DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA–679

INTRODUCTION

The High Plains aquifer in southeastern New Mexico is part of a regional aquifer system extending from South Dakota on the north through Wyoming, Colorado, Nebraska, Kansas, and Oklahoma, to Texas and New Mexico on the south. The principal aquifer, the Ogallala Formation of Tertiary age, is hydraulically connected with other unconsolidated deposits, principally of Quaternary age. Alluvium and terrace deposits hydraulically connected with the Ogallala are included in the High Plains aquifer in New Mexico.

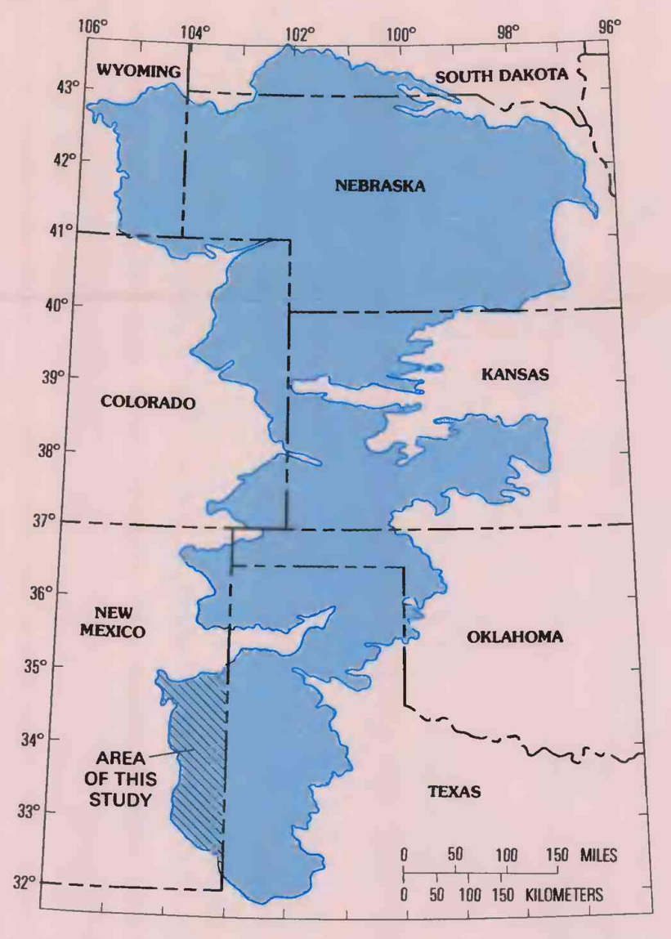
During 1978, the U.S. Geological Survey began a 5-year study of the High Plains regional aquifer system to provide hydrologic information for evaluation of the regional effects of its long-term development and to develop and evaluate computer models for simulation of an aquifer response to alternative changes in ground-water management proposals (Weeks, 1978). This report presents some of the hydrologic information compiled for the New Mexico part of that study.

The High Plains aquifer is the principal source of water in southeastern New Mexico because of its areal extent and the relatively large yields of water to wells completed in the aquifer. The aquifer commonly yields 250 to 800 gallons per minute and locally yields as much as 1,000 gallons per minute to wells. The agricultural economy that exists in the semiarid climate of southeastern New Mexico has expanded significantly because of this major source of water.

The increased use of water from the aquifer has created concern about its dependability for future supplies. If the water is to be used beneficially for an extended period of time, water users and managers need to understand the physical regime, the imposed stresses, and the effect of those stresses on the system and manage the system accordingly.

LOCATION AND GENERAL FEATURES

The High Plains aquifer extends over much of the extreme southeastern part of New Mexico, (index map) and is the principal aquifer in Lea, Roosevelt, and Curry Counties. The aquifer has an areal extent of about 7,600 square miles. Physiographically the area is mostly upland plains and intermediate slopes. Although locally the surface is irregular, the regional slope is eastward at 8 to 20 feet per mile. Large areas on the upland plains are comparatively flat, featureless, and undissected. Much of the surface has very broad gentle swales or low hills, shallow depressions, and some dune-covered areas. Streams draining the plains are all ephemeral flowing only for short periods during and after intense rainfall.



INDEX MAP SHOWING LOCATION OF THE HIGH PLAINS AQUIFER (SHADED) AND STUDY AREA IN NEW MEXICO

METRIC CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
inch	25.40	millimeter
foot	0.3048	meter
foot per mile	0.1894	meter per kilometer
foot per day	0.3048	meter per day
mile	1.609	kilometer
acre	0.4047	hectare
square mile	2.590	square kilometer
gallon per minute	0.06308	liter per second

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows: °C=5/9 (°F−32)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level." NGVD of 1929 is referred to as sea level in this report.

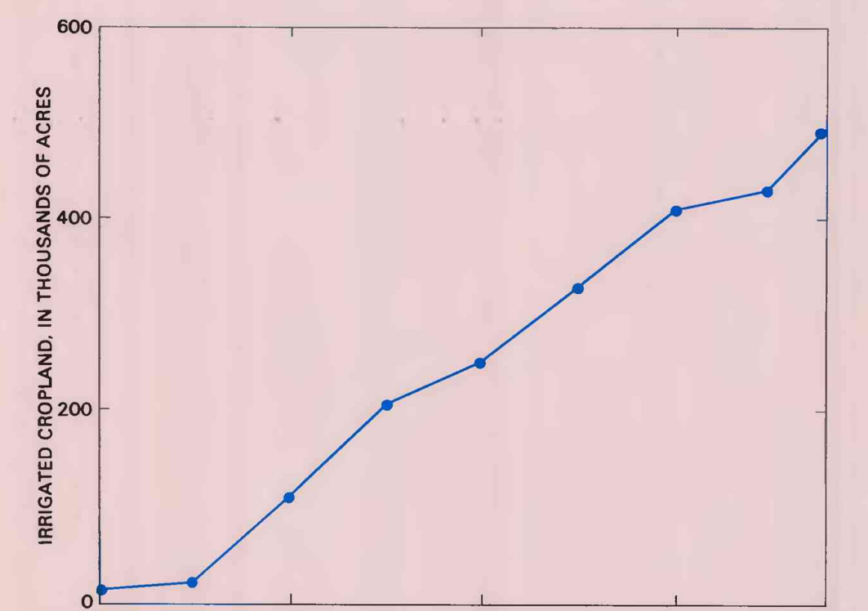
CLIMATE

The semiarid climate of the area is characterized by an average annual precipitation ranging from about 14 to 17 inches, a rapid rate of evaporation, little relative humidity, persistent and significant winds, warm to hot summer days and cool nights, and moderate winters with some severe cold periods. Winter snowfalls and snow cover usually are light and of short duration.

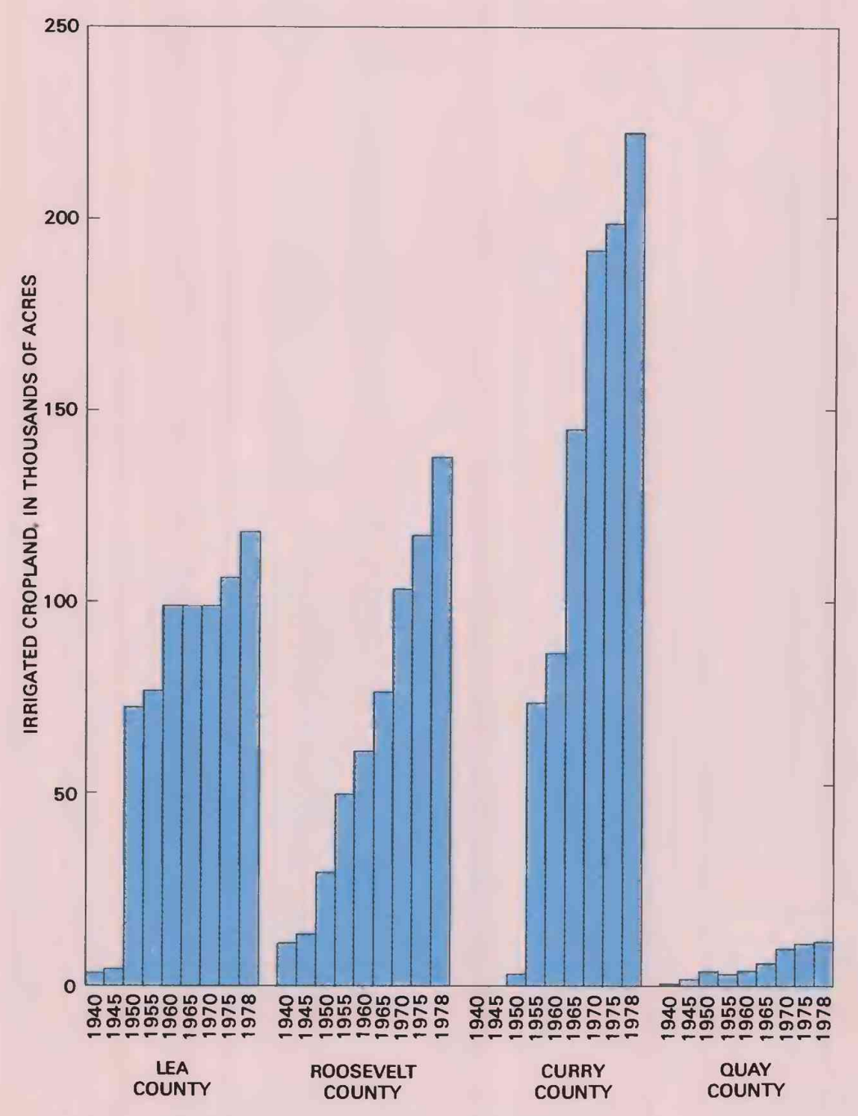
Precipitation records indicate the precipitation usually decreases from east to west and from north to south across the study area. Altitude, precipitation, and temperature data at specific sites are shown in the following table:

Climatological data, 1978, for southern High Plains of New Mexico

Station	Altitude in feet above sea level	Average annual precipitation, in inches	Average annual temperature, in degrees Fahrenheit
Clovis	4,280	17.07	57.4
Portales	4,010	16.40	58.0
Elida	4,350	17.32	57.6
Hobbs	3,615	14.36	61.7



GRAPH OF ESTIMATED TOTAL IRRIGATED CROPLAND, INCLUDING IDLE AND FALLOW LAND IN CROP ROTATION, 1940-78



GRAPH OF ESTIMATED IRRIGATED CROPLAND, INCLUDING IDLE AND FALLOW LAND IN CROP ROTATION, BY COUNTIES 1940-78

IRRIGATION DEVELOPMENT AND WATER-LEVEL CHANGE

Irrigation began in the High Plains before 1910 by farmers irrigating small plots of land using windmills. Irrigation increased slowly and was relatively insignificant until about 1945. Rapid development of irrigated cropland began about 1945 and continued at a relatively constant rate until 1978 as indicated in the graph below. Irrigated cropland increased from about 15,000 acres during 1940 to about 490,000 acres during 1978. The actual cropland irrigated during any year may be 10 to 40 percent less than the potentially available acreage due to crop rotation, precipitation during growing seasons, or economics.

The irrigated area, by counties, within the boundaries of the High Plains is shown in the adjacent graph. Curry County has developed about 222,000 acres for irrigation, Roosevelt County about 138,000, Lea County about 119,000, and Quay County about 11,000 acres. Recently, the most rapid increase in irrigated land has been occurring in Curry and Roosevelt Counties.

Prior to large-scale development of irrigation, the High Plains ground-water system was in a state of dynamic equilibrium, with long-term recharge equal to long-term discharge. Irrigated farming on the High Plains has significantly increased the quantity of water discharged from the system. Increased discharge has resulted in a lowering of the water level as water is removed from storage in the aquifer. The removal of water from storage, or ground-water mining, is most evident in three general areas where irrigation wells are numerous and relatively concentrated: (1) Eastern Lea County; (2) Portales Valley; and (3) southeastern Curry County.

The distribution of irrigated acreage and the decline in water level from predevelopment conditions to 1978 are shown on the water-level-decline map, which illustrates the areal extent of water-level declines and the relationship of irrigated areas to this decline. The greatest decline in water level is in eastern Curry County where levels have declined more than 100 feet near the New Mexico-Texas border. Water levels in the Portales Valley and in eastern Lea County locally have declined more than 60 feet. Water-level declines of 20 to 60 feet are common in all of these areas where irrigation wells are concentrated.

The water level in eastern Lea County has been declining as much as 2 feet per year and is declining at an average rate of 1 foot per year. The water level in Portales Valley has declined as much as 3.5 feet in 1 year and is declining at an average rate of 2 feet per year. The water level in southeastern Curry County has declined as much as 6 feet in 1 year and is declining at an average rate of 3 feet per year.

Hydrographs, which are graphical representations of water-level changes with time in a well, are shown adjacent to the water water-level-decline map for wells in areas that are extensively developed for irrigation. Many of the wells outside extensively developed areas have had little or no continuous water-level decline. The wells for which hydrographs are shown are located on the water-level-decline map.

Continuous large-scale withdrawals of water from the High Plains aquifer will result in a continuing decline in the water table. The areas likely to be most affected are those bordering the non-saturated High Plains deposits and areas where wells penetrate relatively thin saturated zones. Because of decreased well yield and increased power costs, irrigation may become uneconomical in some parts of the area.

WATER QUALITY IN THE HIGH PLAINS AQUIFER

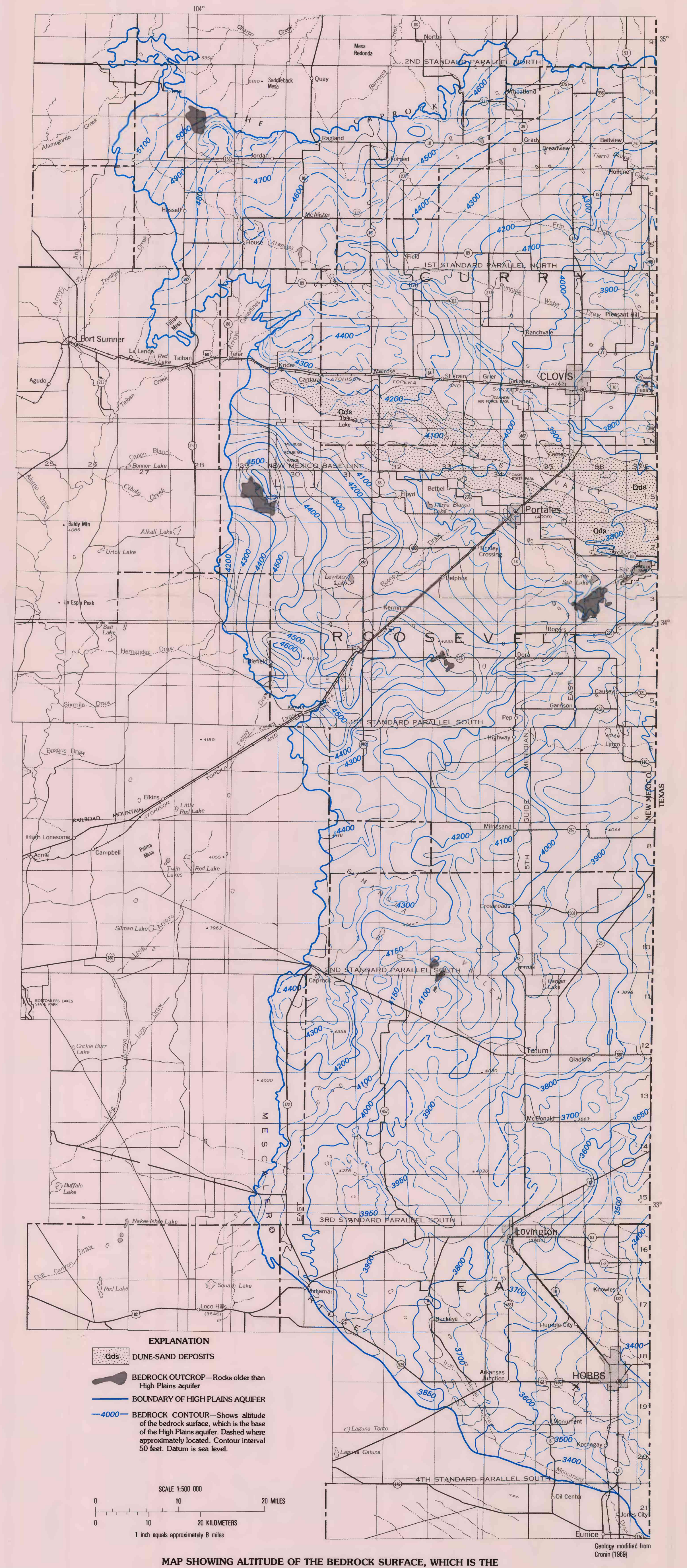
All natural water contains mineral matter dissolved from rock and soil with which it has come in contact. The quantity and kind of dissolved-mineral matter in ground water depends on the type of rocks or soil through which the water has passed and the pressure and temperature. In addition to natural factors, water infiltration from stock ponds, improperly sealed wells, and recycled irrigation water may affect the chemical quality of the ground water.

The chemical composition of water is an important factor in determining its utility because the quality of the water ideally should not adversely affect the user, product, or the land irrigated. The suitability of water for domestic, municipal, stock, industrial, or irrigation use is in part determined by the dissolved-solids concentration. Standards governing the chemical quality of water for public supplies have been established by the U.S. Environmental Protection Agency (1976, 1977). These standards place an upper limit of 500 milligrams per liter on the dissolved-solids concentration of drinking water where better quality is not available; limits have also been placed on concentrations of numerous other selected chemical constituents. Chemical-quality diagrams and concentration of dissolved solids from selected wells are shown on the water-quality map.

Water for stock also is subject to quality limitations. However, most animals apparently can tolerate water that would be considered unsatisfactory for people (Hem, 1970, p. 324).

The usefulness of water for irrigation is also governed by its chemical quality (Hem, 1970, p. 324-333). The dissolved-solids concentration, or the specific conductance, along with the relative proportion of sodium to calcium plus magnesium (called sodium-adsorption ration or SAR) are used to evaluate the suitability of water for irrigation. Important factors other than salinity-sodium hazards are the types and drainage characteristics of the soils, quantity of water applied, and salt or mineral tolerance of crops. Water that may not be chemically suitable for use on normal or relatively impermeable soils may be used on permeable, well-drained soils where rapid leaching is possible.

Water in the High Plains aquifer generally is suitable for domestic, municipal, and irrigation use, but the water typically has large concentrations of calcium, magnesium, and bicarbonate and in some areas may contain objectionably large concentrations of fluoride or chloride. Waters with large concentrations of dissolved-mineral constitutents most commonly are present in areas or zones where the underlying bedrock may be contributing small quantities of more mineralized water to the aquifer. This is most likely to occur in northeasten Lea and southern Roosevelt Counties where the High Plains aquifer overlies rocks of Cretaceous age.



EXPLANATION

Qds DUNE-SAND DEPOSITS

BEDROCK OUTCROP—Rocks older than High Plains aquifer

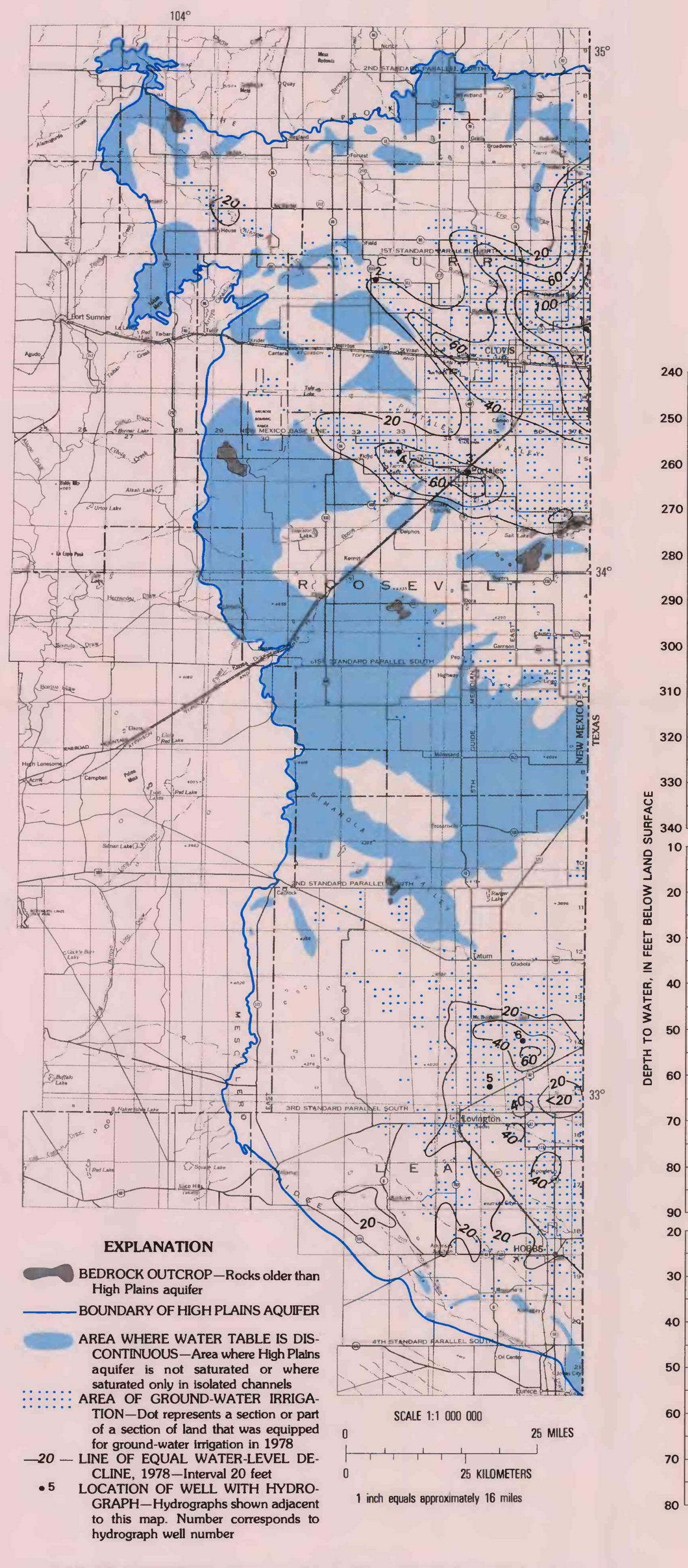
BOUNDARY OF HIGH PLAINS AQUIFER

—4000— BEDROCK CONTOUR—Shows altitude of the bedrock surface, which is the base of the High Plains aquifer. Dashed where approximately located. Contour interval 50 feet. Datum is sea level.

SCALE 1:500 000
0 10 20 MILES
0 10 20 KILOMETERS
1 inch equals approximately 8 miles

Geology modified from Cronin (1969)

MAP SHOWING ALTITUDE OF THE BEDROCK SURFACE, WHICH IS THE BASE OF THE HIGH PLAINS AQUIFER



EXPLANATION

BEDROCK OUTCROP—Rocks older than High Plains aquifer

BOUNDARY OF HIGH PLAINS AQUIFER

AREA WHERE WATER TABLE IS DISCONTINUOUS—Area where High Plains aquifer is not saturated or where saturated only in isolated channels

AREA OF GROUND-WATER IRRIGATION—Dot represents a section or part of a section of land that was equipped for ground-water irrigation in 1978

—20 — LINE OF EQUAL WATER-LEVEL DECLINE, 1978—Interval 20 feet

•5 LOCATION OF WELL WITH HYDROGRAPH—Hydrographs shown adjacent to this map. Number corresponds to hydrograph well number

SCALE 1:1 000 000
0 25 MILES
0 25 KILOMETERS
1 inch equals approximately 16 miles

MAP OF DISTRIBUTION OF 1978 IRRIGATED ACREAGE AND WATER-LEVEL DECLINE FROM PREDEVELOPMENT TO 1978

GEOLOGY

The High Plains aquifer in New Mexico is underlain by rocks of Triassic, Jurassic, and Cretaceous age. The surface depicted by contours on the adjacent map represents the configuration of the buried bedrock surface. The configuration also represents the base of the High Plains aquifer and is useful in determining the thickness of the overlying deposits and in studying the ancestral drainage pattern and mode of deposition of the materials that comprise the High Plains aquifer. Data from several thousand well and test-hole logs were used in constructing the contours showing the base of the High Plains aquifer. In some areas, data are adequate to define in detail the complex surface of the rocks beneath the High Plains aquifer, but in other areas the surface is only approximately defined because detailed data are not available. The most significant features shown on the bedrock-surface map are the generally southeastward slope of the bedrock surface and the southeastward direction of the pre-Tertiary drainage.

The configuration of the bedrock surface underlying the High Plains aquifer affected the depositional pattern and the thickness of the overlying aquifer and subsequently affected ground-water flow through the aquifer. The slope of the bedrock surface ranges from 10 to 20 feet per mile and averages about 15 feet per mile.

The Triassic, Jurassic, and Cretaceous rocks that directly underlie the High Plains aquifer are composed primarily of shale, mudstone, siltstone, and fine-grained sandstone. In addition, there are some lithologic units composed of medium- to very coarse grained sandstone, conglomerate, limestone, and dolomite.

The High Plains aquifer, as defined in this report consists of one or more hydraulically connected geologic units of the late Tertiary or Quaternary age. These rocks overlie the bedrock surface depicted on the adjacent map. The rocks of late Tertiary age consist of the Ogallala Formation, and the Quaternary deposits consist of alluvial, dune sand, and valley-fill deposits. The thickness of the High Plains aquifer ranges from 0 to about 500 feet. The Ogallala is the principal geologic unit in the High Plains aquifer; however, the alluvial deposits are significant in the northern part of Roosevelt County.

The Ogallala Formation is mostly unconsolidated clay, silt, fine- to coarse-grained sand, and gravel. Some caliche is present near the top and locally within the formation. When the Ogallala was deposited, aggrading streams filled valleys eroded deep into pre-Ogallala rocks. Braided steams flowed eastward from the mountains in central and southern New Mexico transporting rock debris, which was deposited as a heterogenous sequence of unconsolidated material. There is evidence that the upper part of the Ogallala in southern New Mexico may contain a considerable thickness of windblown sediments as well (C. V. Theis, U.S. Geological Survey, oral commun., 1980). In the upper part of the Ogallala Formation the sediments have been cemented, chiefly by calcium carbonate, to form single or multiple beds of caliche. The degree of cementation varies greatly, and the thickness of the beds ranges from a few inches to 60 feet. Because the caliche is resistant to erosion, it forms the caprock escarpment along the northern and western boundaries of the High Plains in this area.

The unconsolidated Quaternary alluvial and valley-fill deposits, like the Ogallala Formation, consist of clay, silt, sand, and gravel. These rocks primarily are derived from reworked Ogallala material. The alluvial deposits are believed to have a maximum thickness of about 120 feet in the southeastward trending Portales Valley area in Roosevelt County. The valley is about 50 miles long and reaches a maximum width of about 30 miles. Although this broad flat valley is as much as 250 feet lower than the surrounding terrain, there is no surface-water flow except during the most intense storms that occur at intervals of several years. Minor areas of valley-fill deposits may be located at numerous sites on the High Plains, but these deposits generally are not thick enough to extend down to the water table nor are they areally extensive.

Dune-sand deposits of Quaternary age, consisting predominantly of very fine to medium-grained windblown sand, are part of the High Plains aquifer. The most extensive area of dune sand is in northeastern Roosevelt and southern Currry Counties where the dune-sand deposits are parallel to and overlie the northern edge of the Portales Valley. The dune area is about 50 miles long and ranges from about 3 to 12 miles wide. A few of the dunes reach heights of 40 feet, but most are considerably lower. Many of the older dunes are stabilized and have some vegetation on them, whereas the active dunes have a typical dune topography with an absence of vegetation. The active dunes generally are less than 10 feet high.

GROUND WATER IN THE HIGH PLAINS AQUIFER

CONFIGURATION OF THE WATER TABLE

The configuration of the water table in the High Plains is shown on the adjacent map. The aquifer boundary on the map is the physical limit of the various geologic units comprising the High Plains aquifer. Water-level data for this map were obtained during the winter of 1978, when the effects of seasonal pumping for irrigation were at a minimum.

Hydraulic interconnection between geologic units that comprise the High Plains aquifer is sufficient to permit contouring a continuous water table throughout most of the area. The degree of hydraulic interconnection may vary from place to place; and, locally, some water-yielding beds may have a water level representative of an artesian-pressure surface because of clay lenses within the aquifer. However, from a regional aspect, water-table conditions prevail in the aquifer.

The aquifer is not saturated in some areas, or, the saturation is laterally discontinuous with the principal water body. Isolated wells located in the shaded area on the water-table map may penetrate saturated High Plains sediments in buried channels or sinks in the bedrock. As depicted on the map, the water table is discontinuous throughout an area of about 2,150 square miles.

The water-table map shows a general east-southeastward slope of the water table across the High Plains. The general direction of ground-water movement is at right angles to the water-table contours, in the down-gradient direction. Typically, the slope of the water table is between 10 and 15 feet per mile. The configuration of the water table is controlled by several factors, including (1) Slope of the base of the aquifer; (2) changes in the thickness and hydraulic conductivity of the saturated materials; (3) natural discharge of ground water to springs and seeps; (4) withdrawal of ground water by wells; and (5) recharge by infiltration of water through permeable overlying beds. Typically, closely spaced contours indicate steeply sloping water table, which may be the result of less permeable aquifer material, decreased thickness of the water-bearing materials, steeply sloping bedrock surface, or a combination of these factors. Flattening of the gradient indicated by the widely spaced contours may be due to increased permeability of the aquifer materials, increased thickness of the water-bearing materials, or both.

Up-gradient flexures of water-table contours generally are indicative of the effects of ground-water withdrawals on the aquifer because water tends to flow toward these cones of depression that disturb the general flow pattern. Up-gradient flexures may also be the result of zones of increased permeability that allow water to migrate through the zone and away from the area more rapidly than from adjacent less permeable zones. An example of this condition is in the Portales Valley in Roosevelt County. This effect is magnified in the Portales Valley because a large concentration of irrigation wells creates a regional cone of depression.

Down-gradient flexures or increased spacing of water-table contours indicate recharged by infiltration of water through overlying beds. An example of this type of contour deflection is shown on the water-table map and coincides with the sand-dune area in northeastern Roosevelt and southwestern Curry Counties shown on the bedrock-surface map. Down-gradient flexures also may be caused by a topographic high (hill) in the underlying bedrock surface. An example of this feature is shown in the area near Caprock in western Lea County on the bedrock-surface map.

SATURATED THICKNESS

The saturated thickness in the High Plains aquifer ranges from 0 to slightly more than 200 feet. Areas having the greatest saturated thickness are southeast of Clovis in Curry and Roosevelt Counties and in the vicinity of Lovington and Hobbs in Lea County. The saturated thickness at any point may be estimated by subtracting the altitude of the aquifer base from the altitude of the water table at that point.

An area of about 2,150 square miles, mostly in northern Lea County and southern and western Roosevelt Counties, does not have significant saturated thickness except in narrow Ogallala-filled bedrock channels and depressions. In those areas with only thin basal saturation of the High Plains aquifer sediments, wells cannot be drilled with assurance of obtaining water from the aquifer.

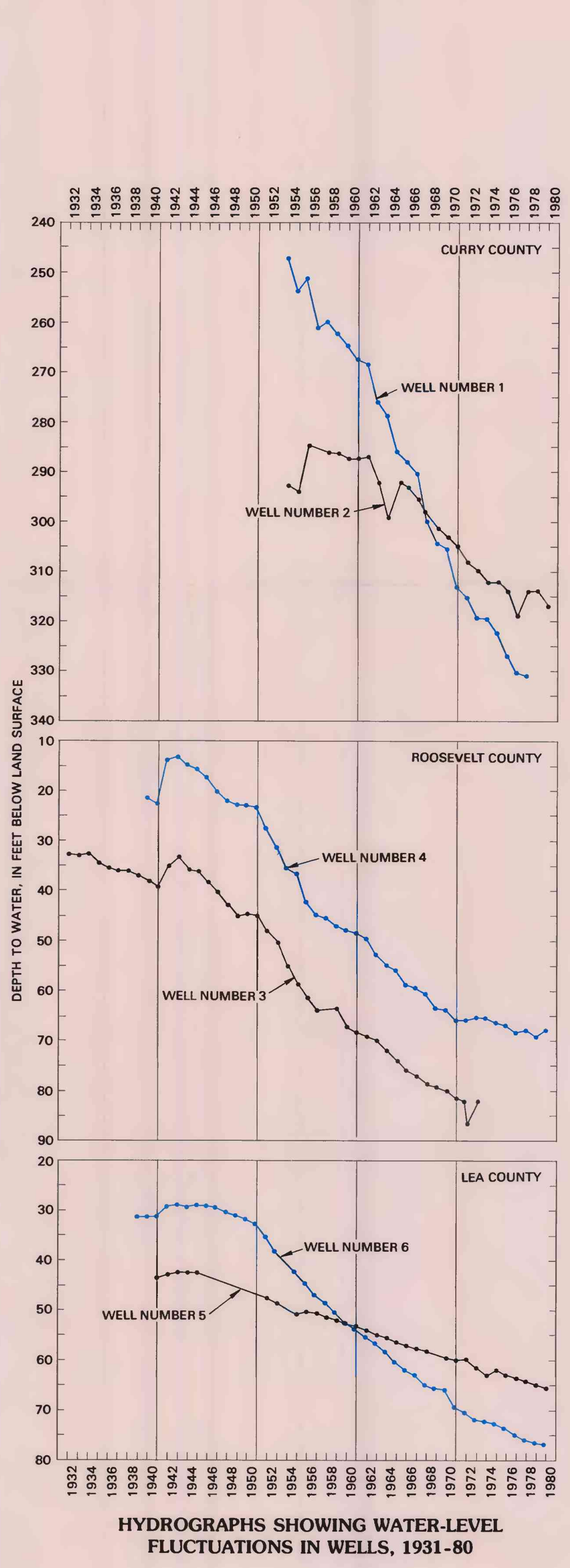
HYDRAULIC PROPERTIES

Hydraulic conductivity and specific yield are two hydrologic properties that were estimated during the course of this study. The hydraulic conductivity may be defined as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The specific yield is the ratio defined by the volume of water that a saturated rock will yield by gravity divided by the volume of the rock.

Hydraulic properties of the aquifer were estimated by using existing aquifer-test data published in previous studies and by using lithologic logs from wells. Based on aquifer tests conducted in the High Plains aquifer and laboratory grain-size analyses, empirical relationships were developed to estimate values of hydraulic conductivity and specific yield for various grain-size materials in the aquifer. Lithologic logs were examined and values were assigned to the various intervals of clay, silt, sand, and gravel in that part of the log representing the saturated zone. Evaluation of 127 fully penetrating logs and 133 partly penetrating logs was made in this manner. The results indicated the High Plains aquifer in Lea County and the southern part of Roosevelt County has a hydraulic conductivity ranging from 25 to 135 feet per day with an average hydraulic conductivity of about 50 feet per day. The results also indicate that the aquifer in northern Roosevelt, Curry, and Quay Counties has a hydraulic conductivity ranging from 11 to 200 feet per day with an average hydraulic conductivity of about 60 feet per day. The evaluation of the lithologic logs indicated that the aquifer has a specific yield ranging from about 0.05 to .20 with an average of about 0.15.

RECHARGE

The quantity of natural recharge to the aquifer from precipitation was not determined; however, previous work by Theis (1932, 1934, 1937), which utilized several methods, determined recharge to be less than 0.5 inch per year. Only 3 to 4 percent of the precipitation falling on the High Plains reaches the water table; the remainder is returned to the atmosphere by evapotranspiration.



HYDROGRAPHS SHOWING WATER-LEVEL FLUCTUATIONS IN WELLS, 1931-80

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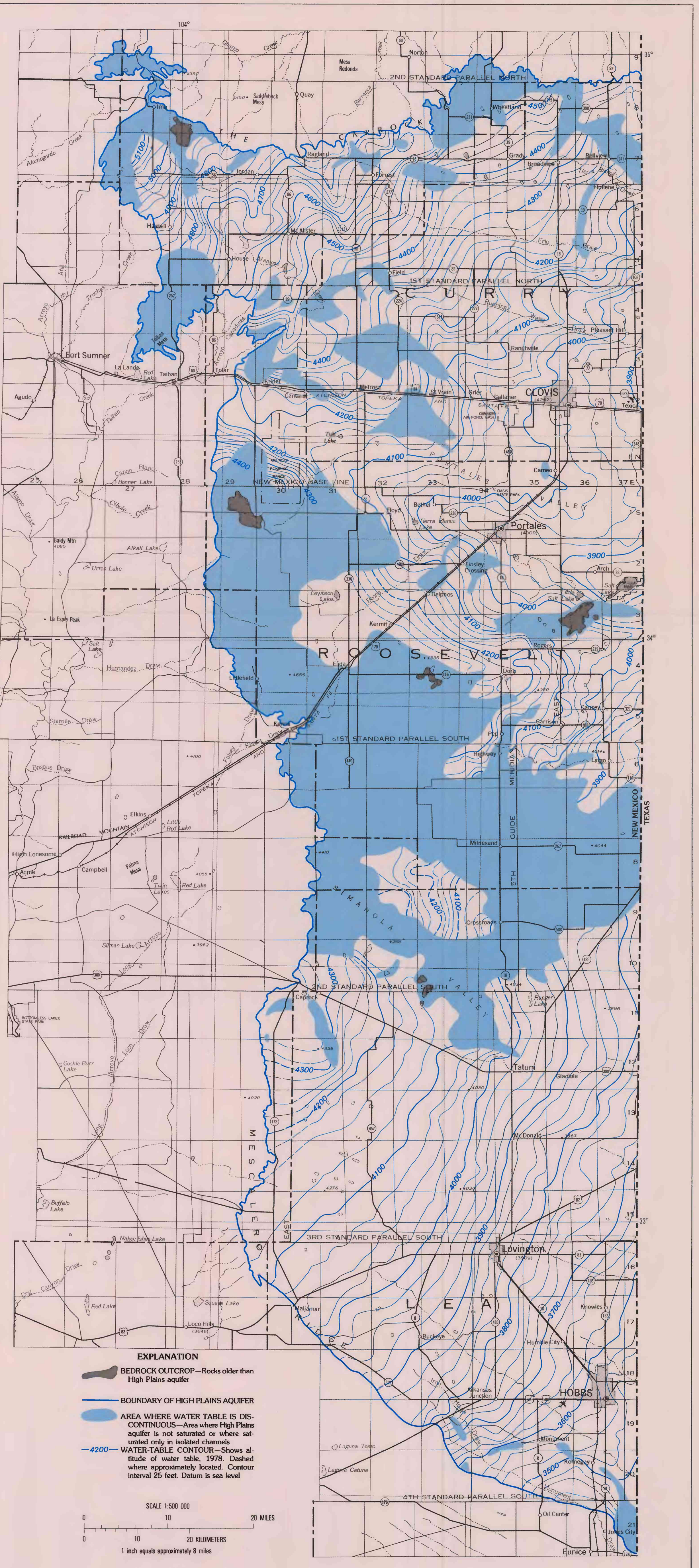


EXPLANATION

BEDROCK OUTCROP—Rocks older than High Plains aquifer

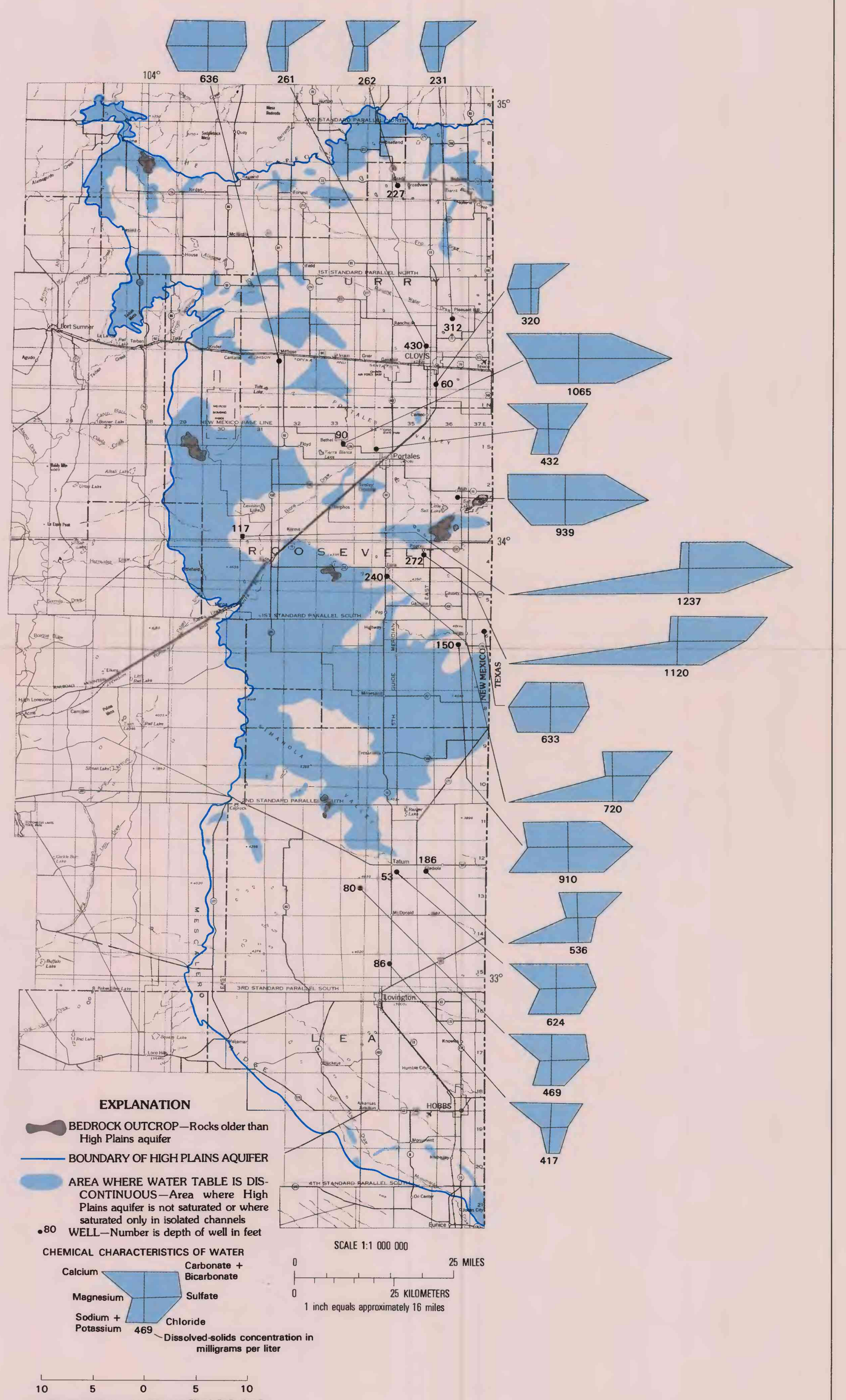
BOUNDARY OF HIGH PLAINS AQUIFER

AREA WHERE WATER TABLE IS DISCONTINUOUS—Area where High Plains aquifer is not saturated or where saturated only in isolated channels

—4200— WATER-TABLE CONTOUR—Shows altitude of water table, 1978. Dashed where approximately located. Contour interval 25 feet. Datum is sea level

SCALE 1:500 000
0 10 20 MILES
0 10 20 KILOMETERS
1 inch equals approximately 8 miles

MAP SHOWING ALTITUDE AND CONFIGURATION OF THE WATER TABLE FOR THE HIGH PLAINS AQUIFER, 1978



EXPLANATION

BEDROCK OUTCROP—Rocks older than High Plains aquifer

BOUNDARY OF HIGH PLAINS AQUIFER

AREA WHERE WATER TABLE IS DISCONTINUOUS—Area where High Plains aquifer is not saturated or where saturated only in isolated channels

•80 WELL—Number is depth of well in feet

CHEMICAL CHARACTERISTICS OF WATER

Calcium
Magnesium
Sodium + Potassium
Carbonate + Bicarbonate
Sulfate
Chloride
469 Dissolved-solids concentration in milligrams per liter

10 5 0 5 10
CONCENTRATION, IN MILLIEQUIVALENTS PER LITER

SCALE 1:1 000 000
0 25 MILES
0 25 KILOMETERS
1 inch equals approximately 16 miles

MAP SHOWING GENERALIZED WATER QUALITY IN THE HIGH PLAINS AQUIFER

Base from U.S. Geological Survey
State base map, 1967
Revised as of 1984

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GEOHYDROLOGY OF THE HIGH PLAINS AQUIFER IN SOUTHEASTERN NEW MEXICO

By

Donald L. Hart, Jr. and Douglas P. McAda

1985

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