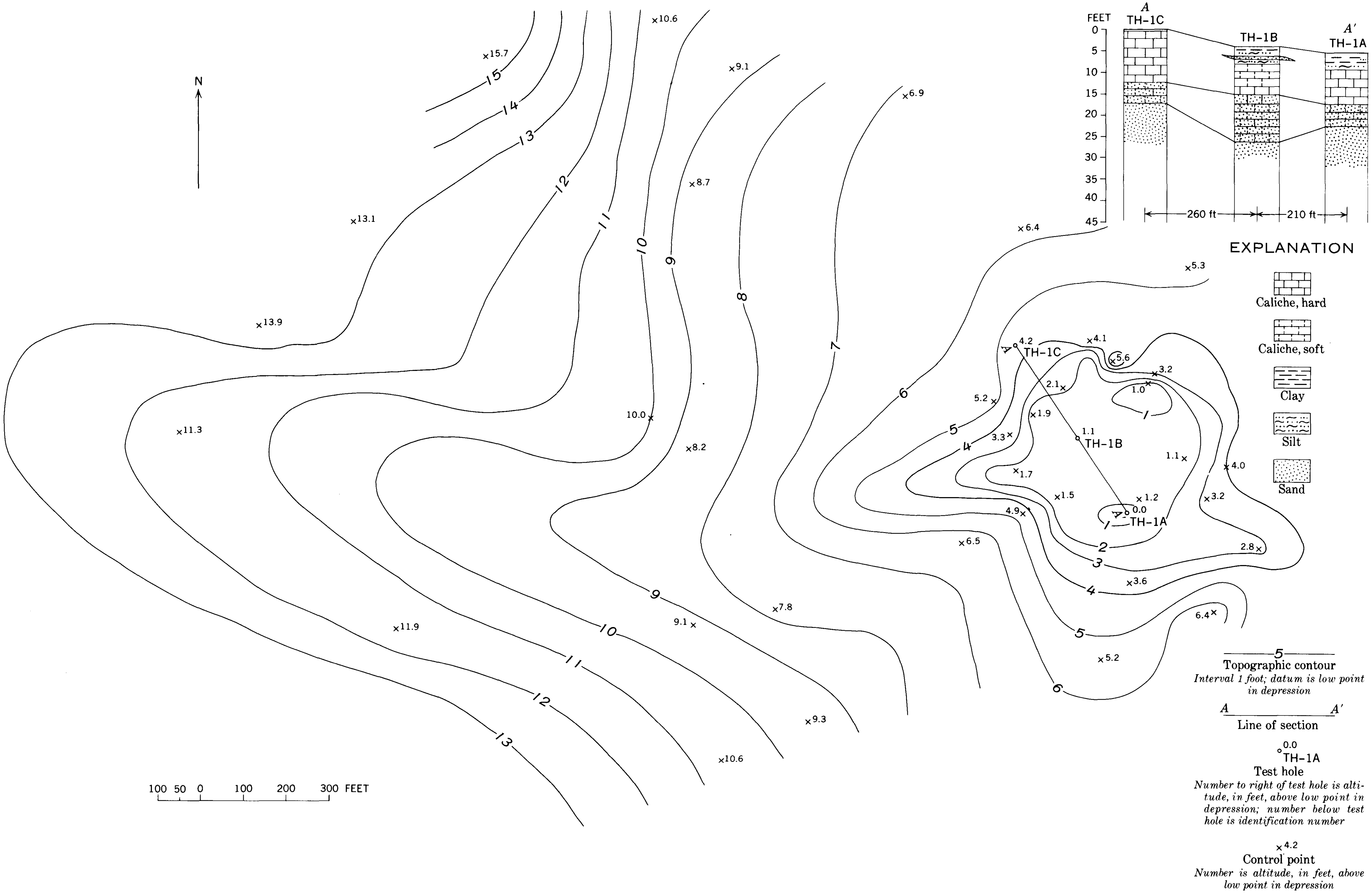
White, W. N., Broadhurst, W. L., and Lang, J. W., 1946, Ground water in the High Plains of Texas: U.S. Geol. Survey Water-Supply Paper 889–F, p. 381–420, pls. 17–21.

○



MAP SHOWING THE AREA OF INVESTIGATION, PHYSIOGRAPHIC ZONES, AND SELECTED DEPRESSIONS, IN NORTHERN LEA COUNTY, NEW MEXICO

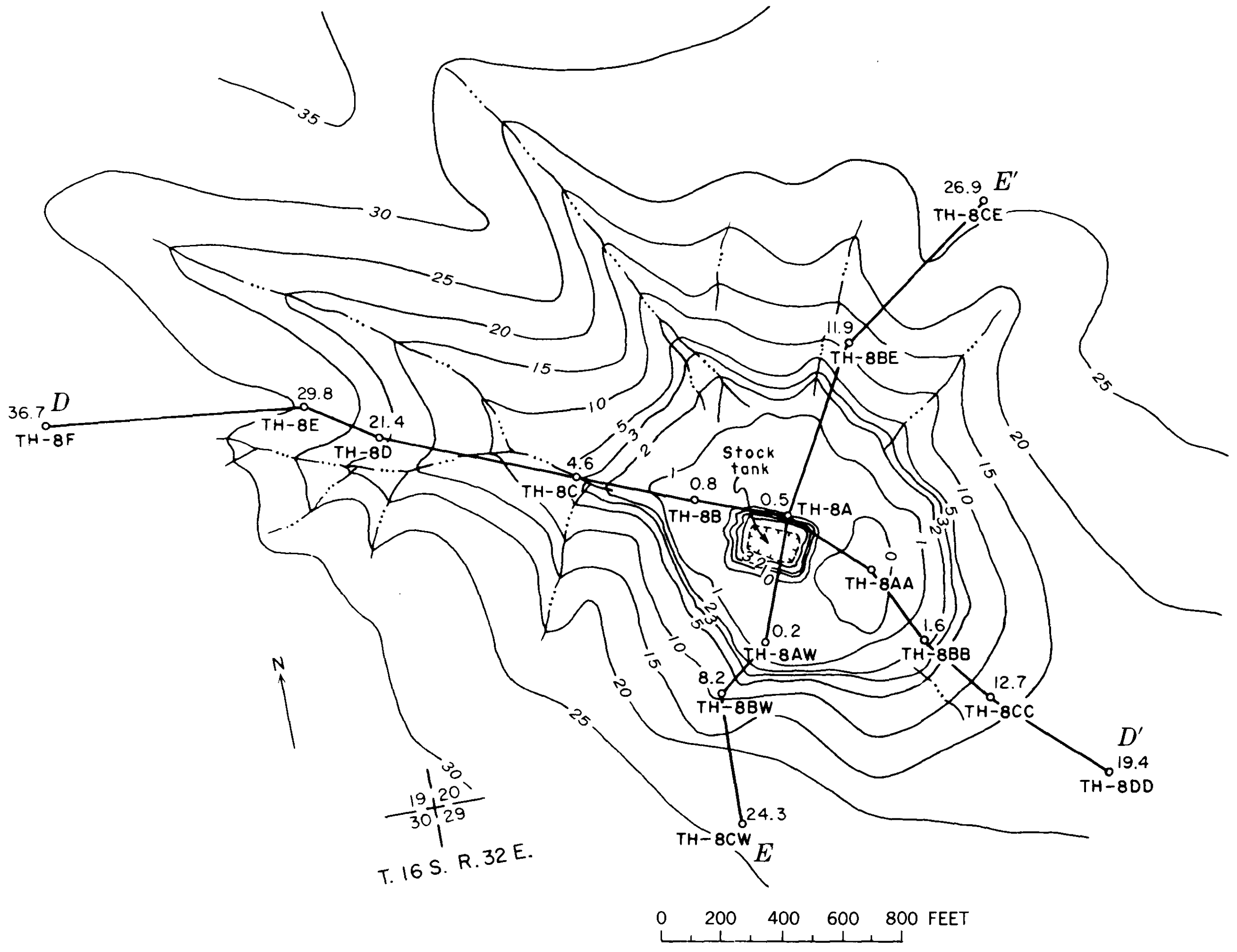
798-157 O - 66 (In pocket) No. 1

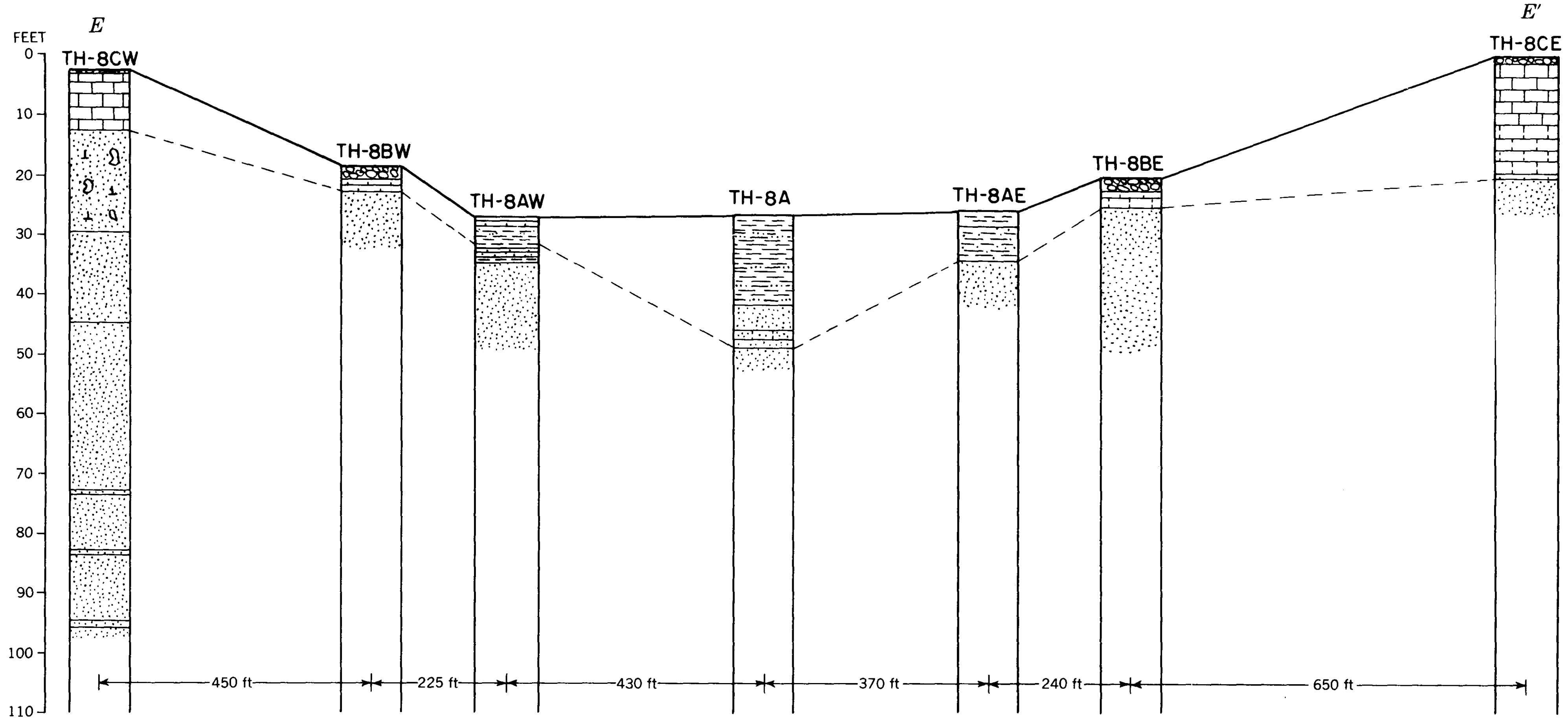


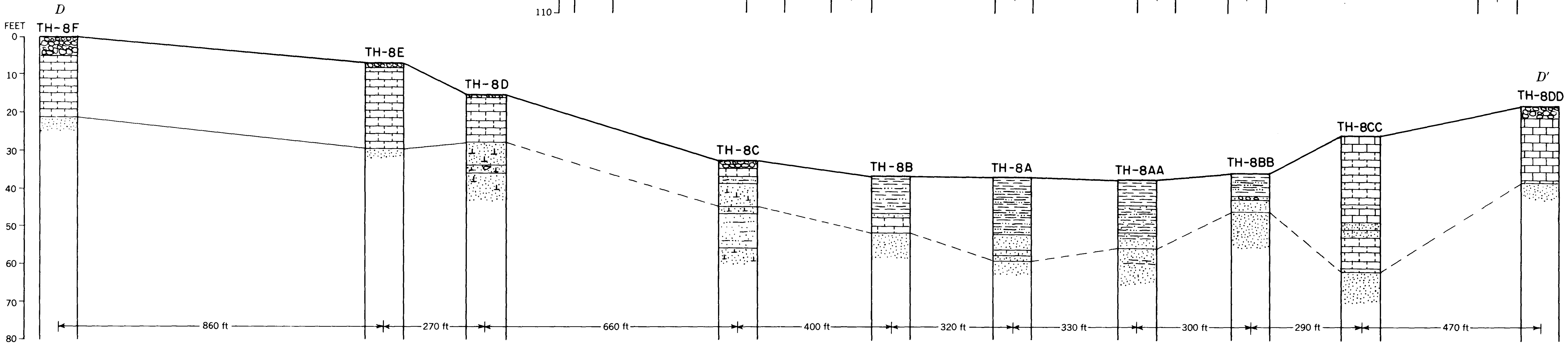
TOPOGRAPHIC MAP OF DEPRESSION D-1 (LOT 9, SEC. 6, T. 16 S., R. 36 E.) SHOWING TEST HOLES AND SECTION *A-A'*, NORTHERN LEA COUNTY, NEW MEXICO

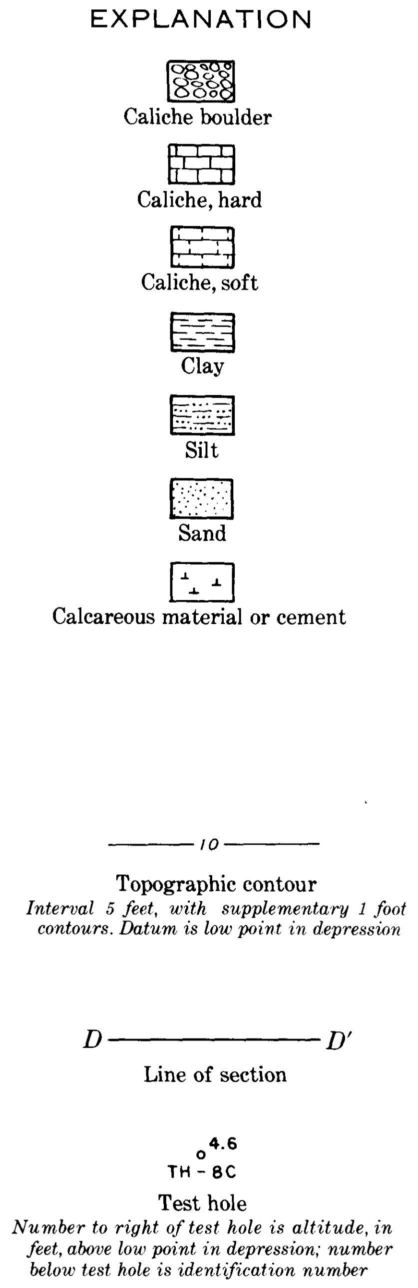
798-157 O - 66 (In pocket) No. 2

PREPARED IN COOPERATION WITH THE
NEW MEXICO STATE ENGINEER AND THE LEA COUNTY SOIL
AND WATER CONSERVATION DISTRICT









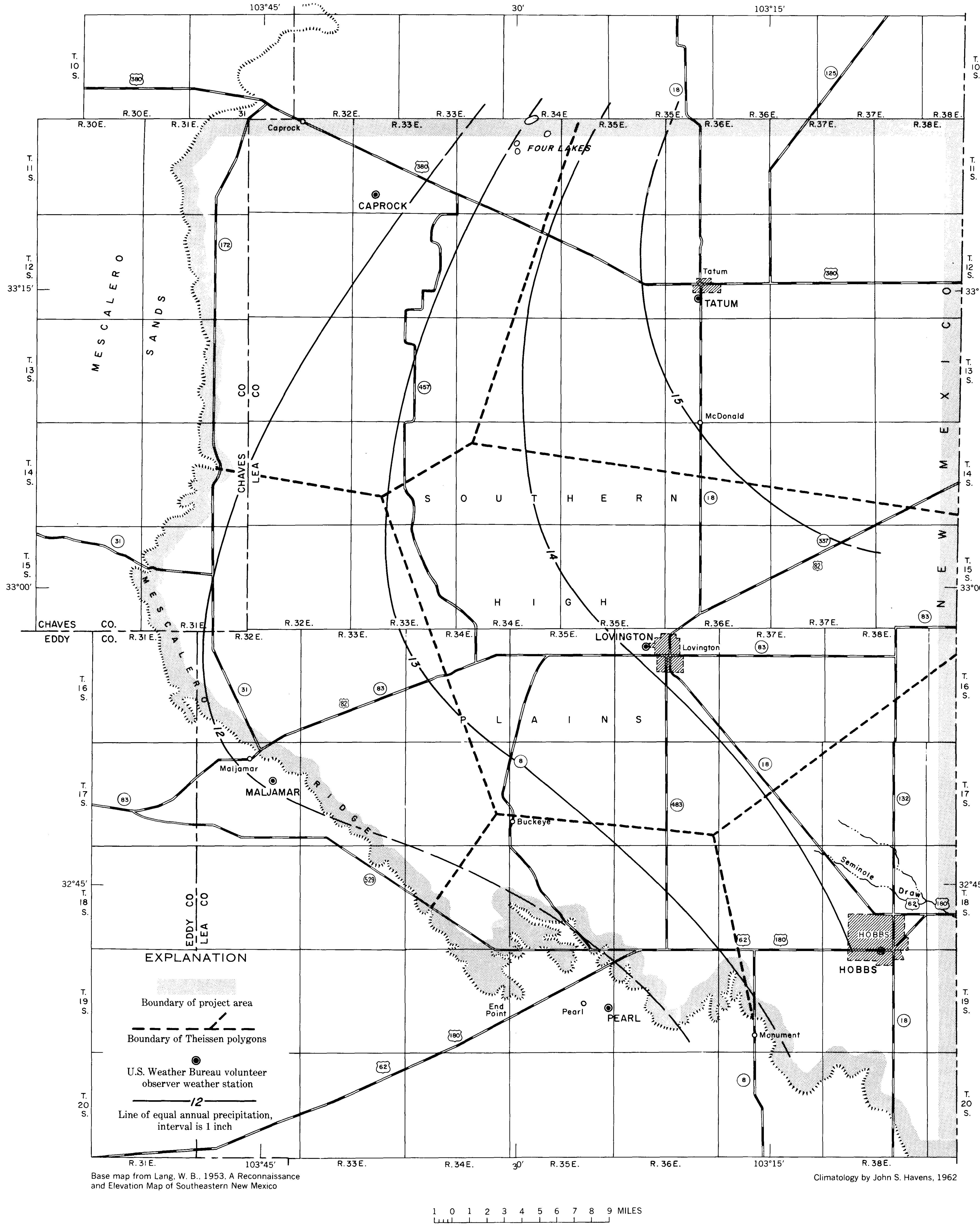
SECTIONS *D-D′* AND *E-E′* ACROSS DEPRESSION D-8 (NE¼ SEC. 20, T. 16 S., R. 32 E.) AND TOPOGRAPHIC MAP OF DEPRESSION SHOWING TEST HOLES AND SECTIONS, NORTHERN LEA COUNTY, NEW MEXICO

798-157 O - 66 (In pocket) No. 3

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
NEW MEXICO STATE ENGINEER AND THE LEA COUNTY
SOIL AND WATER CONSERVATION DISTRICT

WATER-SUPPLY PAPER 1819-F
PLATE 4



MAP OF THEISSEN POLYGON NETWORK AREAS CONTROLLED BY SIX WEATHER STATIONS IN NORTHERN LEA COUNTY, NEW MEXICO, AND ISOHYETAL LINES OF ANNUAL PRECIPITATION

798-157 O - 66 (In pocket) No. 4