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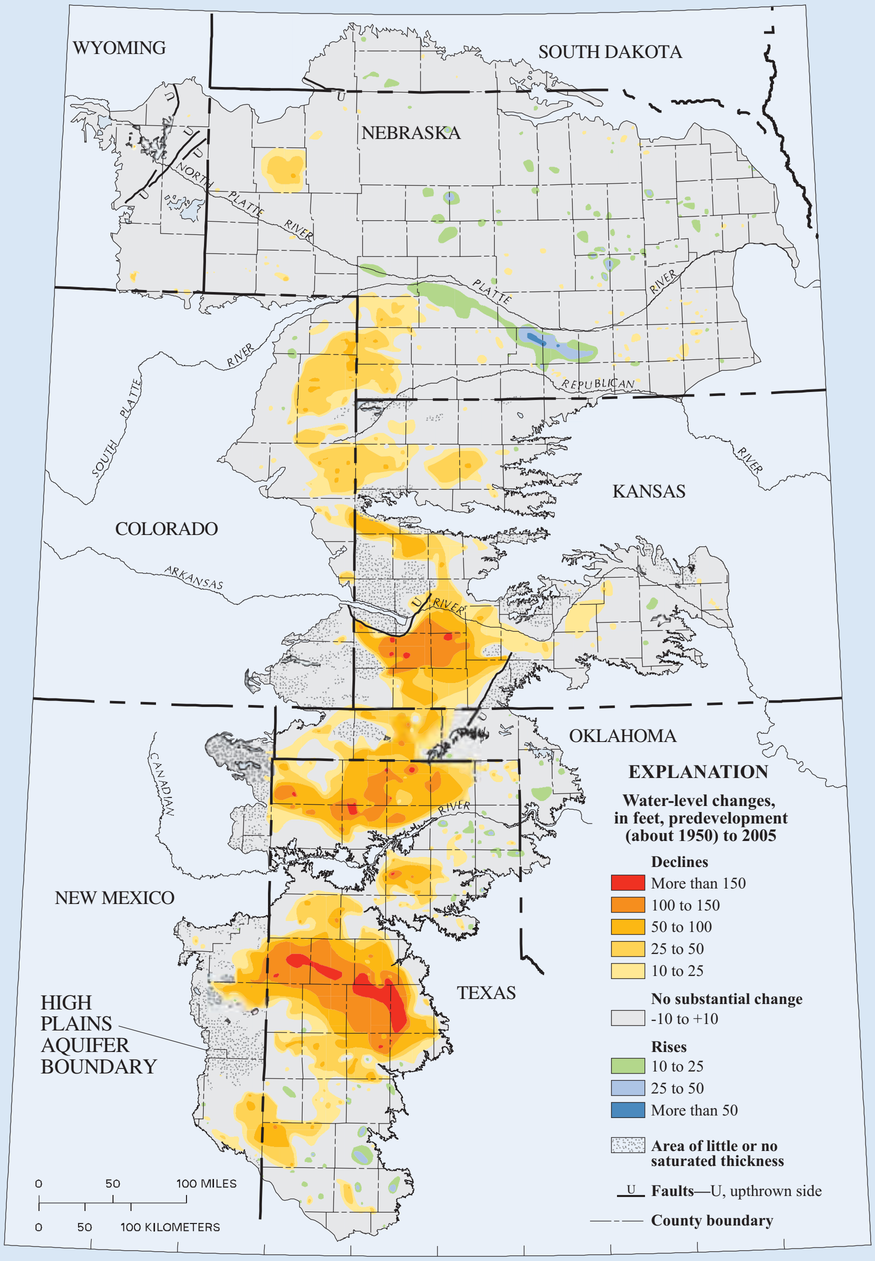
Water-Level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005



Scientific Investigations Report 2006–5324

U.S. Department of the Interior
U.S. Geological Survey

Water-Level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005

By V.L. McGuire

Prepared in cooperation with numerous Federal, State, and local agencies

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U.S. Geological Survey

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Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot	0.3048	meter
meter	3.281	foot
mile	1.609	kilometer
	Area	
acre	4,047	square meter
square meter	10.76	square foot
square mile	2.590	square kilometer
	Volume	
acre-foot	1,233	cubic meter

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Water-Level Changes in the High Plains Aquifer, Predevelopment to 2005 and 2003 to 2005

By V.L. McGuire

Abstract

The High Plains aquifer underlies 111.6 million acres (174,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water-level declines began in parts of the High Plains aquifer soon after the beginning of extensive ground-water irrigation. This report presents water-level changes in the High Plains aquifer from the time prior to substantial ground-water irrigation development (about 1950) to 2005 and from 2003 to 2005.

Water-level changes from predevelopment to 2005 ranged between a rise of 84 feet and a decline of 277 feet. Area-weighted, average water-level change in the aquifer was a decline of 12.8 feet from predevelopment to 2005, a decline of 0.8 foot from 2003 to 2004, and a decline of 0.2 foot from 2004 to 2005. Total water in storage in the aquifer in 2005 was about 2,925 million acre-feet, which was a decline of about 253 million acre-feet (or 9 percent) since predevelopment.

Introduction

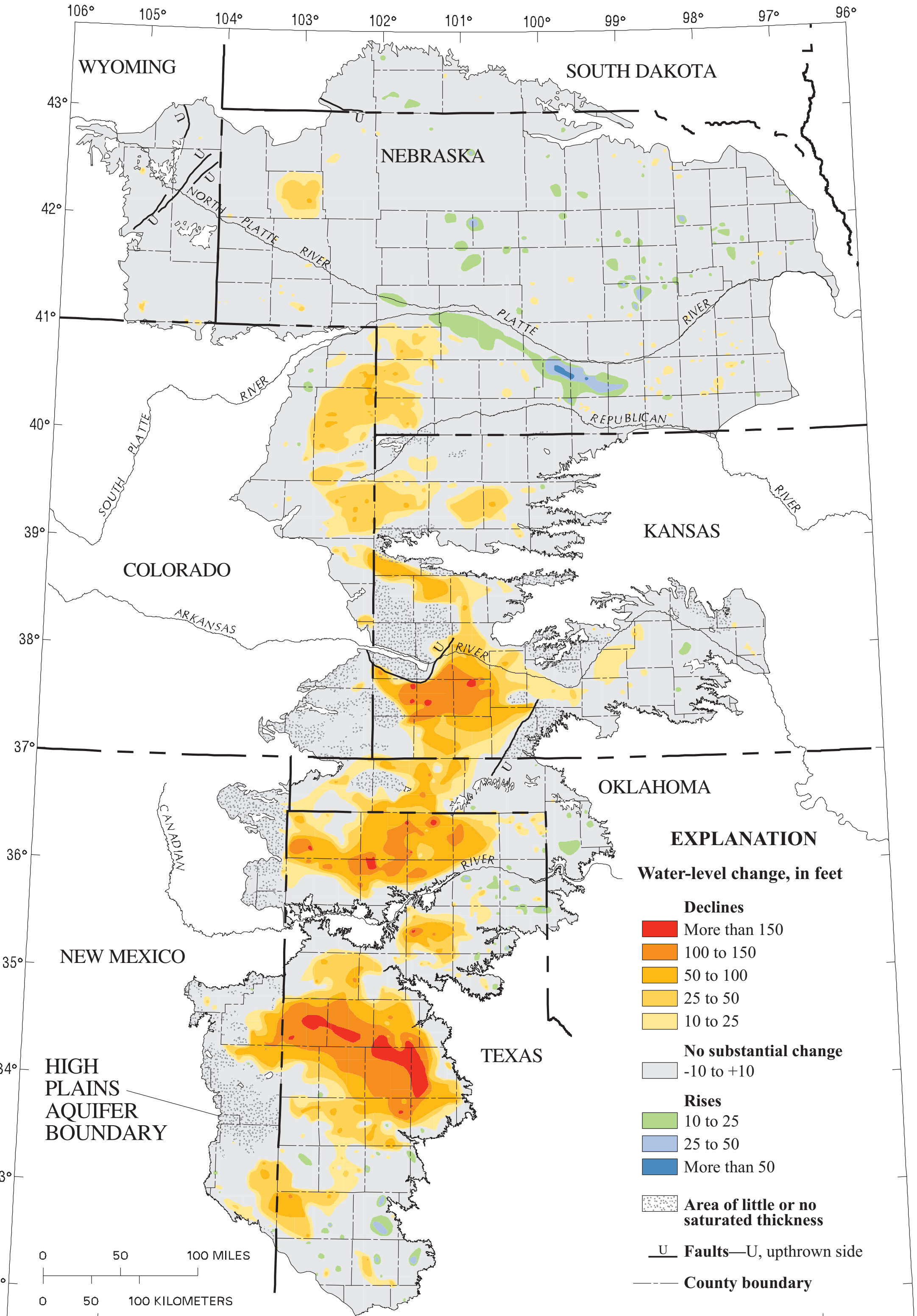
The High Plains aquifer underlies 111.6 million acres (174,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (fig. 1; Sharon Qi, U.S. Geological Survey, written commun., 2006). The aquifer is generally unconfined; that is, the top of the aquifer is connected to the atmosphere (Weeks and Gutentag, 1981). Gutentag and others (1984) reported that, in a few parts of the aquifer area, the aquifer is not saturated and the water table is discontinuous. Wells drilled in areas delineated as areas of little or no saturated thickness (fig. 8 in Gutentag and others, 1984) likely will not yield water unless the well penetrates saturated sediment in buried channels or sinks in the bedrock.

The area overlying the High Plains aquifer is one of the major agricultural regions in the world; in parts of the area, farmers began using ground water for irrigation extensively in the 1930s and 1940s. Estimated irrigated acreage in the area overlying the High Plains aquifer increased rapidly from 1940 to 1980 but did not change greatly from 1980 to 2002: 1949—2.1 million acres, 1980—13.7 million acres, 1997—13.9 million acres, 2002—12.7 million acres (Heimes and Luckey, 1982; Thelin and Heimes, 1987; U.S. Department of Agriculture, 1999, 2004). Irrigated acres in 2002 were 12 percent of the aquifer area, not including the areas with little or no saturated thickness.

Ground-water withdrawals for irrigation and other uses are compiled from water-use data and reported by the U.S. Geological Survey (USGS) and agencies in each State about every five years. Ground-water withdrawals from the High Plains aquifer for irrigation increased from 4 to 19 million acre-feet from 1949 to 1974; ground-water withdrawals for irrigation in 1980, 1985, 1990, and 1995 were from 4 to 18 percent less than withdrawals for irrigation in 1974. Ground-water withdrawals from the aquifer for irrigation in 2000 were 21 million acre-feet (Heimes and Luckey, 1982; Maupin and Barber, 2005; U.S. Geological Survey, 2006).

Water-level declines began in parts of the High Plains aquifer soon after the beginning of extensive irrigation using ground water (Luckey and others, 1981). Water-level changes in the aquifer result from an imbalance between discharge and recharge. Discharge is primarily ground-water withdrawals for irrigation, but discharge also includes evapotranspiration, where the water table is near land surface, and seepage to streams and springs, where the water table intersects the land surface. Recharge is primarily from precipitation; other sources of recharge are seepage from streams, canals, and reservoirs and irrigation return flow. By 1980, water levels in the High Plains aquifer in parts of Texas, Oklahoma, and southwestern Kansas had declined more than 100 feet (Luckey and others, 1981). Water-level declines may result in increased costs for ground-water withdrawals because of increased pumping lift and decreased well yields (Taylor and Alley, 2001). Water-level declines also can affect ground-water availability, surface-water flow, and near-stream (riparian) habitat areas (Alley and others, 1999).

In response to water-level declines in the High Plains aquifer, the USGS, in cooperation with numerous Federal, State, and local water-resources agencies, began monitoring more than 7,000 wells in 1988 to assess the annual water-level change in the aquifer. Water levels for 2004 were based on measurements from 8,915 wells, and 9,224 wells were measured for the 2005 water levels (table 1).



Base from U.S. Geological Survey digital data, 1:2,000,000
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Figure 1. Water-level changes in the High Plains aquifer, predevelopment to 2005 (modified from Lowry and others, 1967; Luckey and others, 1981; Gutentag and others, 1984; and Nebraska Conservation and Survey Division, 2005).

Table 1. Number of wells used in this report for 2004 and 2005 water levels in the High Plains aquifer and number of wells used for the water-level comparison periods—predevelopment to 2005, 2003 to 2004, and 2004 to 2005.

State	Number of wells measured		Number of wells used for water-level comparison periods		
	2004	2005	Predevelopment to 2005	2003 to 2004	2004 to 2005
Colorado	514	504	367	441	477
Kansas	1,260	1,210	511	1,211	1,181
Nebraska	3,752	4,008	1,634	3,484	3,613
New Mexico	84	73	[1]141	80	63
Oklahoma	149	161	110	138	141
South Dakota	113	112	73	110	111
Texas	2,988	3,101	828	2,491	2,666
Wyoming	55	55	18	44	50
High Plains aquifer	**8,915**	**9,224**	**3,682**	**7,999**	**8,302**

[1]Includes 2001 to 2004 water levels, instead of 2005 water levels, for 121 wells in the predevelopment to 2005 comparison period because many wells in New Mexico are measured on a 5-year schedule.

This report presents water-level changes in the High Plains aquifer from the time prior to substantial ground-water irrigation development (about 1950) to 2005 and from 2003 to 2005. The water-level measurements used in this report generally were collected in winter or early spring when irrigation wells typically were not pumping and water levels generally had recovered from the stress of pumping during the previous irrigation season. The exceptions were 2005 water levels in many wells in the northern part of the Texas Panhandle. These wells apparently had not recovered when the wells were measured; therefore, for 41 wells, estimates were used for the 2005 water level (Dale Hallmark, Texas North Plains Ground Water Conservation District, written commun., August 2006).

Methods

The map of water-level changes from predevelopment to 2005 (fig. 1) was generated manually by contouring water-level-change ranges using predevelopment and 2005 water-level data from available wells and areas of water-level changes from previous reports (Lowry and others, 1967; Luckey and others, 1981; Gutentag and others, 1984; Nebraska Conservation and Survey Division, 2005). The predevelopment-to-2005, area-weighted, average water-level change (table 2) was computed by making a grid of the map of water-level change, predevelopment to 2005, using 500-meter by 500-meter cells, multiplying the mid-range of the associated water-level change contours times the cell area for each cell, summing the result, and dividing the sum by the aquifer area, not including the areas with little or no saturated thickness.

Generalized annual water-level changes, 2003 to 2004 and 2004 to 2005, were computed with computer-generated Thiessen polygons (Thiessen, 1911). Thiessen polygons apportion the water-level change in each well to an area around the well; the size of each polygon depends on the proximity of neighboring wells. The 2003 to 2004 and 2004 to 2005 area-weighted, average water-level changes were computed by summing the quantity equal to the area of each Thiessen polygon multiplied by the actual water-level-change value associated with the Thiessen polygon and then dividing the result by the aquifer area, not including areas with little or no saturated thickness. The maps of water-level change for 2003 to 2004 and 2004 to 2005 are not included in this report because the report emphasizes long-term water-level trends; however, the associated area-weighted, average water-level-

Table 2. Area-weighted, average water-level changes in the High Plains aquifer, not including the areas of little or no saturated thickness—predevelopment to 2005, 2003 to 2004, and 2004 to 2005.

[-, indicates water-level decline; no sign, indicates water-level rise]

State	Area-weighted, average water-level change		
	Predevelopment to 2005 (feet)	2003 to 2004 (feet)	2004 to 2005 (feet)
Colorado	-10.9	-0.5	-0.7
Kansas	-19.2	-1.1	-.2
Nebraska	-.5	-.9	-.4
New Mexico	-15.1	-.9	-.4
Oklahoma	-13.2	-.1	.1
South Dakota	.2	-.3	-.2
Texas	-35.2	-.9	.2
Wyoming	-.2	-.6	-.8
High Plains aquifer	**-12.8**	**-.8**	**-.2**

Table 3. Change in water in storage in the High Plains aquifer, predevelopment to 2005, 2003 to 2004, and 2004 to 2005.

[-, indicates water-storage decline; no sign, indicates water-storage rise]

State	Change in water in storage		
	Predevelopment to 2005 (million acre-feet)	2003 to 2004 (million acre-feet)	2004 to 2005 (million acre-feet)
Colorado	-15.4	-0.6	-0.8
Kansas	-58.9	-2.7	-.6
Nebraska	-19.4	-5.5	-2.2
New Mexico	-9.7	-.5	-.2
Oklahoma	-11.5	-.1	.1
South Dakota	-.6	-.2	-.1
Texas	-135.4	-3.0	.6
Wyoming	-1.6	-.4	-.6
High Plains aquifer	**-252.5**	**-13.0**	**-3.9**

change and storage-change statistics are given in tables 2 and 3.

Change in water in storage in the High Plains aquifer for each period was calculated using area-weighted, average specific yield of the aquifer and change in aquifer volume for the period from corresponding water-level-change maps (fig. 2). Specific yield is an estimate of the amount of water that a volume of an unconfined aquifer will yield by gravity drainage (Lohman, 1979). Area-weighted, average specific yield of the High Plains aquifer is 15.1 percent; specific yield ranges from near 0 to 30 percent (Gutentag and others, 1984). In this report, calculations of water in storage used the area-weighted, average specific yield of the aquifer to be consistent with previous reports (Kastner and others, 1989; McGuire, 2004b). The change in aquifer volume, predevelopment to 2005, was calculated by summing change in aquifer volume, predevelopment to 2000 (McGuire and others, 2003), and the annual change in aquifer volume, 2000 to 2005 (McGuire, 2003, 2004a, 2004b).

Total water in storage in the High Plains aquifer, 2005, was calculated by summing water in storage in 2000 and the change in water in storage, 2000 to 2005 (McGuire, 2003, 2004a, 2004b). Water in storage in 2000 was derived by multiplying aquifer volume in 2000 by area-weighted, average specific yield of the aquifer. The aquifer volume in 2000 was calculated by making a grid of saturated thickness for 2000 (McGuire and others, 2003) using 500-meter by 500-meter cells, multiplying the mid-range of the associated saturated thickness contour times the cell area for each cell, and summing the results. Saturated thickness, 2000, was mapped by superimposing contours of the water table in 2000 over contours of the base of the aquifer (modified from Weeks and Gutentag, 1981).

The map of percentage change in saturated thickness, predevelopment to 2005 (fig. 3), was generated manually by contouring water-level change as a percentage of predevelopment saturated thickness using predevelopment and 2005 water-level data from available wells, areas of water-level changes from previous reports, and base of aquifer data (Lowry and others, 1967; Luckey and others, 1981; Weeks and Gutentag, 1981; Nebraska Conservation and Survey Division, 2005).

Water-Level Changes, Predevelopment to 2005

The map of water-level changes in the High Plains aquifer from predevelopment to 2005 (fig. 1) is based on water levels from 3,682 wells (table 1) and, in areas with few predevelopment water levels, other previously published data (Lowry and others 1967; Luckey and others, 1981; Nebraska Conservation and Survey Division, 2005). The areas with few predevelopment water levels are in the central part of the Nebraska Panhandle, west-central Nebraska, and southeastern Wyoming.

The water-level changes from predevelopment to 2005 ranged between a rise of 84 feet and a decline of 277 feet. Area-weighted, average water-level change from predevelopment to 2005 was a decline of 12.8 feet (table 2). Approximately 25 percent of the aquifer area had more than 10 feet of

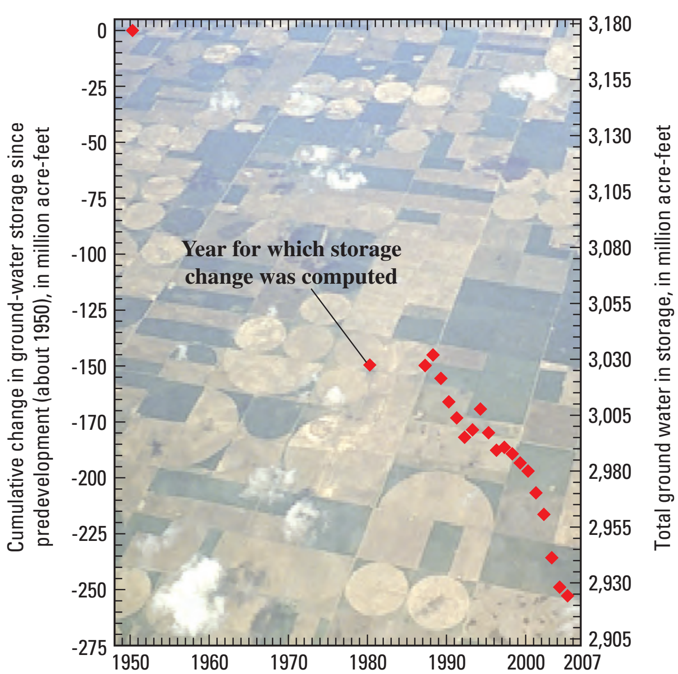

Figure 2. Cumulative change and total ground water in storage in the High Plains aquifer, predevelopment to 2005 (modified from McGuire, 2004b) (background photograph courtesy of Kevin Dennehy, U.S. Geological Survey).

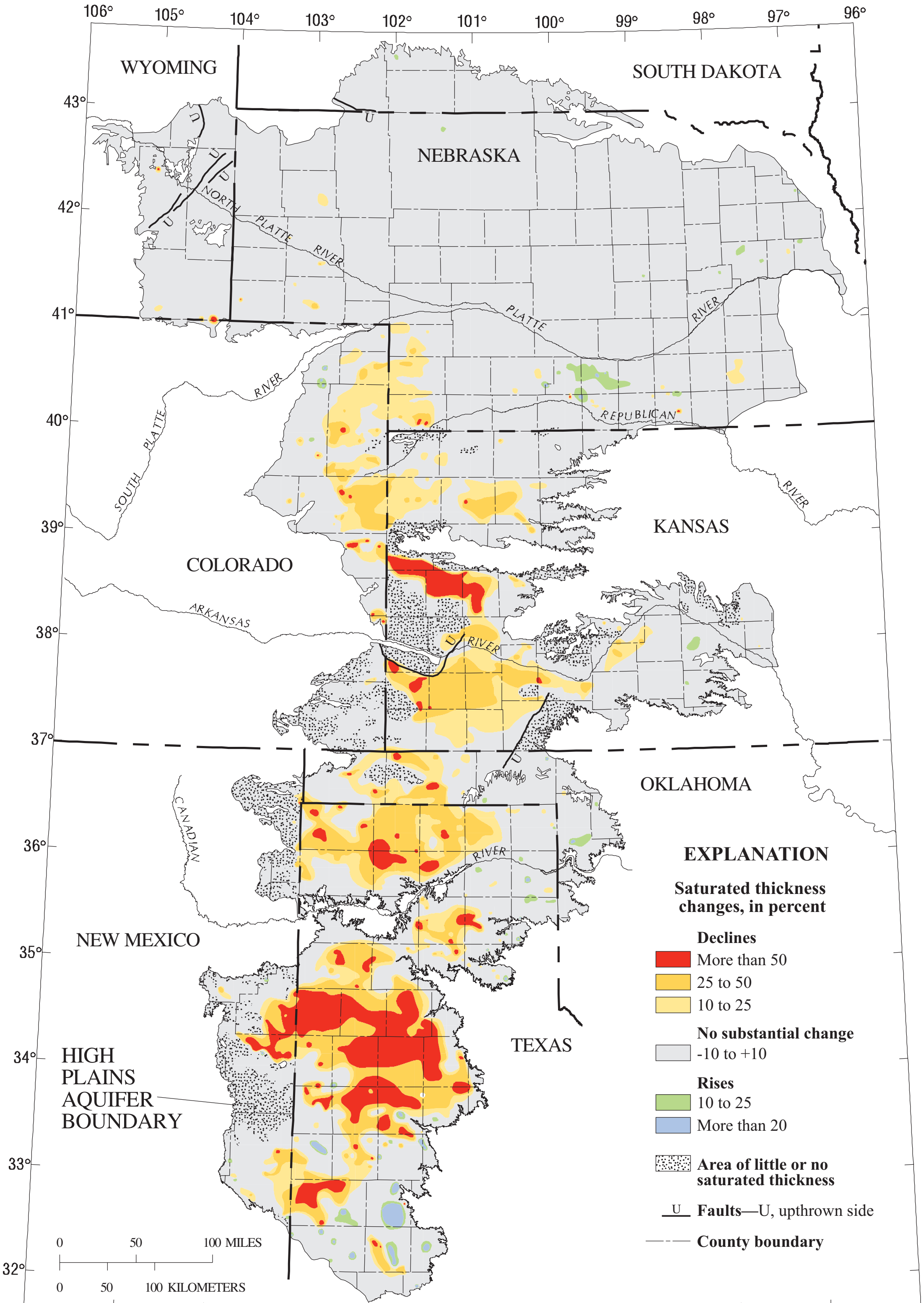

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Figure 3. Percentage change in saturated thickness of the High Plains aquifer, predevelopment to 2005 (modified from Luckey and others, 1981; Gutentag and others, 1984).

water-level decline from predevelopment to 2005; 17 percent had more than 25 feet of water-level decline, and 9 percent had more than 50 feet of water-level decline. Approximately 2 percent of the aquifer area had more than 10 feet of water-level rise from predevelopment to 2005.

Water-Level Changes, 2003 to 2004

Water levels were measured in 7,999 wells during the preirrigation season of both 2003 and 2004 (table 1); the preirrigation season is generally December to April, but the actual dates depend on location. Water-level changes from 2003 to 2004 ranged between a rise of 10 feet and a decline of 10 feet. Water-level declines of 3 feet or greater occurred in 12 percent of the measured wells. Area-weighted, average water-level change in the High Plains aquifer from 2003 to 2004 ranged by State from a decline of 1.1 feet in Kansas to a decline of 0.1 foot in Oklahoma (table 2); overall, area-weighted, average water-level change in the High Plains aquifer from 2003 to 2004 was a decline of 0.8 foot (table 2).

Water-Level Changes, 2004 to 2005

Water levels were measured in 8,302 wells during the preirrigation season of both 2004 and 2005 (table 1); water-level changes ranged between a rise of 11 feet and a decline of 10 feet. Water-level declines of 3 feet or greater occurred in 5 percent of the measured wells. Area-weighted, average water-level change from 2004 to 2005 ranged by State from a decline of 0.8 foot in Wyoming to a rise of 0.2 foot in Texas (table 2); overall, area-weighted, average water-level change in the High Plains aquifer from 2004 to 2005 was a decline of 0.2 foot (table 2).

Change in Water in Storage, Predevelopment to 2005

Total water in storage in 2005 was about 2,925 million acre-feet, which was a decline of about 253 million acre-feet (or 9 percent) since predevelopment (fig. 2 and table 3). Water in storage for predevelopment was inferred from water in storage in 2000 and water-level changes, predevelopment to 2000 (McGuire and others, 2003). Changes in storage occurred prior to predevelopment, but these changes in storage were not estimated for this report.

The effect of a given change in the volume of water in storage in an area depends partly on the starting saturated thickness of the aquifer. The map showing percentage change in saturated thickness (fig. 3) represents water-level change, predevelopment to 2005, as a percentage of predevelopment saturated thickness. The map is similar in some areas to the water-level-change map (fig. 1). However, an area of large water-level change would not show up on this map if predevelopment saturated thickness was much larger and the change did not substantially alter the saturated thickness. Conversely, an area with small water-level change may result in a large percentage change in saturated thickness because of relataively small predevelopment saturated thickness. By 2005, 12 percent of the aquifer area had sustained more than a 25-percent decrease in saturated thickness since predevelopment, 4 percent of the aquifer area had more than a 50-percent decrease in saturated thickness, and 1 percent of the aquifer area had more than a 10-percent increase.

Summary

The High Plains aquifer underlies 111.4 million acres (174,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water-level declines began in parts of the High Plains aquifer soon after the beginning of extensive ground-water irrigation. In response to the water-level declines in the High Plains aquifer, the USGS, in cooperation with numerous Federal, State, and local water-resources agencies, began monitoring more than 7,000 wells in 1988 to assess the annual water-level change in the aquifer. Water levels for 2004 were based on measurements from 8,915 wells, and 9,224 wells were measured for the 2005 water levels. This report presents water-level changes in the High Plains aquifer from the time prior to substantial ground-water irrigation development (about 1950) to 2005 and from 2003 to 2005. The water-level measurements used in this report generally were collected in winter or early spring when irrigation wells typically were not pumping and water levels generally had recovered from the stress of pumping during the previous irrigation season.

The map of water-level changes in the High Plains aquifer from predevelopment to 2005 is based on water levels from 3,682 wells and other published data. The water-level changes from predevelopment to 2005 ranged between a rise of 84 feet and a decline of 277 feet. Area-weighted, average water-level change from predevelopment to 2005 was a decline of 12.8 feet.

Water levels were measured in 7,999 wells during the preirrigation season of both 2003 and 2004; water-level changes ranged between a rise of 10 feet and a decline of 10 feet. Area-weighted, average water-level change in the High Plains aquifer from 2003 to 2004 was a decline of 0.8 foot.

Water levels were measured in 8,302 wells during the preirrigation season of both 2004 and 2005; water-level changes ranged between a rise of 11 feet and a decline of 10 feet. Area-weighted, average water-level change in the High Plains aquifer from 2004 to 2005 was a decline of 0.2 foot.

Total water in storage in 2005 was about 2,925 million acre-feet, which was a decline of about 253 million acre-feet (or 9 percent) since predevelopment. Water in storage for predevelopment was inferred from water in storage in 2000 and water-level changes, predevelopment to 2000. The effect of a given change in the volume of water in storage in an area depends partly on the starting saturated thickness of the aquifer. By 2005, 12 percent of the aquifer area had sustained more than a 25-percent decrease in saturated thickness since predevelopment, 4 percent of the aquifer area had a decrease of more than 50 percent, and 1 percent of the aquifer area had more than a 10-percent increase.

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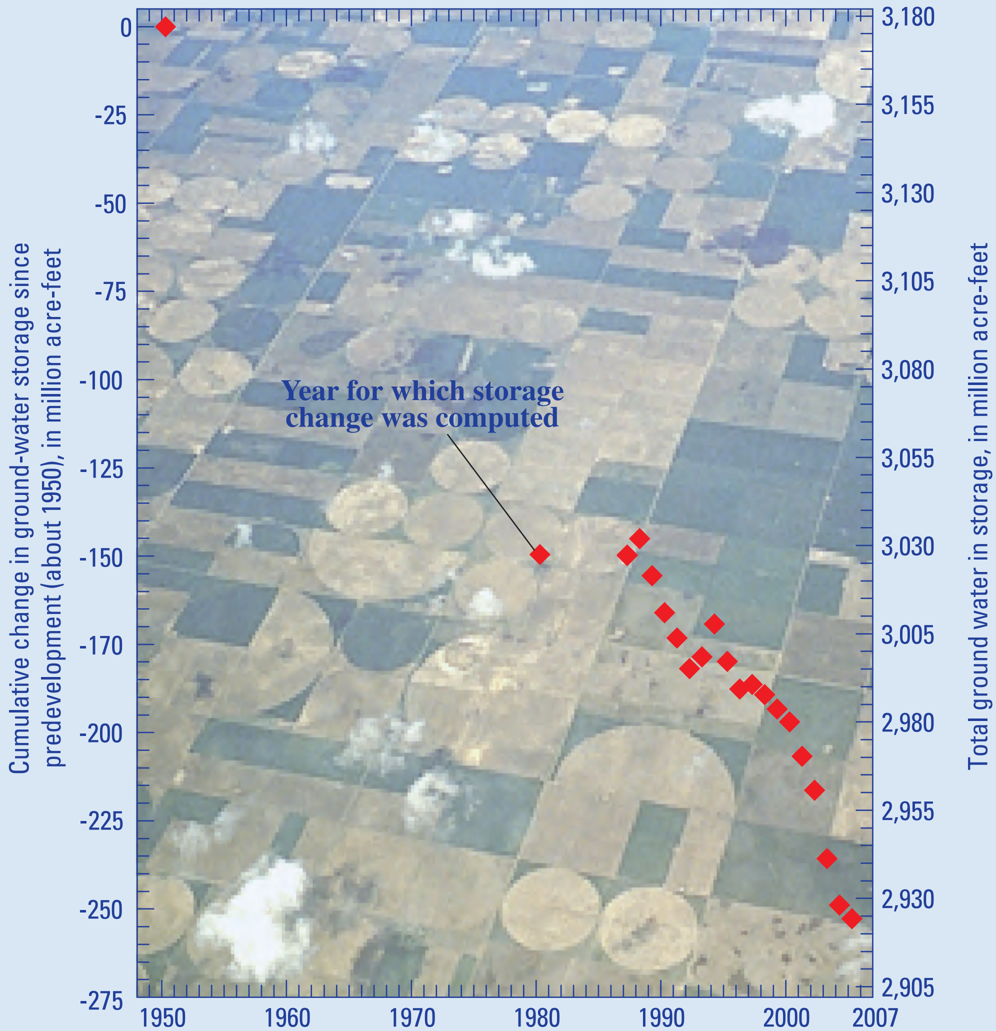
For more information concerning the research described in this report, contact:

U.S. Geological Survey
5231 South 19th Street
Lincoln, NE 68512
(402) 328–4100
http://ne.water.usgs.gov



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