INTRODUCTION

The U.S. Geological Survey initiated a 5-year study of the High Plains regional aquifer in 1978 to provide (1) hydrologic information needed to evaluate the effects of continued ground-water development, and (2) computer models to predict aquifer response to changes in ground-water development. The plan of study for the High Plains Regional Aquifer-System Analysis is described by Weeks (1978). This report is the first of several reports that describe the hydrologic characteristics of the High Plains aquifer. The purpose of this report is to provide an introductory description of the study area and High Plains aquifer. The water-table map was compiled from maps prepared by U.S. Geological Survey hydrologists in each of the eight States in the High Plains. Their work is an integral part of this investigation.

Physiography and Climate

The High Plains include parts of eight States--Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Flat to gently rolling terrain characterizes the High Plains region, which is a remnant of a vast plain which was formed by sediments deposited by streams flowing eastward from the Rocky Mountains. Subsequently, erosion isolated the plains from the mountains and formed escarpments that typically mark the boundary of the High Plains. Wind-blown sand and silt, derived from the beds of rivers that eroded the plains, were deposited over large areas of the High Plains. The fluvial (stream-deposited) and eolian (wind-blown) sediments that form the High Plains affect both the topography and ground-water hydrology by controlling the structure of both the land surface and the aquifer.

The largest expanse of wind-blown sand deposits and dune topography in the Western Hemisphere is in Nebraska (Madson, 1978) between the Platte and Niobrara Rivers. Within these sand hills, lakes and meadows occur between dunes where the water table is at or near land surface. Smaller areas of sand dunes occur in many parts of the High Plains as shown on the water-table map.

Many lakes also occur on the High Plains outside of Nebraska. However, these lakes are shallow depressions or playas that collect and store water during periods of runoff; some of the deeper playas hold water throughout the year. According to Fenneman (1931), these playas originally formed where irregularities on the plain allowed water to collect. Water percolating downward dissolved soluble material and the resulting compaction of the sediments formed the playa. Playas are most prevalent south of the Arkansas River. Because playas in the High Plains are generally above the regional water table, the water surfaces in the playas do not reflect the altitude of the water table in the underlying aquifer, as many of the lakes do in the sand hills of Nebraska.

Precipitation is the principal source of recharge to the ground-water system in the High Plains. Mean annual precipitation increases from 14 inches in southeastern Wyoming and eastern New Mexico to about 30 inches in eastern Nebraska and central Kansas. Mean annual precipitation increases eastward across the High Plains by about 1 inch every 25 miles. Typically, about 75 percent of the precipitation falls during the growing season, April through September, a condition favorable to agriculture. However, much of the rain results from local thunderstorms, so large variations in precipitation can occur from place to place and year to year.

Persistent winds and high summer temperatures cause high rates of evaporation in the High Plains. Mean annual evaporation from Class A pans ranges from about 60 inches in northern Nebraska to 100 inches in western Texas. Because of the large evaporative demand, little precipitation is available to recharge the ground-water system. Except in sand-dune areas where water can readily percolate down to the water table, most of the water that enters the soil is returned to the atmosphere by evapotranspiration. Recharge to the ground-water system may be several inches per year in sand-dune areas; but, over the much larger part of the High Plains where soils can hold the water for subsequent evapotranspiration, recharge may average less than 0.5 inch per year.

Ground water from the High Plains aquifer discharges naturally to streams, and to springs and seeps along the eastern escarpment. Streams that originate in the High Plains are generally ephemeral in their upper reaches and perennial where their channels are incised to the water table. The Niobrara, Loup, Republican, Smoky Hill, Red, and Brazos Rivers are among those streams which have their headwaters on the High Plains. Some streams draining the High Plains--The Platte, Arkansas, Cimarron, North Canadian, and Canadian Rivers--have headwaters in the mountains to the west; but, of these, only the Platte River is perennial throughout its course across the High Plains.

Agriculture and Irrigation

Irrigation of crops is the largest use of water in the High Plains. About 95 percent of the water for irrigation is obtained from ground water. Prior to 1930, agriculture consisted primarily of dryland farming and cattle grazing. Although ground-water irrigation technology was developing on the plains, the number of irrigation wells did not increase rapidly until after the drought of 1930-39. By 1952, about 26,000 wells pumped 3 million acre-feet of water to irrigate about 2.7 million acres (Lohman, 1953); and in 1977, about 168,000 wells pumped 30 million acre-feet of water to irrigate about 16 million acres. Estimates of acreage irrigated by wells in the High Plains during 1977 are summarized in the table. The data were obtained from State and Federal agencies and adjusted to include only the acreage irrigated by ground water. In 1977, about 35 percent of the area of the High Plains was cropland, and 14 percent of the High Plains was irrigated by ground water. Based on U.S. Department of Agriculture crop statistics, about 15 percent of the corn, 70 percent of the grain sorghum, and 23 percent of the upland cotton produced in the United States was grown on the High Plains in 1977.

The agricultural economy of the High Plains developed rapidly because of availability of low-cost energy and water. However, in recent years, energy costs have risen sharply and availability of ground water in the High Plains has declined. As the water table declines and the cost of pumping increases, it becomes less profitable to irrigate. In some areas (primarily in Texas), pumping rates have decreased and costs have increased to the point where it is no longer profitable to irrigate, and many farmers have returned to dryland farming.

HIGH PLAINS AQUIFER

Geologic Description

The High Plains aquifer, as defined in this report, includes an area of 177,000 square miles and consists of one or more hydraulically connected geologic units of late Tertiary or Quaternary age. In ascending order, the late Tertiary rocks consist of the Brule Formation, Arikaree Group, and Ogallala Formation. The Quaternary deposits consist of alluvial, dune-sand, and valley-fill deposits.

The Brule Formation crops out or underlies much of western Nebraska, northeastern Colorado, southwestern South Dakota, and southeastern Wyoming. The Brule is predominately a massive siltstone containing beds of sandstone and channel deposits of sand. Localized lenticular beds of volcanic ash, claystone, and fine sand are present, also. Maximum thickness of the Brule is about 600 feet.

The Brule Formation generally has low permeability. However, in some places, permeability of the formation has been increased by secondary porosity--joints, fractures, and solution openings. The Brule Formation is considered an aquifer only in areas where it contains saturated zones resulting from interconnected secondary porosity. Where secondary porosity has not been developed, the top of the Brule Formation is considered the base of the High Plains aquifer. Well yields from the Brule Formation are highly variable because the yield depends on the degree to which secondary porosity has been developed. Wells yielding up to 1,500 gallons per minute from fractured Brule have been reported along Lodgepole Creek in Nebraska and Wyoming and in the vicinity of Julesburg in northeastern Colorado. However, the quantity of water available from the Brule Formation is typically less than 300 gallons per minute.

In this study, the Arikaree Group (or Formation) includes all late Tertiary deposits between the underlying Brule Formation and the overlying Ogallala Formation. The Arikaree crops out in or underlies parts of western Nebraska, south-western South Dakota, southeastern Wyoming, and northeastern Colorado. The Arikaree is predominately a massive, very fine - to fine-grained sandstone, but contains localized beds of volcanic ash, silty sand, and sandy clay. Maximum thickness of the Arikaree is about 1,000 feet in western Nebraska and in Platte County, Wyoming.

Wells in the Arikaree Group generally do not yield large quantities of water. In Wyoming and probably western Nebraska, well yields of about 350 gallons per minute can be expected from about 200 feet of saturated thickness. In Niobrara County, Wyoming, yields of 600 gallons per minute have been reported from 700 feet of saturated thickness. Secondary porosity, similar to that in the Brule, also occurs in the Arikaree Group.

The term Ogallala Formation, as used in this report, refers to all late Tertiary rocks in the study area that are younger than the Arikaree Group. The Ogallala Formation is the principal geologic unit in the High Plains aquifer and underlies about 156,000 square miles of the study area. Thickness of the Ogallala ranges from 0 to about 700 feet. When the Ogallala was deposited, aggrading streams filled and buried valleys cut deep into pre-Ogallala rocks. Braided streams flowed eastward from the mountains carrying rock debris, which was deposited as a heterogeneous sequence of clays, silts, sands, and gravels (Fenneman, 1931). The distribution of sediment types within the Ogallala Formation is largely random (Breyer, 1975).

Within the Ogallala, zones cemented with calcium carbonate are resistant to weathering and form ledges in outcrops. The most distinctive of these layers, the Ogallala cap rock (often called caliche or mortar bed), extends over large areas near the top of the Ogallala Formation in Texas and New Mexico and may be as thick as 60 feet.

Saturated sediments in the Ogallala are not evenly distributed throughout the area. Irrigation wells with yields of about 1,000 gallons per minute can be developed from about 100 feet of saturated sand and gravel. In the southern High Plains and in parts of western Kansas, wells pumping 100 gallons per minute are developed in areas with as little as 20 feet of saturated sand and gravel.

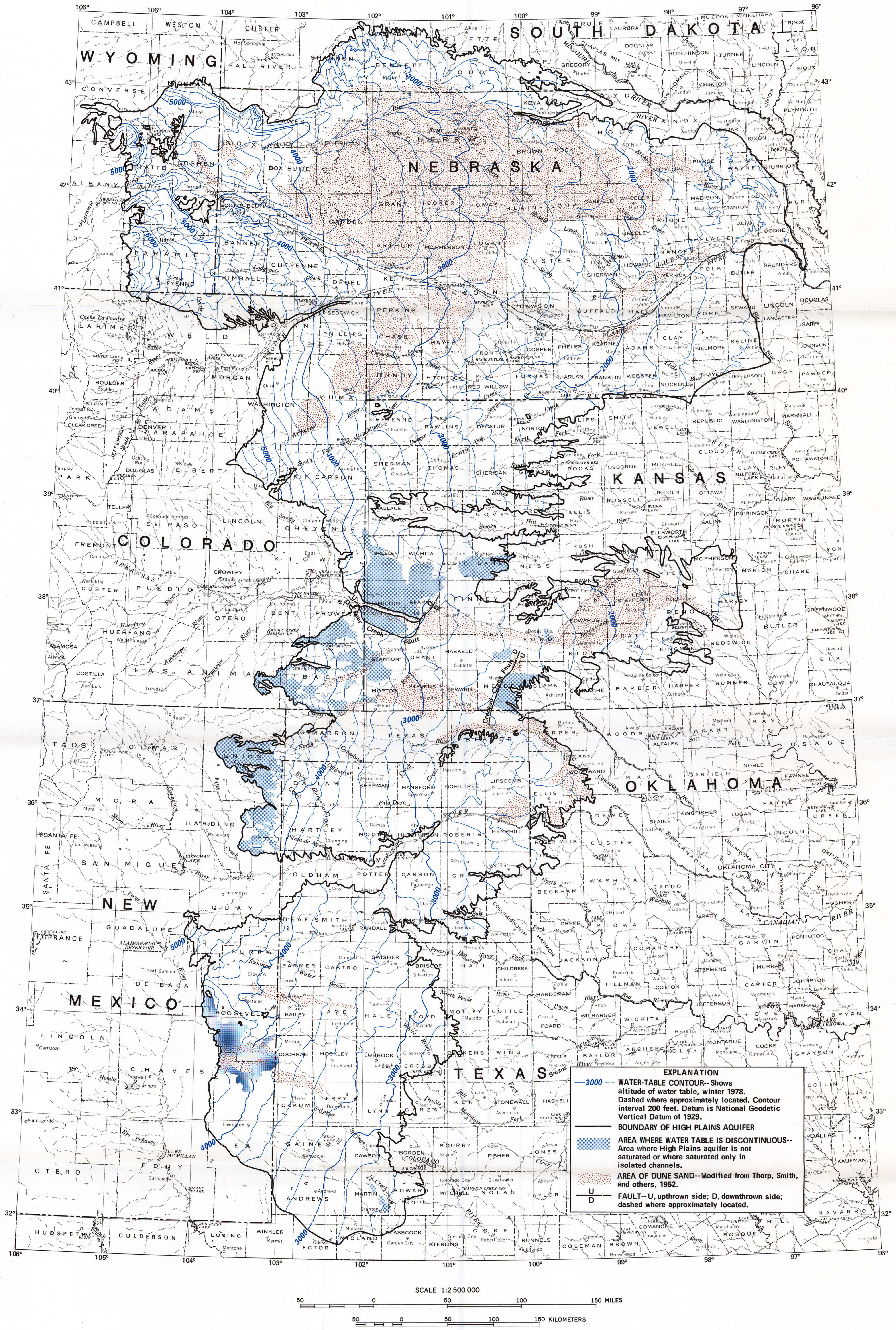
Unconsolidated alluvial deposits of Quaternary age that are in hydraulic connection with Tertiary deposits are considered to be part of the High Plains aquifer. Much of the gravel, sand, silt, and clay in the alluvial deposits are reworked from the Ogallala Formation (Gutentag, 1963). These Quaternary alluvial deposits have a maximum thickness of about 300 feet. Alluvial deposits comprise the High Plains aquifer in south-central Nebraska and the Great Bend area in central Kansas. In western Kansas, central Nebraska, Oklahoma Panhandle, and western Texas, Quaternary alluvial deposits directly overlie the Ogallala Formation to form one aquifer.

Dune-sand deposits of Quaternary age, consisting predominately of very fine to medium wind-blown sand, are part of the High Plains aquifer. The most extensive area of dune sand is in west central Nebraska where the deposits have a maximum thickness of about 300 feet. Large areas also are covered by dune-sand deposits south of the Arkansas River in Kansas. In the Great Bend area, dune sand is saturated in many places and forms part of the aquifer system. In Kearny, Finney, Hamilton, and Gray Counties, Kansas, the water table generally lies below the dune-sand deposits. In these counties, the areas of dune sand are recharge areas for the underlying alluvial deposits and Ogallala Formation. Recharge areas also occur where dune sand overlies the High Plains aquifer in other parts of the study area.

Valley-fill deposits consist of unconsolidated gravel, sand, silt, and clay associated with the most recent cycle of erosion and deposition along present streams. These deposits are as much as 60 feet thick. Valley-fill deposits that are hydraulically connected to underlying Tertiary or Quaternary deposits are considered part of the High Plains aquifer. The valley-fill deposits and associated streams form stream-aquifer systems which link the High Plains aquifer to surface streams, particularly along the Platte and Arkansas Rivers.

Area of High Plains aquifer and estimated acreage irrigated by ground water, 1977

State	Area of State within High Plains (square miles)	(percent)	Area of High Plains within State (percent)	Estimated irrigated acres	Estimated number of wells
Colorado---------	14,870	14	8	585,000	4,300
Kansas-----------	31,050	38	18	3,250,000	23,000
Nebraska---------	64,400	83	36	5,560,000	59,300
New Mexico-------	9,710	8	6	480,000	6,000
Oklahoma---------	7,350	11	4	225,000	2,200
South Dakota-----	5,290	7	3	20,000	160
Texas------------	36,080	13	20	6,000,000	72,000
Wyoming----------	8,190	8	5	90,000	1,140
TOTALS---------	176,940	--	100	16,210,000	168,100



ALTITUDE AND CONFIGURATION OF WATER TABLE

Water-Table Configuration

The configuration of the water table in the High Plains is shown on the 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 and spring of 1978, when effects of seasonal pumping for irrigation were at a minimum. Because of severe winter weather, water-level data for Nebraska are collected during the spring prior to pumping for irrigation. The Nebraska data were used without adjustment because data from observation wells with continuous records in Nebraska show little change (about 1 foot) from winter to spring. Water-level data are collected during the winter in the other States.

Hydraulic interconnection between geologic units that comprise the High Plains aquifer is sufficient to permit contouring a continuous water table throughout the region. 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 greater than that of the water table. However, from a regional aspect, water-table conditions prevail in the aquifer.

In a few areas, the aquifer is not saturated and the water table is discontinuous. Wells drilled in these areas will not yield water unless they happen to penetrate saturated sediments in buried channels in the bedrock. The major areas, where the water table is discontinuous, are shown on the map.

The water-table map shows a general eastward 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 direction of greatest slope, or hydraulic gradient. The velocity of water moving through the aquifer is proportional to the hydraulic gradient. The slope of the water table ranges from about 34 feet per mile near Cheyenne, Wyoming, to about 7 feet per mile near Aurora, Nebraska. Typically, the slope of the water table is between 10 and 15 feet per mile. Based on average values of hydraulic gradient and aquifer parameters, the velocity of water moving through the aquifer is about 1 foot per day which is typical of sand and gravel aquifers.

The configuration of the water-table contours is controlled by several factors, including (1) slope of the bedrock base of the aquifer, (2) changes in the thickness and hydraulic conductivity of saturated materials, (3) discharge of ground water into streams, (4) pumpage of ground water by wells, (5) recharge to the aquifer from streams, and (6) recharge by infiltration of water through permeable soils. Typically, many of these factors control the water-table configuration in any particular area. For example, along the western border of the High Plains, especially in southeastern Wyoming, the closely spaced contours which indicate a steep slope of the water surface may be the result of low permeability, reduced thickness of water-bearing materials, a steep slope of the bedrock surface, or a combination of these factors. Flattening of the gradient indicated by the widely spaced contours such as those near the eastern border of the High Plains, may be due to high permeability of the material through which the water is moving, increased thickness of water-bearing materials, or both.

Up-gradient flexures of water-table contours near streams indicate ground-water flows toward and discharges into streams. This is most evident along the Platte River in Morrill and Garden Counties, Nebraska, and the Canadian River in Hemphill and Roberts Counties, Texas. Down-gradient flexures of water-table contours near streams indicate water flows from streams into the aquifer. The 2,000-foot contour crossing the Platte River in Adams County, Nebraska, and the 1,800-foot contour in Hamilton County, Nebraska, suggest this condition. Lack of flexures in areas where contours cross stream valleys may indicate that the water table lies below the streambed. This condition is true for most ephemeral streams in the High Plains.

Up-gradient flexures of water-table contours in areas away from perennial streams are indicative of the effects of ground-water pumpage on the aquifer. Water tends to flow toward these cones of depression which disturb the general flow pattern. Flexures in the water-table contours caused, at least in part, by the effects of pumpage are shown by the 2,800-foot contour in Grant and Finney Counties, Kansas, and Texas County, Oklahoma, and the 3,200-foot contour in Lubbock County, Texas. The best example of this condition is shown by the 4,000- and 4,200-foot contours in Curry and Roosevelt Counties, New Mexico. Here, development of irrigation wells in a zone of high permeability has caused pronounced flexures of the water-table contours.

Down-gradient flexures or increased spacing of water-table contours in areas away from perennial streams indicate recharge by infiltration of water through the overlying soil profile. Recharge is indicated by the water-table contours in areas covered by dune sand in Colorado, Kansas, and Nebraska, and to a lesser extent in New Mexico, Oklahoma, and Texas. Also, down-gradient flexures, such as that in Floyd County, Texas, can be caused by a topographic high (hill) in the bedrock surface.

Faulting of the bedrock materials also affects normal ground-water flow pattern. Along the Bear Creek Fault in Stanton County, Kansas, the 3,200-foot water-table contour does not extend across the fault because the water table is not present (little or no saturated thickness) on the upthrown side. Eastward along the fault, in Grant and Kearny Counties, the 3,000-foot contour is displaced, but it is not greatly affected by the fault because there is sufficient saturated thickness on the upthrown side of the fault to maintain a continuous water table. Along the Crooked Creek Fault in Meade County, Kansas, the 2,400-foot contour ends abruptly at the fault, because the bedrock is exposed and the water table is discontinuous on the upthrown (east) side. The 2,400-foot contour in Beaver County, Oklahoma, and Meade County, Kansas, is projected across the fault, because saturated thickness south of the Cimarron River is sufficient to maintain a continuous water table.

In summary, the water-table map shows that the High Plains aquifer is continuous throughout its extent. Ground water generally flows west to east and discharges to wells and streams or along the eastern boundary of the aquifer. The configuration of the water table indicates that areas overlain by dune sand are major recharge areas for the High Plains aquifer.

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CONVERSION FACTORS

Multiply inch-pound unit	By	To obtain metric unit
inch	25.4	millimeter
foot	0.3048	meter
foot per mile	0.19	meter per kilometer
foot per day	0.3048	meter per day
mile	1.609	kilometer
acre	0.4047	square hectometer
acre foot	1,233	cubic meter
square mile	2.590	square kilometer
gallon per minute	0.06309	liter per second

Base from U.S. Geological Survey
United States base map, 1972

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WATER TABLE IN THE HIGH PLAINS AQUIFER IN 1978 IN PARTS OF COLORADO, KANSAS, NEBRASKA, NEW MEXICO, OKLAHOMA, SOUTH DAKOTA, TEXAS, AND WYOMING

By
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1980

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