U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

INTRODUCTION

The High Plains aquifer underlies parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. About 20 percent of the irrigated land in the United States is in the region underlain by the High Plains aquifer, and nearly 30 percent of the ground water used for irrigation in the United States is pumped from the High Plains aquifer (Weeks and others, 1988). The large volume of water withdrawn from the aquifer for irrigation purposes since 1940 has had a substantial effect on water levels in the aquifer.

Water-level changes in the High Plains aquifer, however, have not been uniform. Large regional differences in rates of ground-water recharge and withdrawals for irrigation as a result of regional variability in climate, soil, land use, and historical development of irrigated agriculture have substantially affected the geographical patterns of water-level change in the High Plains aquifer.

The High Plains Regional Aquifer-System Analysis, completed by the U.S. Geological Survey (USGS) in the mid-1980's, indicated that substantial water-level declines had occurred in large parts of the High Plains aquifer (Gutentag and others, 1984). Congress recognized that accurate information on the conditions and water-level changes in the High Plains aquifer is necessary to make sound management decisions concerning the use of water, to project future economic conditions, and to conduct hydrologic research pertaining to the High Plains aquifer. Congress passed the Water Resources Research Act of 1984 (Public Law 98-242), which mandated and funded a program for the USGS to monitor water-level changes in the aquifer annually, starting in 1988. The Federal Reports Elimination and Sunset Act of 1995 (Public Law 104-66) and the Omnibus Water Resources Development Act of 1986 (Public Law 98-662) amended Public Law 98-242. Congress now mandates that the USGS in cooperation "...with the States of the High Plains region is authorized and directed to monitor the water levels of the Ogallala [High Plains] aquifer, and report biennially to Congress."

The purpose of this report is to present (1) the water-level changes in the High Plains aquifer for three time periods: predevelopment to nonirrigation season (generally October through March) 1979–80, nonirrigation season 1979–80 to nonirrigation season 1994–95, and nonirrigation season 1993–94 to nonirrigation season 1994–95; and (2) the precipitation pattern in the region underlain by the High Plains aquifer for 1994 and 1981–94. The water-level changes and precipitation patterns are shown in maps; periodic water levels for selected wells are shown in hydrographs. In this report, the "High Plains region," "central High Plains region," "northern High Plains region," and "southern High Plains region" are the terms used to designate the areas underlain by the High Plains aquifer or its subdivisions (fig. 1).

EXTENT AND DESCRIPTION OF THE HIGH PLAINS AQUIFER

The High Plains aquifer underlies about 174,050 square miles in Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (fig. 1). The High Plains aquifer, formerly known as the Ogallala aquifer, consists of one or more geologic units of late Tertiary or Quaternary age that are hydraulically connected, including Quaternary deposits, the Ogallala Formation, the Arikaree Group, and the Brule Formation (table 1). The Ogallala Formation is generally the principal unit of the High Plains aquifer (Gutentag and others, 1984).

Table 1. Geologic units of the High Plains aquifer
[Sources: Gutentag and others, 1984; Emry and others, 1987; Tedford and others, 1987; Swinehart, 1989]

Geologic unit composing the aquifer	System (series) and time of deposition, in millions of years before present	Composition	Location where geologic unit is a substantial part of the High Plains aquifer: Colorado	Kansas	Nebraska	New Mexico	Oklahoma	South Dakota	Texas	Wyoming
Dune sand	Quaternary (Holocene), 0.008 to 0.0015	Sand, very fine to medium-grained, unconsolidated.		X	X					
Valley-fill and alluvial deposits	Quaternary (Holocene and Pleistocene), 1.8 to present	Clay, silt, sand, and gravel, unconsolidated.		X	X	X				
Ogallala Formation	Tertiary (Miocene), 19 to 5	Clay, silt, sand, and gravel, generally unconsolidated; where cemented by calcium carbonate, mortar beds formed.	X	X	X	X	X	X	X	X
Arikaree Group	Tertiary (Miocene and Oligocene), 29 to 19	Sandstone, very fine to fine-grained, with beds of volcanic ash, silty sand, and sandy clay.			X			X		X
Brule Formation	Tertiary (Oligocene), 31 to 29	Siltstone, massive, with beds of sandstone, volcanic ash, and clay.	X		X					X

The characteristics of the High Plains aquifer in 1980 are summarized by State in table 2. The ranking of the States in 1980 from greatest to least percentage of aquifer area are: Nebraska, Texas, Kansas, Colorado, New Mexico, Wyoming, Oklahoma, and South Dakota. The ranking of States in 1980 from greatest to least percentage of aquifer volume is: Nebraska, Texas, Kansas, Colorado, Oklahoma, Wyoming, South Dakota, and New Mexico.

Table 2. Characteristics of the High Plains aquifer in 1980
[Modified from Gutentag and others, 1984]

Characteristic	Unit of measnrement	Total	Colorado	Kansas	Nebraska	New Mexico	Oklahoma	South Dakota	Texas	Wyoming
Area underlain by aquifer	Square miles	174,050	14,900	30,500	63,650	9,450	7,350	4,750	35,450	8,000
Percentage of total aquifer area	Percent	100	8.6	17.5	36.6	5.4	4.2	2.7	20.4	4.6
Percentage of each State underlain by aquifer	Percent	–	14	38	83	8	11	7	13	8
Average area-weighted saturated thickness in 1980	Feet	190	79	101	342	51	130	207	110	182
Volume of drainable water in storage in 1980	Million acre-feet	3,250	120	320	2,130	50	110	60	390	70
Percentage of total volume of drainable water in storage in 1980	Percent	100	3.7	9.9	65.5	1.5	3.4	1.8	12.0	2.2

HIGH PLAINS WATER-LEVEL MONITORING PROGRAM

Table 3. Number of observation wells measured for the water-level comparison periods—1980–95 and 1994–95.

State	Number of observation wells measured: 1980 and 1995	1994 and 1995
Colorado	519	571
Kansas	965	1,112
Nebraska	2,000	2,831
New Mexico	186	211
Oklahoma	198	225
South Dakota	38	53
Texas	1,974	2,218
Wyoming	21	45
High Plains	**5,901**	**7,266**

An extensive network of observation wells is necessary to monitor water levels in the High Plains aquifer (fig. 1). This network consists of many smaller networks of observation wells measured by numerous Federal, State, and local agencies. Local water and natural resource conservation districts are responsible for most of these smaller observation-well networks and the majority of water-level measurements. The total number of wells measured in 1980 and again in 1995 was 5,901; the total number measured in 1994 and again in 1995 was 7,266 (table 3). During the year, the USGS compiles the water-level measurements from these local networks and maintains a statewide data base in all of the States in the High Plains region except Texas; in Texas, the Texas Water Development Board maintains the statewide data base. The USGS determines the water level for each measured well that best represents nonpumping conditions and compiles the water-level data annually into an aquifer data base.

Water-level measurements are usually made in late winter and early spring when water levels generally represent nonpumping conditions. These measurements normally represent the highest water level during the year. Most observation wells are privately owned irrigation wells. The large diameter and high pumping capacity of these wells make them particularly well suited for monitoring water-level changes because they are less prone to plugging than wells of small diameter and low pumping capacity.

FACTORS AFFECTING WATER-LEVEL CHANGE

Water-level change in the High Plains aquifer results from an imbalance between recharge and discharge. Human activities such as pumping wells and diverting streams have contributed to this imbalance in many parts of the High Plains aquifer, resulting in substantial water-level change through time.

RECHARGE

Precipitation is the principal source of natural ground-water recharge to the High Plains aquifer. Other sources include seepage from streams, canals, and reservoirs and irrigation return flow. Several factors that can affect the proportion of available water that ultimately recharges the aquifer include topography, soil texture and thickness, vegetation or crop type, evapotranspiration, and the lithology and thickness of the unsaturated zone.

Recharge to the High Plains aquifer usually results from conditions present during the nongrowing season, when evapotranspiration is minimal and soil water can accumulate in the root zone and percolate downward. In the drier western portion of the High Plains region, the recharge process may occur only as an isolated event every several years. In the wetter eastern portion of the High Plains region, the recharge process is more frequent (Dugan and Zelt, in press).

Dugan and Zelt (in press) calculated estimated average annual potential ground-water recharge to the High Plains aquifer from precipitation and irrigation return flow using soil and vegetation characteristics and 1951–80 climatic data. Their recharge estimate ranges from 0.25 to 0.5 inch in the western portion of the High Plains region, where annual precipitation is generally less than 16 inches, to 4-6 inches in the eastern portion of the northern and central High Plains region, where precipitation generally exceeds 24 inches. Expressed as a percentage of average annual precipitation, their recharge estimate ranges from less than 2 percent in the western portion of the High Plains region to more than 17 percent in the eastern portion of the northern High Plains region (McGrath and Dugan, 1993; Dugan and Zelt, in press).

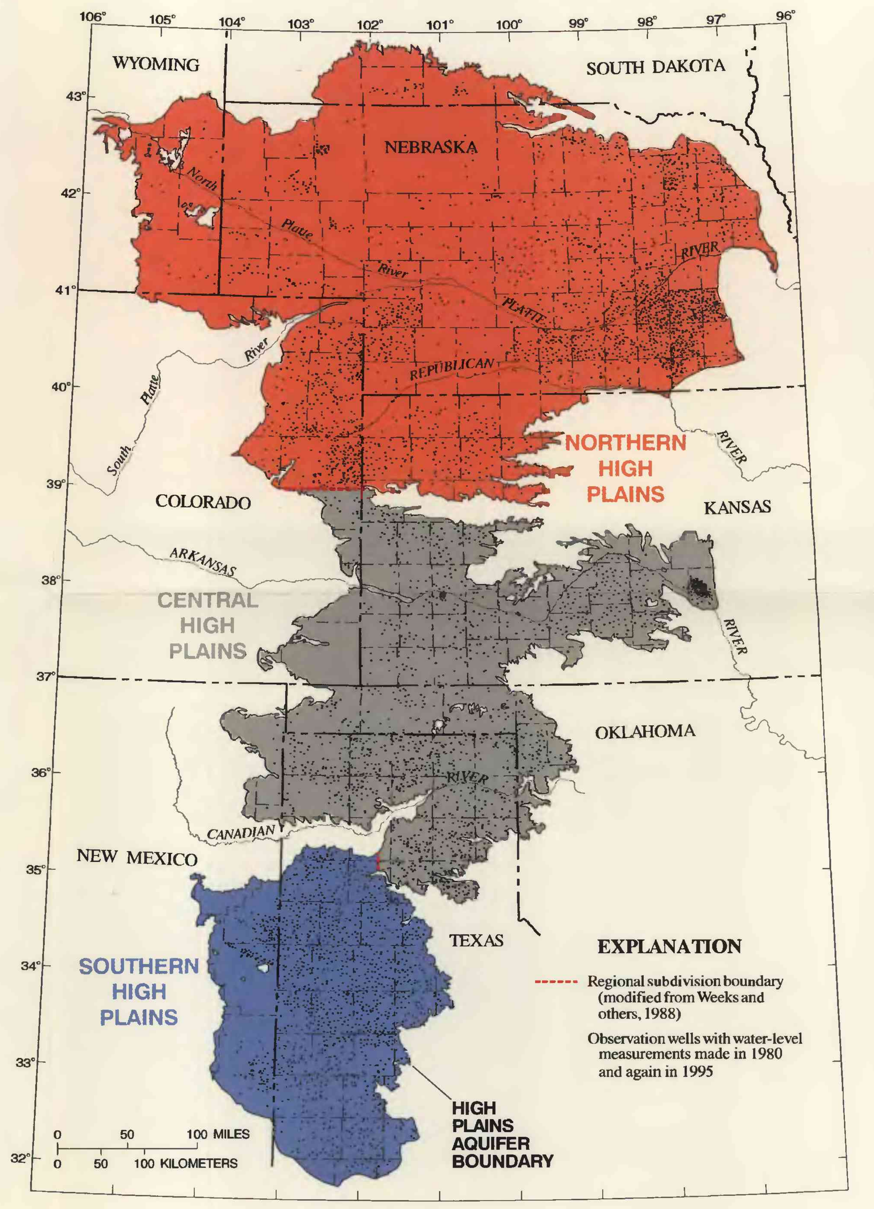

Figure 1. Regional subdivisions of the High Plains aquifer and location of observation wells with water-level measurements made in 1980 and in 1995.

DISCHARGE

Natural discharge from the High Plains aquifer occurs as evapotranspiration where the water table is near the land surface and as seepage from the aquifer where the water table intersects the land surface. Under natural conditions, this type of discharge would tend to balance long-term natural recharge. Under current conditions, water is discharged artificially from the aquifer predominantly by pumping of wells. Where pumpage exceeds recharge, water is removed from storage and the water table declines. Part of this loss from storage may be alleviated by decreases in natural discharge or by increases in induced recharge from streams.

Nearly 95 percent of the ground water withdrawn from the High Plains aquifer in 1990, more than 15.7 million acre-feet, was for irrigated agriculture, and about 84 percent of these withdrawals were in Kansas, Nebraska, and Texas (table 4). Ground-water withdrawals from the High Plains aquifer for irrigation decreased more than 12 percent from 1980 to 1990, and withdrawals for livestock and irrigation decreased about 3 percent from 1985 to 1990 (Thelin and Heimes, 1987; Carr and others, 1990; Marilee Horn, U.S. Geological Survey, written commun., 1996).

Table 4. Ground-water withdrawals from the High Plains aquifer in 1980 for irrigation and ground-water withdrawals from the High Plains aquifer in 1985 and 1990 by type of use
[Data from Thelin and Heimes, 1987; Carr and others, 1990; Marilee Horn, U.S. Geological Survey, written commun., 1996. Withdrawals in thousands of acre-feet; ---, data categories combined; NA, data not available]

State	Year	Nonagricultural nse: Domestic (public and private water supplies)	Nonagricultural nse: Mining, industrial, commercial, and thermo-electric-power generation	Agricultural use: Livestock	Agricultural use: Irrigation	Total
Colorado	1990	15.5	0.5	10.2	1,177.1	1,203.3
	1985	----6.2----		----877.1----		883.3
	1980	NA	NA	NA	1,023	NA
Kansas	1990	54.4	19.4	51.6	3,938.2	4,063.6
	1985	----92.7----		----4,324.0----		4,416.7
	1980	NA	NA	NA	4,130	NA
Nebraska	1990	214.0	26.3	103.5	4,763.4	5,107.2
	1985	----197.1----		----5,598.5----		5,795.6
	1980	NA	NA	NA	6,395	NA
New Mexico	1990	27.2	22.4	4.0	737.5	791.1
	1985	----50.0----		----603.0----		653.0
	1980	NA	NA	NA	519	NA
Oklahoma	1990	17.3	0.8	13.0	375.5	406.6
	1985	----8.0----		----270.0----		278.0
	1980	NA	NA	NA	540	NA
South Dakota	1990	2.9	0	1.2	18.3	22.4
	1985	----3.0----		----21.7----		24.7
	1980	NA	NA	NA	33	NA
Texas	1990	95.0	62.1	39.1	4,586.1	4,782.3
	1985	----188.8----		----4,531.7----		4,720.5
	1980	NA	NA	NA	5,170	NA
Wyoming	1990	11.4	0.7	1.3	145.1	158.5
	1985	----33.0----		----266.7----		299.7
	1980	NA	NA	NA	170	NA
Total	1990	437.7	132.2	223.9	15,741.2	16,535.0
	1985	----578.8----		----16,492.7----		17,071.5
	1980	NA	NA	NA	17,980	NA

The rate of withdrawal per irrigated acre can be estimated by a crop's consumptive irrigation requirements (CIR), which is the minimum supplemental water required to maintain adequate soil water for optimal plant growth. This requirement, which is unique for each crop, is dependent largely on (1) potential evapotranspiration, (2) the growth characteristics of the crop, (3) soil water available at the beginning of the irrigation season, and (4) irrigation-season precipitation. The average annual CIR for corn, the principal irrigated crop in the High Plains region, is 18.5 inches in the southern and central High Plains region and 13 inches in the northern High Plains region (McGrath and Dugan, 1993; Dugan and Zelt, in press). This range was estimated using 1951 to 1980 precipitation, temperature, and solar radiation data. The calculation of CIR assumes that solar radiation and ambient air temperature are the climatic factors controlling potential evapotranspiration. The use of CIR as an estimate of water withdrawn from the aquifer assumes that (1) water applied in excess of the CIR becomes recharge to the aquifer, and runoff is negligible; and (2) irrigation systems are 100-percent efficient. Thus, when factors such as wind significantly affect evapotranspiration, or when irrigation systems are significantly less than 100-percent efficient, the actual rate of withdrawal per irrigated acre probably will be underestimated by the CIR.

GROUND-WATER IRRIGATION DEVELOPMENT AND WATER-LEVEL CHANGE, PREDEVELOPMENT TO 1980

Ground-water irrigation increased rapidly in the High Plains region after 1940 because of (1) the droughts in the 1930's and the mid-1950's; (2) technological advances in drilling, pumping, and irrigation systems; (3) profitable crop prices; (4) inexpensive energy sources; and (5) available financing. Total ground-water irrigated acres in the High Plains region were: 1949–2.1 million acres; 1959–6.1 million acres; 1969–9.0 million acres; 1978–12.9 million acres; 1980–13.7 million acres. Ground-water irrigation increased first in the southern High Plains region, then in the central High Plains region, and finally in the northern High Plains region. The Texas portion of total ground-water irrigated acres decreased from 76 percent in 1949 to 28 percent in 1980; the Nebraska portion of total ground-water irrigated acres increased from 16 percent in 1949 to 38 percent in 1980 (Gutentag and others, 1984; Thelin and Heimes, 1987).

Water-level declines in the High Plains aquifer generally followed the northward movement of irrigation development. Water-level declines were observed in the southern High Plains aquifer in about 1940, in the central High Plains aquifer early in the 1950's, and in the northern High Plains aquifer in the 1960's. By 1980, water-level declines exceeded 10 feet in most of the southern High Plains aquifer, the western portion of the central High Plains aquifer, and in small portions of the northern High Plains aquifer; water-level declines exceeded 100 feet in an area about 100 miles long and 10 to 50 miles wide in the central portion of the southern High Plains aquifer and in two much smaller areas in the northern portion of the central High Plains aquifer (fig. 2). The average area-weighted water level in the High Plains aquifer declined nearly 10 feet, or about 0.25 foot per year, from 1940 to 1980 (Gutentag and others, 1984).

Water-level rises were also observed in portions of the High Plains aquifer in 1980. The largest area of water-level rise was an area about 130 miles long and 6 to 20 miles wide, south of the Platte River in the central portion of the northern High Plains aquifer (fig. 2). In this area, water levels rose more than 10 feet because of seepage losses from surface-water diversions for irrigation and power generation.

WATER-LEVEL CHANGE, 1980 to 1995

Water-level change in the High Plains aquifer from 1980 to 1995 (fig. 3, sheet 2) is based on measurements from 5,901 wells (table 3) and reflects a slightly different pattern of change in comparison to the pattern of change observed from predevelopment to 1980 (fig. 2). Substantial declines have continued in the western portion of the central High Plains aquifer, the northern portion of the southern High Plains aquifer, and the southwestern portion of the northern High Plains aquifer. Some areas that had substantial water-level declines from predevelopment to 1980 in the southern and northern High Plains aquifer, however, had considerably slower rates of decline, or rising water levels, since 1980.

The average area-weighted water level in the High Plains aquifer declined 2.4 feet from 1980 to 1995 compared to 9.9 feet from predevelopment to 1980 (table 5). Considering 1940 as the time of initial irrigation development, the rate of water-level decline decreased from nearly 0.25 foot per year from 1940 to 1980 to 0.16 foot per year from 1980 to 1995. Much of the reduction in the rate of water-level decline since 1980 can be attributed to an average area-weighted water-level rise of 1.8 feet, or 0.12 foot per year, in Nebraska.

The smaller rate of water-level decline for the High Plains after 1980 can also be attributed, in part, to a much smaller rate of decline in Texas. In Texas, water levels, which had declined an area-weighted average of 33.7 feet, or 0.84 foot per year, from 1940 to 1980, declined an area-weighted average of 4.8 feet, or 0.32 foot per year, from 1980 to 1995. This decrease in the rate of water-level decline occurred even though total acres irrigated in 1994 from the High Plains aquifer in Texas was 4.05 million acres, which is 0.17 million acres greater than in 1980 (Thelin and Heimes, 1987; Texas Water Development Board, 1996). The rate of water-level decline after 1980 slowed in Texas and reversed in some areas in Texas primarily due to decreased pumpage as a result of (1) improved irrigation-management practices, (2) a reduction in the number of acres irrigated since the 1970's in those areas in Texas prone to large rates of water-level decline, and (3) annual precipitation averaging as much as 4 inches above normal during 1981–94 (Dugan and Schild, 1992). Some of the areas of water-level rise in the southern High Plains aquifer probably are also associated with the recovery of local cones of depression caused by decreased pumpage (Kastner, Schild, and Spahr, 1989).

Table 5. Average area-weighted water-level changes and estimated changes in volume of water in storage in the High Plains aquifer, predevelopment to 1980 and 1980 to 1995

State	Average area-weighted water-level change (feet): Predevelopment to 1980 [1]	1980 to 1995	Estimated changes in volume of water in storage (million acre-feet): Predevelopment to 1980 [1]	1980 to 1995
Colorado	-4.2	-4.2	-6.0	-6.0
Kansas	-9.9	-7.5	-29.0	-22.0
Nebraska	0	1.8	0	10.9
New Mexico	-9.8	-3.1	-9.0	-2.8
Oklahoma	-11.3	-2.8	-8.0	-2.0
South Dakota	0	-0.6	0	-0.3
Texas	-33.7	-4.8	-114.0	-16.4
Wyoming	0	-3.4	0	-2.6
High Plains	**-9.9**	**-2.4**	**-166.0**	**-40.1**

[1] From Gutentag and others (1984, p. 47).

In contrast, the rate of water-level decline in the High Plains aquifer in Kansas increased after 1980. Considering 1950 as the beginning of irrigation development in Kansas, water levels declined an area-weighted average of 9.9 feet, or 0.33 foot per year, from 1950 to 1980, and an area-weighted average of 7.5 feet, or 0.50 foot per year, from 1980 to 1995. The increase in the rate of decline in Kansas from 1980 to 1995 can be attributed, in part, to the continued increase in irrigation in the late 1970's and early 1980's.

Other factors that appear to have contributed to a reduction in the overall rate of water-level decline in the High Plains aquifer since 1980 include:

1. Average precipitation from 1981 to 1994 was generally greater than normal throughout the High Plains region (fig. 4). Area-weighted average annual precipitation during 1981–94 was 21.82 inches, which is 1.23 inches above, or 106 percent of, normal (table 6).

2. Later phases of irrigation development in the High Plains region shifted geographically from areas of larger potential rates of aquifer depletion to areas of smaller potential rates of depletion. From predevelopment to the 1970's, most irrigated land was in the central and southern High Plains region where recharge tends to be small and CIR large. By 1980, more than half of the 14 million acres irrigated were in the northern High Plains region, mainly in Nebraska, where recharge is generally larger and CIR is smaller than in the central and southern High Plains region (Thelin and Heimes, 1987; McGrath and Dugan, 1993; Dugan and Zelt, in press).

3. Significant advances to improve the efficiency of irrigation systems have substantially reduced the ground-water pumpage needed to meet CIR. These include the surge-application systems used with furrow irrigation and low-pressure nozzles on drop tubes used with center pivot irrigation.

4. Irrigation-management practices, including irrigation scheduling based on soil-water conditions and crop growth stages, reuse of irrigation water, and the conversion to crops other than corn or to corn varieties with a smaller CIR, have further reduced ground-water pumpage.

5. Water-level declines in some areas prior to 1980 prompted local regulation of ground-water withdrawals for irrigation and development of irrigated land.

6. Declining or stable commodity prices, increased production costs (including higher energy and fertilizer prices), and various agricultural programs of the Federal Government have contributed to the removal of marginally profitable land from irrigated production and have stimulated more efficient irrigation practices on remaining irrigated land.

Table 6. Average annual area-weighted precipitation in the High Plains region during 1981–94, departure from 30-year normal (1961–90), and percentage of normal
[Data from National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, North Carolina]

State	Average annual area-weighted precipitation (inches)	Departnre from 30-year normal (inches)	Percentage of normal
Colorado	17.21	+1.04	106
Kansas	23.16	+0.96	104
Nebraska	24.40	+1.32	106
New Mexico	18.18	+1.67	110
Oklahoma	22.88	+1.00	105
South Dakota	20.91	+1.44	107
Texas	20.37	+1.39	107
Wyoming	15.36	+0.86	106
High Plains	**21.82**	**+1.23**	**106**

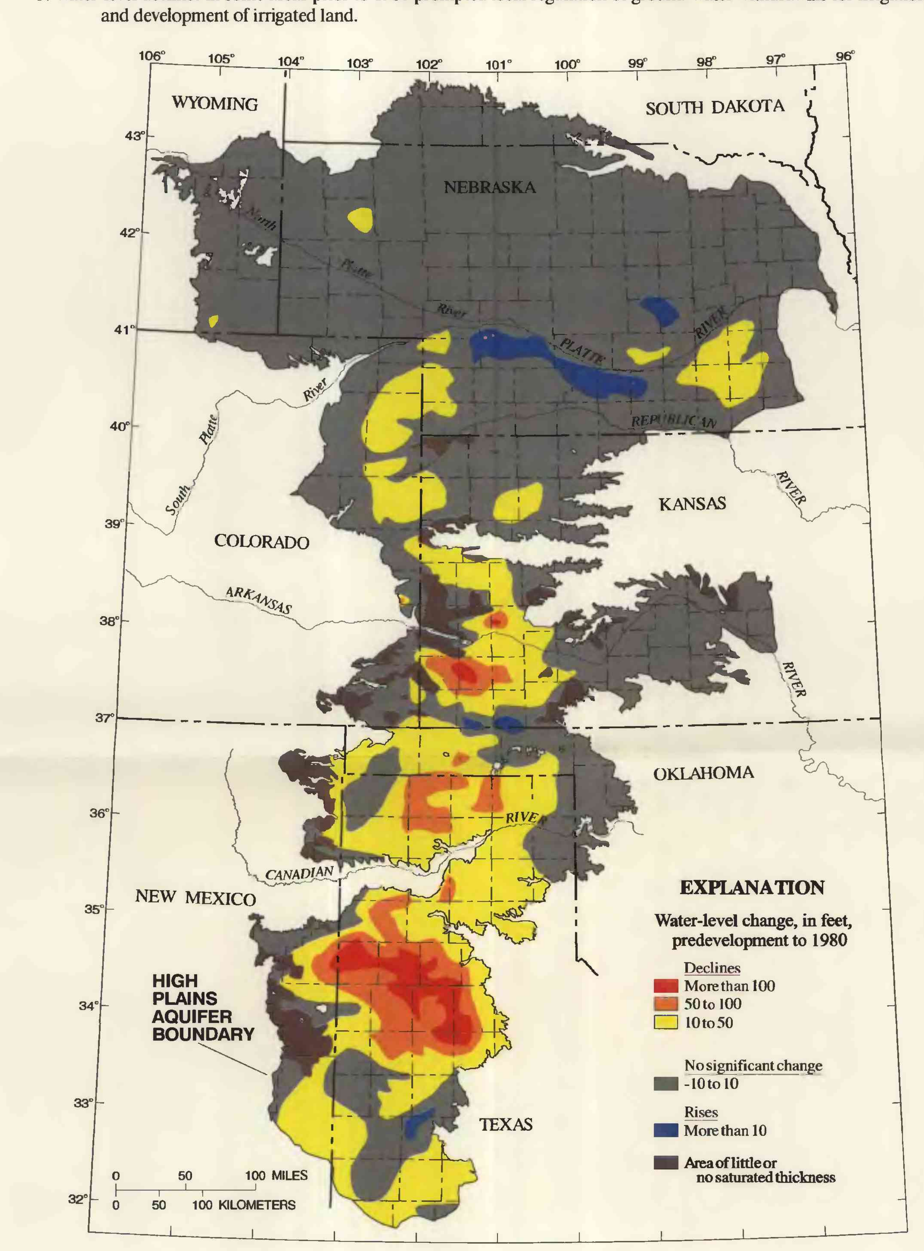

Figure 2. Water-level change in the High Plains aquifer, predevelopment to 1980. (Modified from Luckey and others, 1981)

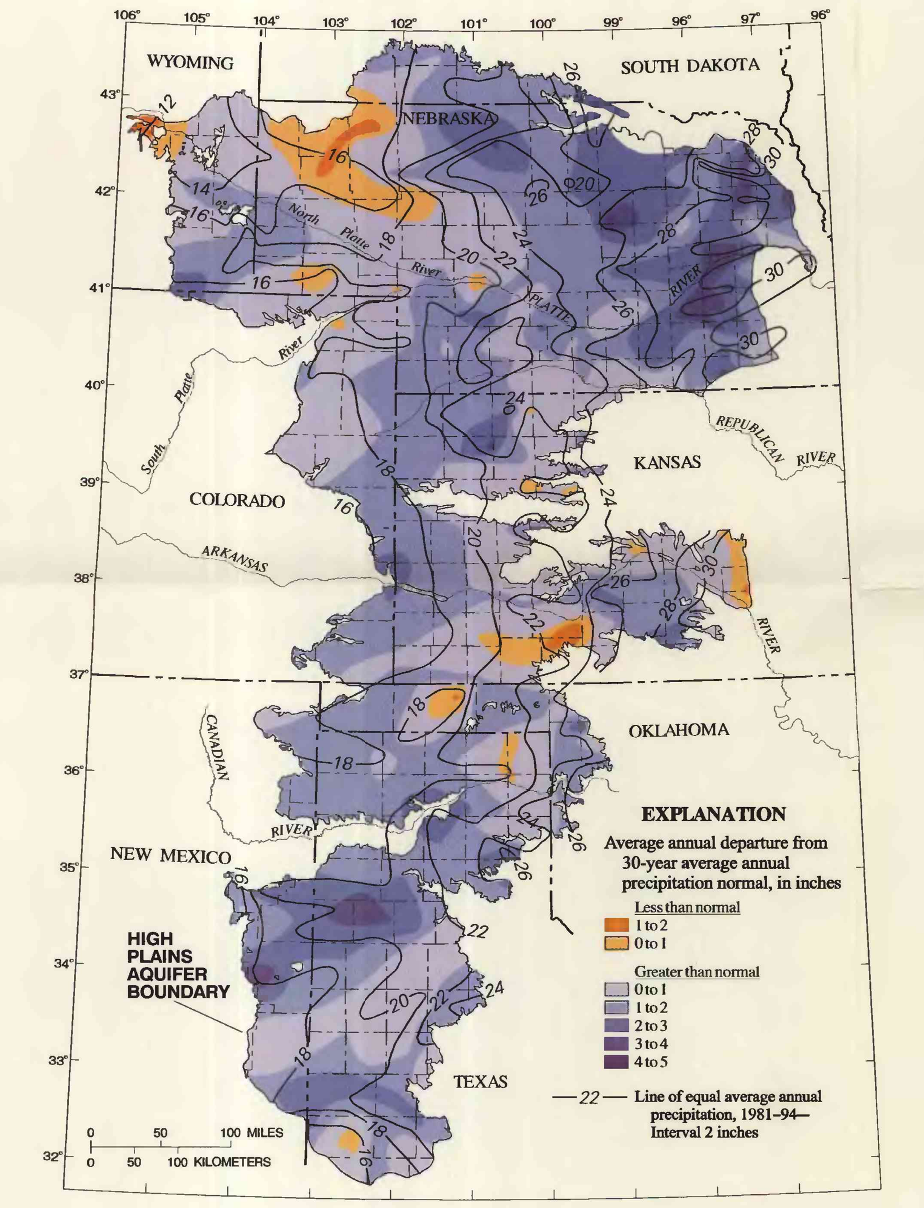

Figure 4. Average annual precipitation, 1981–94, and departure from 30-year normal (1961–90).

WATER-LEVEL CHANGE, 1994 TO 1995

The average area-weighted water level in the High Plains aquifer declined 0.66 foot from 1994 to 1995 after a 0.56-foot rise from 1993 to 1994 and a 0.21-foot rise from 1992 to 1993 (table 7). The water-level decline from 1994 to 1995 may be partially attributed to increased ground-water withdrawals for irrigation in 1994 because precipitation in the High Plains region averaged 1.30 inches less than normal in 1994 while precipitation was an average of 4.24 inches greater than normal in 1993 and 2.03 inches greater than normal in 1992 (table 7).

The area-weighted average water level declined in the High Plains aquifer from 1994 to 1995 and area-weighted average precipitation in the High Plains region was less than normal in 1994. However, the water-level and precipitation patterns vary across the region (fig. 5, sheet 2, and fig. 6).

Table 7. Average annual area-weighted water-level changes in the High Plains aquifer, 1989 to 1995; annual area-weighted precipitation and departures from normal, 1988 to 1994; and periods used to calculate the 30-year precipitation normal

Water-level change period	Average annual area-weighted water-level change (feet)	Precipitation year	Area-weighted precipitation (inches)	Average area-weighted departure of precipitation from normal (inches)	30-year normal period	Data source
1988 to 1989	-0.65	1988	18.84	-0.94	1951–80	Dugan and others, 1990
1989 to 1990	-0.63	1989	17.00	-2.78	1951–80	Dugan and Schild, 1992
1990 to 1991	-0.42	1990	19.28	-0.50	1951–80	McGrath and Dugan, 1993
1991 to 1992	-0.55	1991	20.99	+1.21	1951–80	Dugan and others, 1994
1992 to 1993	+0.21	1992	21.81	+2.03	1951–80	Dugan and Cox, 1994
1993 to 1994	+0.56	1993	24.02	+4.24	1951–80	Dugan and Sharpe, 1996
1994 to 1995	-0.66	1994	18.32	-1.30	1961–90	This report
Annual average	**-0.31**		**20.04**	**+0.28**		

Table 8. Average area-weighted water-level change in the High Plains aquifer from 1994 to 1995

State	Average area-weighted water-level change (feet)
Colorado	-0.72
Kansas	-1.20
Nebraska	+0.17
New Mexico	-0.91
Oklahoma	-0.40
South Dakota	+0.10
Texas	-1.77
Wyoming	-0.78
High Plains	**-0.66**

Average area-weighted water-level declines in the High Plains aquifer from 1994 to 1995 by State ranged from 0.40 foot in Oklahoma to 1.77 feet in Texas (table 8). Water-level declines of at least 1 foot are observed in extensive areas of the central and southern High Plains aquifer and some areas of the northern High Plains aquifer; declines exceeding 3 feet were common in Grant, Haskell, Reno, and Stevens Counties in Kansas; Cimarron County in Oklahoma; and Andrews, Armstrong, Carson, Castro, Crosby, Gaines, Hale, Parmer, Sherman, and Swisher Counties in Texas (fig. 5, sheet 2). The areas with water-level declines in central Kansas and the Texas Panhandle generally received less than normal precipitation in 1994. The areas with water-level declines, in southwestern Kansas and the Oklahoma Panhandle, and the areas with water-level rises, in eastern Nebraska, generally received normal to greater than normal precipitation in 1994.

Average area-weighted water-level rises in the High Plains aquifer from 1994 to 1995 by State ranged from 0.10 foot in South Dakota to 0.17 foot in Nebraska (table 8). Water-level rises of 1 to 3 feet were common in the central and eastern portion of the northern High Plains aquifer from 1994 to 1995. Precipitation was generally normal to more than 5 inches greater than normal during 1994 in those parts of the High Plains region with water-level rises from 1994 to 1995 (fig. 5, sheet 2, and fig. 6). Average area-weighted precipitation during 1994 was 0.43 inch less than normal in Nebraska and 0.16 inch greater than normal in South Dakota (table 9).

Table 9. Average area-weighted precipitation in 1994 in the High Plains region and comparison to 30-year normal (1961–90) precipitation
[Data from National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, North Carolina]

State	Average area-weighted precipitation (inches)	Average area-weighted departnre from 30-year normal (inches)	Percentage of normal
Colorado	16.12	-0.29	98.2
Kansas	19.60	-1.51	92.8
Nebraska	20.91	-0.43	98.8
New Mexico	12.98	-3.48	78.9
Oklahoma	19.65	+0.03	100.2
South Dakota	18.68	+0.16	100.9
Texas	16.05	-2.62	86.0
Wyoming	12.02	-2.97	80.2
High Plains	**18.32**	**-1.30**	**93.4**

REGIONAL VARIABILITY OF REMAINING SATURATED THICKNESS

Changes in the saturated thickness of the High Plains aquifer since predevelopment, measured in 1980 and 1995, further indicate large regional differences in the rate of aquifer depletion (table 10). In New Mexico and Texas, about 79 and 73 percent, respectively, of predevelopment saturated thickness remains as of 1995. In Colorado, Kansas, and Oklahoma about 90, 84, and 90 percent, respectively, remains, and about 100 percent remains in Nebraska, South Dakota, and Wyoming. In those areas where water-level declines exceed 140 feet since predevelopment (fig. 2 and fig. 3, sheet 2), remaining saturated thickness is generally less than 50 percent.

Table 10. Average area-weighted saturated thickness of the High Plains aquifer, predevelopment, 1980, and 1995

State	Predevelopment (feet)	1980 (feet)	1980 as a percentage of predevelopment	1995 (feet)	1995 as a percentage of predevelopment
Colorado	83.2	79.0	95	74.8	90
Kansas	110.9	101.0	91	93.5	84
Nebraska	342.0	342.0	100	343.8	101
New Mexico	60.8	51.0	84	47.9	79
Oklahoma	141.3	130.0	92	127.2	90
South Dakota	207.6	207.0	100	206.4	99
Texas	143.7	110.0	77	105.2	73
Wyoming	182.0	182.0	100	178.6	98
High Plains	**199.9**	**190.0**	**95**	**187.6**	**94**

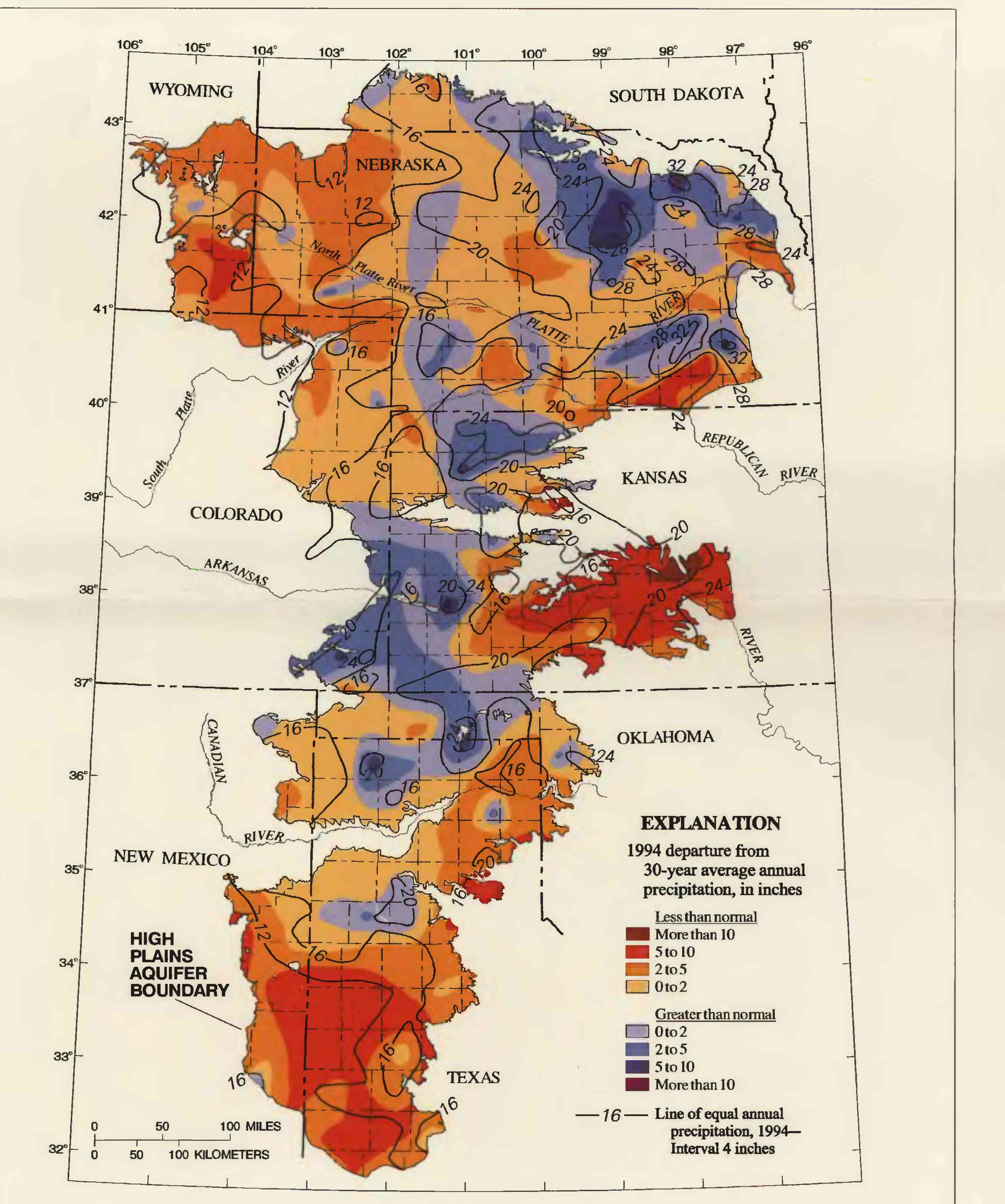

Figure 6. Annual precipitation, 1994, and departure from 30-year normal (1961–90).

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CONVERSION FACTORS

Multiply	By	To obtain	Multiply	By	To obtain
acre	4,047	square meter	inch	25.4	millimeter
acre-foot	1,233	cubic meter	mile	1.609	kilometer
acre-foot per acre	0.3048	cubic meter per square meter	million gallons per day (Mgal/d)	0.003785	million cubic meters per day
foot	0.3048	meter	thousand acre-feet per year	0.003377	million cubic meters per day
gallon per minute	0.06309	decimeter per second	square mile	2.590	square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER–PREDEVELOPMENT TO 1995

By
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1997

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