Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-level Changes and Changes in Water in Storage in the High Plains Aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009

Virginia L. McGuire
Nebraska Water Science Center, vlmcguir@usgs.gov

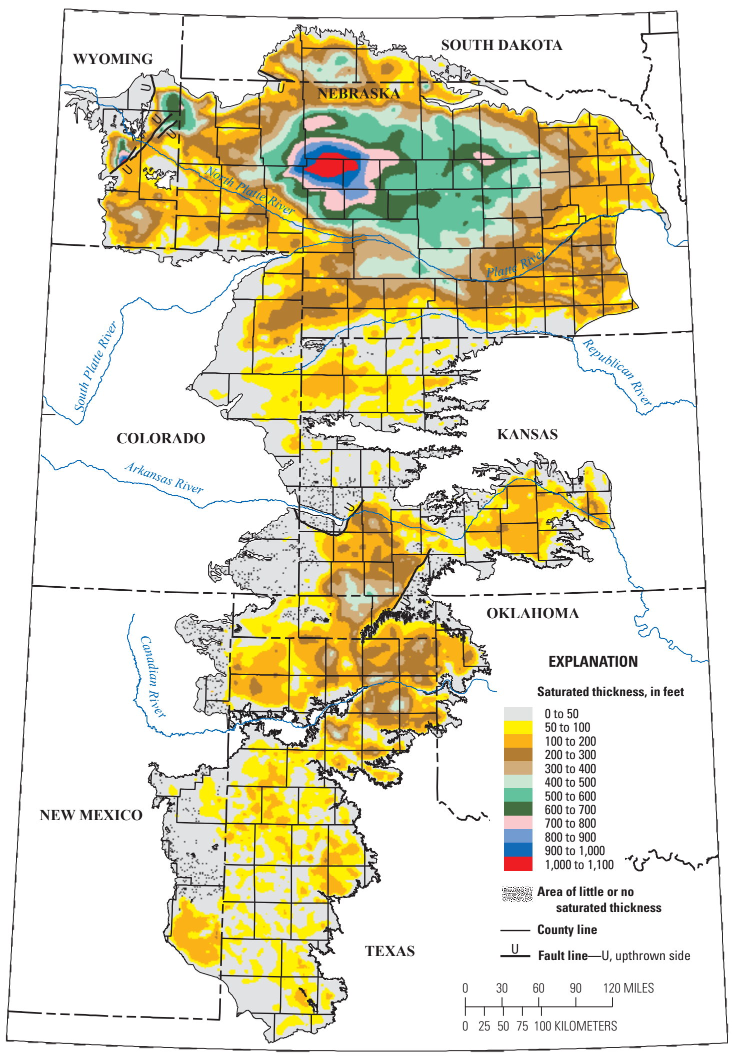
Kris D. Lund
Nebraska Water Science Center

Brenda K. Densmore
Nebraska Water Science Center, bdensmore@usgs.gov

USGS
science for a changing world

Prepared in cooperation with the U.S. Department of Agriculture, Farm Service Agency

Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-Level Changes and Changes in Water in Storage in the High Plains Aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009



Scientific Investigations Report 2012–5177

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

Cover: Figure 1 from the report with modifications.

Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-Level Changes and Changes in Water in Storage in the High Plains Aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009

By Virginia L. McGuire, Kris D. Lund, and Brenda K. Densmore

Prepared in cooperation with the U.S. Department of Agriculture, Farm Service Agency

Scientific Investigations Report 2012–5177

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

Suggested citation:
McGuire, V.L., Lund, K.D., and Densmore, B.K., 2012, Saturated thickness and water in storage in the High Plains aquifer, 2009, and water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009: U.S. Geological Survey Scientific Investigations Report 2012–5177, 28 p.

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)*	1,233	cubic meter (m^3)

*One acre-foot of water is equivalent to the volume of water that would cover 1 acre (43,560 ft^2) to a depth of 1 foot (325,851 gallons or 43,560 ft^3).

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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

Altitude, as used in this report, refers to distance above the vertical datum.

Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-Level Changes and Changes in Water in Storage in the High Plains Aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009

By Virginia L. McGuire, Kris D. Lund, and Brenda K. Densmore

Abstract

The High Plains aquifer underlies about 112 million acres (about 175,000 square miles) in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water levels declined in parts of the High Plains aquifer soon after the onset of substantial irrigation with groundwater (about 1950). This report presents the volume of saturated aquifer material and drainable water in storage in the High Plains aquifer in 2009; water-level changes in the High Plains aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009; and changes in the volume of drainable water in storage in the aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009. The volume data were calculated from raster files with a cell size of about 62 acres.

The volume of water in storage in the High Plains aquifer in 2009 is estimated at about 3.0 billion acre-feet. Area-weighted, average water-level changes for the aquifer were declines of 2.0 feet from 1980 to 1995, 1.3 feet from 1995 to 2000, 2.8 feet from 2000 to 2005, and 1.0 foot from 2005 to 2009. Estimated changes in water in storage were declines of 36.0 million acre-feet from 1980 to 1995, 23.5 million acre-feet from 1995 to 2000, 46.7 million acre-feet from 2000 to 2005, and 18.3 million acre-feet from 2005 to 2009.

Introduction

The High Plains aquifer underlies about 112 million acres [about 175,000 square miles (mi^2)] in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (Qi, 2010; Weeks and Gutentag, 1981). Groundwater in the High Plains aquifer generally is under unconfined conditions; that is, the aquifer, from a regional perspective, has a water table where, by definition, the water pressure is atmospheric (Weeks and Gutentag, 1981). The saturated thickness of the aquifer (defined as the distance from the water table to the base of the aquifer) in 2000 ranged from less than 50 feet (ft) to about 1,200 ft (McGuire and others, 2003). Gutentag and others (1984) reported that, in a few parts of the aquifer, the water table is discontinuous; these areas are labeled as "areas of little or no saturated thickness." According to Gutentag and others (1984), wells drilled in these areas of little or no saturated thickness likely will not yield water unless the well penetrates saturated sediment in either buried channels or depressions in the bedrock.

The area overlying the High Plains aquifer is one of the primary agricultural regions of the Nation. In parts of the area, farmers and ranchers began extensive pumping of groundwater for irrigation in the 1930s and 1940s. Estimated irrigated acreage in the area overlying the High Plains aquifer increased from 1940 to 1980, but did not change substantially from 1980 to 2005—2.1 million acres in 1949, 13.7 million acres in 1980, 13.9 million acres in 1997, 12.7 million acres in 2002, and 15.5 million acres in 2005 (Heimes and Luckey, 1982; Thelin and Heimes, 1987; U.S. Department of Agriculture, 1999 and 2004; Kenny and others, 2009). In 2005, irrigated acres overlaid 14 percent of the aquifer area, not including the areas with little or no saturated thickness (Kenny and others, 2009).

About every 5 years, groundwater withdrawals for irrigation and other uses are compiled from water-use data and reported by the U.S. Geological Survey (USGS) and State agencies. Groundwater withdrawals from the High Plains aquifer for irrigation increased from 4 to 19 million acre-feet (acre-ft) from 1949 to 1974; groundwater withdrawals for irrigation in 1980, 1985, 1990, and 1995 were 4 to 18 percent less than withdrawals for irrigation in 1974 (Heimes and Luckey, 1982; U.S. Geological Survey, 2008). Groundwater withdrawals from the High Plains aquifer for irrigation were 21 million acre-ft in 2000 and 19 million acre-ft in 2005 (Maupin and Barber, 2005; U.S. Geological Survey, 2008; Kenny and others, 2009).

Water-level declines began in parts of the High Plains aquifer soon after the onset of substantial pumpage of groundwater for irrigation—about 1950 (Gutentag and others, 1984). By 1980, water levels in the High Plains aquifer in parts of

Texas, Oklahoma, and southwestern Kansas had declined more than 100 ft (Luckey and others, 1981).

Long-term water-level changes in the aquifer result from an imbalance between discharge and recharge. Discharge from the High Plains aquifer primarily consists of groundwater withdrawals for irrigation, but also includes groundwater withdrawals for public supply and other uses, evapotranspiration where the water table is near land surface, and seepage to streams, springs, and other surface-water bodies where the water table intersects the land surface (Maupin and Barber, 2005). Recharge to the aquifer primarily is from precipitation, with other sources of recharge including seepage from streams, canals, and reservoirs, and irrigation return flows (Luckey and Becker, 1999). Water-level declines may result in increased costs for groundwater withdrawals because of increased pumping lift and decreased well yields (Taylor and Alley, 2001). Water-level declines also can affect groundwater availability for well owners, stream flows, and near-stream (riparian) habitat areas (Alley and others, 1999).

The purpose of this report is to present the saturated thickness and volume of drainable water in storage in the High Plains aquifer in 2009; water-level changes in the High Plains aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009; and changes in the volume of drainable water in storage in the aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009. Water-volume data were generated as raster files with a cell size of about 62 acres, to allow for overlaying those data with other data at the farm-field scale, given that the accuracy of the interpolations are dependent on the density of water-level data. In addition, the interpolation process used to generate the raster file in this report result in cell values that are generally similar to, but commonly not exactly equal to, values based on water-level measurements.

Water levels used in this report generally were measured in wells in winter or early spring. During that period, irrigation wells typically are not pumping, and water levels generally have recovered from pumping during the previous irrigation season. Water levels were not used in this report if water levels appeared to be affected by pumping in the measured well or in nearby wells. Drainable water in storage is the fraction of water in the aquifer that will drain by gravity and can be withdrawn by wells. Drainable water in storage is referred to as “water in storage” in this report. Remaining water in the aquifer is held to the aquifer material by capillary forces and generally cannot be withdrawn by wells.

Methods

Characteristics of Raster Files

The water-volume data for this report are presented as raster files, which were generated using a geographic information system (GIS). The specific GIS program used was ESRI® Arc/Info™ version 9.3 (Environmental Systems Research Institute, 1992 and variously dated). The raster files are in Albers equal-area conic projection with a North American Datum of 1983 (NAD 83). The cell size for all raster files was about 62 acres [500 meters (m) by 500 m]. The cell-value unit for water-level change was feet. The cell-value unit for change in water in storage was square meter-feet (m^2-ft); water in storage values were summarized in this report in units of million acre-ft. The cell-value unit for specific yield was a dimensionless decimal fraction (less than 1). Raster files in this report are saturated thickness, 2009; specific yield; and water-level changes from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009.

Process to Compile Water-Level Data

Water-level data used in this report generally were measured with an electric or steel tape using methods similar to those described by Cunningham and Schalk (2011). Most of the wells were measured manually one to two times per water year. The water year starts in October in the prior year and ends in September in the given year. Generally, if a well was measured one time per water year, the well was measured in the winter or early spring, or, if a well was measured two times per water year, the well was measured in winter or early spring and in the late fall. Some wells were measured nearly continuously by using instrumentation (data recorders with sensors or floats) installed in the well that recorded the water level periodically (generally every 15 to 60 minutes) (Cunningham and Schalk, 2011). Water-level data used to map water-level changes were compiled for each of the specified water years (1980, 1995, 2000, 2005, and 2009) from data used in previous reports on water-level changes in the High Plains aquifer (U.S. Geological Survey, 2012). Available water-level data for each well were reviewed to select a static water level for each applicable water year (that is, a water level that has recovered from pumping in the previous irrigation season) and a water level that is consistent with water levels in neighboring wells. If a static water level was not available for a given well for the specified water year, the water-level data for that well for the specified water year were not used in this report.

In all eight States underlain by the High Plains aquifer, available water levels for 1980 were compiled by Weeks and Gutentag (1981). The 1980 water levels generally were measured after the irrigation season in 1979 and before the irrigation season in 1980 (that is, in water year 1980).

In seven of the eight States that are underlain by the High Plains aquifer—Colorado, Kansas, Nebraska, Oklahoma, South Dakota, Texas, and Wyoming—most water-level data used in this report were from wells measured annually. The estimated 2009 saturated thickness of the High Plains aquifer in these seven States was calculated using water levels measured in water year 2009. Water-level changes for the various water-level comparison periods (1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009) in these seven States were calculated from wells with a static water level for water years at the beginning and end of each period.

In areas underlain by the High Plains aquifer in New Mexico, some wells were measured only once every 5 years. In this report, to expand the number of wells in New Mexico for a specified year, the latest static water level measured in the specified year, and in other years, was used to estimate the water level for that well for the specified year. The estimated 2009 saturated thickness of the High Plains aquifer in New Mexico was calculated using the latest available static water-level measurement from 2005 to 2009 for each well. To estimate change in water levels for wells in New Mexico, the most recent water-level measurement from 1995, 1996, or 1997 was selected as the estimated water level for 1995; the most recent water-level measurement from 2000, 2001, and 2002 was selected as the estimated water level for 2000; the most recent water-level measurement from 2005, 2006, and 2007 was selected as the estimated water level for 2005; and the most recent water-level measurement from 2009 and 2010 was selected as the estimated water level for 2009. In New Mexico, water-level change for the various water-level comparison periods (1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009) was calculated for wells with an estimated static water level at the beginning and end of each period.

Process to Generate Raster File of the Aquifer Base

Contours of the altitude of the base of the aquifer used for a saturated thickness map for the year 2000 (McGuire and others, 2003) were based on available base-of-aquifer maps (Weeks and Gutentag, 1981; Borman and Meredith, 1983; Borman and others, 1984; Hart and McAda, 1985; Juracek and Hansen, 1995; Luckey and Becker, 1999; Houston and others, 2003). The base-of-aquifer contours from those published maps were reviewed and reconciled in areas where they differed. The base-of-aquifer contours were converted to a raster file using the GIS command “topogrid” (Environmental Systems Research Institute, 1992 and variously dated).

Process to Generate Raster File of Saturated Thickness, 2009

Saturated thickness in 2009 was mapped using calculated saturated thickness for each well with a measured or estimated water level for 2009. Before calculating the saturated thickness for each well with a static water level in 2009, (1) the altitude of the aquifer base was estimated using the GIS command “latticespot” (Environmental Systems Research Institute, 1992 and variously dated) and the raster file of the aquifer base, and (2) the altitude of the water table in 2009 was calculated by subtracting depth to water from land surface from the land-surface elevation (U.S. Geological Survey, 2011). Saturated thickness then was calculated by subtracting the altitude of the aquifer base from the altitude of the water table in 2009. In areas with minimal water-level data and irrigation, such as in northwestern Wyoming, previously published contours of saturated thickness were assumed to represent current (2009) conditions (Weeks and Gutentag, 1981; Qi and others, 2002). The saturated thickness raster file was generated using the GIS command “topogrid” (Environmental Systems Research Institute, 1992 and variously dated); inputs to the “topogrid” command were the saturated thickness values for each well and previously published contours of saturated thickness. The resultant raster file was examined in areas with minimal water-level data and irrigation using the GIS command “con;” if the cell value was greater than or less than the range of the corresponding saturated thickness contours in previously published maps, the cell value was changed to the mid-range of the corresponding saturated thickness contours of those maps.

Process to Generate Raster File of Specific Yield

Specific yield of the aquifer is needed to calculate water in storage. Specific yield was mapped for the High Plains aquifer from area-weighted, average specific yields derived from lithologic logs for selected wells or test holes generally drilled to the base of the aquifer (Gutentag and others, 1984). A specific yield raster file was created from a contour map of specific yield ranges in the High Plains aquifer (Gutentag and others, 1984; Cederstrand and Becker, 1998). The GIS command “polygrid” (Environmental Systems Research Institute, 1992 and variously dated) was used to convert the average of the assigned range for the specific yield polygons to a raster file of the area. The specific yield value of cells in this raster file of specific yield is hereafter referred to as the average-mapped specific yield value.

Process to Calculate Water in Storage, 2009

Water in storage in the High Plains aquifer in 2009 was calculated for each cell by multiplying the raster value of saturated thickness for 2009, times the raster value of average-mapped specific yield, times a conversion factor to convert m^2-ft to million acre-ft. Summaries of water in storage by State and by county were calculated by aggregating the raster values for water in storage, 2009, for the aquifer area, not including the areas of “little or no saturated thickness” as delineated by Gutentag and others (1984).

Process to Generate Raster Files of Water-Level Changes, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009

The raster file of water-level changes in the High Plains aquifer from 1980 to 1995 was generated using the following approach:

1. Water-level data for all wells with static water-level data for 1980 and 1995 were compiled.

2. An attribute, labeled "FSA_delta80_95," was calculated as water level, 1980, minus water level, 1995, for each well and added to the point data set of water-level change, 1980 to 1995.

3. An attribute, labeled "beginval," was added to the published contours of water-level change, 1980 to 1995 (McGuire and Sharpe, 1997); "beginval" was populated with the beginning range value of the contour. For example, for contours of a 5 ft to 10 ft rise, "beginval" was set to 5 ft; for contours of a -5 ft to -10 ft decline, "beginval" was set to -5 ft.

4. The GIS command "topogrid" (Environmental Systems Research Institute, 1992 and variously dated) was used to generate an initial raster file of water-level change. Inputs included the point data set of water-level change for 1980 to 1995 (attribute "FSA_delta80_95") and modified contours of water-level change, 1980 to 1995 (attribute "beginval").

5. The GIS command "contour" (Environmental Systems Research Institute, 1992 and variously dated) was applied to the initial raster output from topogrid to generate the water-level change contours (attribute "contour") for the -3 ft and 3 ft contours of water-level change, 1980 to 1995. In areas with little water-level data, contours from McGuire and Sharpe (1997) and the -3 ft and 3 ft contours were modified manually to make the interpolation more realistic. Contours were built as polygons and the polygon attribute "startval" was set equal to one for polygons formed by the -3 ft and 3 ft contours and set to zero for all other polygons. The polygons formed by the -3 ft and 3 ft contours delineate areas of no substantial water-level change on the map. The GIS command "polygrid" was used to generate a raster file of no substantial change using the polygon attribute "startval."

6. The GIS command "topogrid" (Environmental Systems Research Institute, 1992 and variously dated) was used to generate a raster file of water-level changes, 1980 to 1995. Inputs to the topogrid process included a point data set of water-level change for 1980 to 1995 (attribute "FSA_delta80_95") and the modified contours of water-level change, 1980 to 1995 (attribute "contour"). This raster file was modified using the GIS function "con" to change the cell values to null in areas where the aquifer is not present (Gutentag and others, 1984) and to change the cell value to zero in areas of no substantial change. This modified raster file was used to show water-level changes from 1980 to 1995 in this report.

7. The final raster file from step 6 was further modified using the GIS function "con" to change the cell values to null in the areas of little or no saturated thickness as described by Gutentag and others (1984). This modified raster file was used for statistical analysis and to calculate summary tables in this report.

The raster files of water-level change in the High Plains aquifer for 1995 to 2000, 2000 to 2005, and 2005 to 2009 were calculated using a similar approach as previously described; however, because contours for water-level change were not available for the entire High Plains aquifer for these selected time periods, contours of water-level change were generated from water-level-change data using the GIS command "topogrid" (Environmental Systems Research Institute, 1992 and variously dated) and then modified manually. Areas deemed to have no substantial change for the 1995 to 2000, 2000 to 2005, and 2005 to 2009 time periods were those with water-level change between -1 ft and 1 ft. The water-level change point data and modified contours of water-level change were input to the second run of the GIS command "topogrid" to generate the revised raster file of water-level change. The water-level change value in areas of no substantial change was set to 0 using the GIS command "con." The definition of areas having no substantial change for the 1995 to 2000, 2000 to 2005, and 2005 to 2009 time periods was set to a smaller value (-1 ft to 1 ft) than for the 1980 to 1995 time period (-3 ft to 3 ft) because the durations of the time periods were shorter (4 to 5 years versus 15 years) and the magnitudes of the water-level changes were smaller.

Process to Calculate Changes in Water in Storage, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009

Changes in water in storage in the High Plains aquifer in the 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009 time periods were calculated by multiplying the raster values of water-level change for each period by the raster values of average-mapped specific yield and by a conversion factor to convert m^2-ft to million acre-feet. Totals of changes in water in storage by State and county were calculated by aggregating the values for change in water in storage for each period.

Water-Level Data

Water-level data used in this report were provided by the following Federal, State, and local entities through data files, and loaded into the U.S. Geological Survey National Water Information System (U.S. Geological Survey, 2011); the sources for the water-level data are noted below:

- Colorado: Division of Water Resources (also known as the Office of the State Engineer);

- Kansas: Department of Agriculture—Division of Water Resources and Kansas Geological Survey (Kansas Geological Survey, 2010);
- Nebraska: Central Nebraska Public Power and Irrigation District, applicable Natural Resources Districts, and the University of Nebraska—Lincoln, Conservation and Survey Division;
- New Mexico: Office of the State Engineer;
- Oklahoma: Water Resources Board;
- South Dakota: Department of Environment and Natural Resources;
- Texas: Groundwater Conservation Districts and the Water Development Board (Texas Water Development Board, 2010);
- Wyoming: State Engineer's Office; and
- Federal: Bureau of Reclamation, U.S. Fish and Wildlife Service, and U.S. Geological Survey offices in Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming (U.S. Geological Survey, 2011).

The number of water-level measurements in wells that are screened in the High Plains aquifer vary annually. To estimate the saturated thickness of the High Plains aquifer in Colorado, Kansas, Nebraska, Oklahoma, South Dakota, Texas, and Wyoming in 2009, this report uses 8,690 water levels measured during water year 2009 (table 1). To estimate the saturated thickness of the High Plains aquifer in New Mexico in 2009, this report uses water levels measured in 2009 and, for wells not measured in 2009, the most recent water-level data collected from 2005 to 2008. In New Mexico, 307 wells were used to estimate saturated thickness in 2009 (table 1); 246 of those wells were measured in at least one of the water years from 2005 to 2008, and 61 of those wells were measured in water year 2009 (table 2).

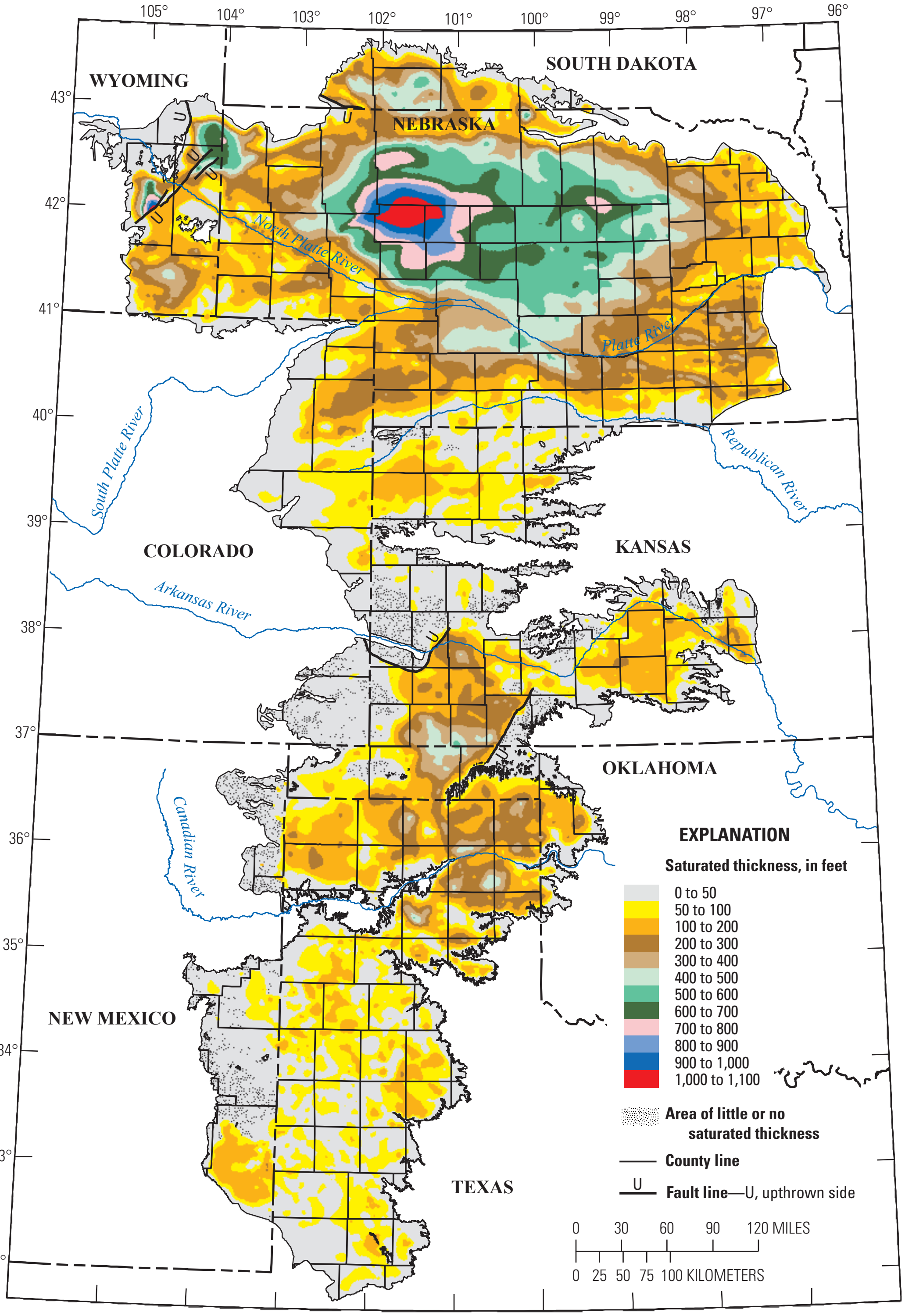
To estimate water-level changes in the applicable water-level comparison periods, water-level data were compiled for 1980, 1995, 2000, 2005, and 2009. The 1980 water levels generally were measured in water year 1980 (Weeks and Gutentag, 1981) in the eight States that overlie the aquifer. For wells located in Colorado, Kansas, Nebraska, Oklahoma, South Dakota, Texas, and Wyoming, the 1995, 2000, 2005, and 2009 water levels for the water-level comparison periods were measured in the corresponding water years (table 1). For wells located in New Mexico, the 1995, 2000, 2005, and 2009 water levels for the water-level comparison periods were measured in the corresponding water year and in one or two of the following water years (table 2).

Saturated Thickness and Water in Storage, 2009

The volume of saturated material in the High Plains aquifer in 2009 was estimated from the saturated thickness map of the aquifer for 2009 (fig. 1). The volume of saturated material in the aquifer in 2009 ranged from 200 million acre-ft in New Mexico to 13,200 million acre-ft in Nebraska (table 3). Water in storage in the High Plains aquifer in 2009 was calculated

Table 1. Number of wells used in this report to estimate water-level changes in the High Plains aquifer for the water-level comparison periods from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and number of wells used in this report to estimate saturated thickness of the High Plains aquifer, 2009, by State and in total.

State	Number of wells used to estimate water-level changes by water-level comparison period				Number of wells used to estimate saturated thickness, 2009
	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Colorado	515	492	475	318	345
Kansas	883	827	1,031	955	1,708
Nebraska	1,961	2,453	3,310	3,573	3,676
New Mexico	236	329	252	72	307
Oklahoma	198	151	105	124	132
South Dakota	45	55	83	88	85
Texas	1,925	1,630	1,948	2,256	2,491
Wyoming	20	34	44	43	253
High Plains aquifer	5,783	5,971	7,248	7,429	8,997



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
Albers Equal-Area projection
Standard parallels 29° 30' and 45° 30', central meridan -101°
North American Datum of 1983 (NAD 83)

Aquifer boundary from Qi (2010); saturated thickness modified from Weeks and Gutentag (1981); areas of little or no saturated thickness from Gutentag and others (1984)

Figure 1. Saturated thickness of the High Plains aquifer, 2009.

Table 2. Number of wells screened in the High Plains aquifer in New Mexico and measured in winter or spring, 1995 to 2010; used to estimate saturated thickness, 2009; and used to estimate water level for 1980, 1995, 2000, 2005, and 2009, by water year.

[All wells have a static water level in winter or spring of the specified year; water year, October of the prior year through September of the given year; --, not applicable]

Water year	Number of wells measured in winter or spring, by water year	Number of wells used to estimate saturated thickness, 2009	Number of wells measured, by water year							
			Water-level comparison periods							
			1980 to 1995		1995 to 2000		2000 to 2005		2005 to 2009	
			1980	1995	1995	2000	2000	2005	2005	2009
1980	238	--	236	--	--	--	--	--	--	--
1995	235	--	--	12	3	--	--	--	--	--
1996	751	--	--	61	211	--	--	--	--	--
1997	547	--	--	163	115	--	--	--	--	--
1998	138	--	--	--	--	--	--	--	--	--
1999	24	--	--	--	--	--	--	--	--	--
2000	114	--	--	--	--	2	1	--	--	--
2001	269	--	--	--	--	171	122	--	--	--
2002	206	--	--	--	--	156	129	--	--	--
2003	148	--	--	--	--	--	--	--	--	--
2004	79	--	--	--	--	--	--	--	--	--
2005	73	6	--	--	--	--	--	7	1	--
2006	306	198	--	--	--	--	--	158	11	--
2007	102	23	--	--	--	--	--	87	60	--
2008	67	19	--	--	--	--	--	--	--	--
2009	71	61	--	--	--	--	--	--	--	18
2010	77	--	--	--	--	--	--	--	--	54
Total	3,445	307	236	236	329	329	252	252	72	72

Table 3. Distribution of aquifer area, area of little or no saturated thickness, and volume of saturated material, High Plains aquifer, 2009, by State and in total.

[--, not applicable]

State	Area underlain by High Plains aquifer, in square miles[1]	Area with little or no saturated thickness, in square miles[2]	Volume of saturated aquifer material, in million acre-feet
Colorado	13,300	1,400	500
Kansas	30,900	5,340	1,600
Nebraska	64,600	80	13,200
New Mexico	9,300	3,590	200
Oklahoma	7,400	340	500
South Dakota	4,900	--	600
Texas	36,300	30	2,100
Wyoming	8,100	--	800
High Plains aquifer	175,000	10,800	19,500

[1]Aquifer boundary from Qi (2010), which is a modification of the Weeks and Gutentag (1981) boundary.

[2]As described by Gutentag and others (1984).

by multiplying the volume of saturated material in the aquifer by average-mapped specific yield (fig. 2; Gutentag and others, 1984; Cederstrand and Becker, 1998).

The specific yield of the High Plains aquifer was estimated using drillers' and geologists' descriptive logs of rocks and sediment comprising the aquifer matrix from wells and test holes generally drilled to the base of the aquifer (Gutentag and others, 1984). An area-weighted, average specific yield was calculated for each well or test hole, and specific yield was mapped for defined areas of the aquifer, for example, 0–5 percent, 5–10 percent, and so forth. Specific yield of the High Plains aquifer ranges from near zero to about 30 percent; the average of the mapped specific yield ranges from 2.5 to 27.5 percent (fig. 2). Average area-weighted specific yield, using average-mapped specific yield and not including areas of little or no saturated thickness, by State, ranges from 8.1 percent in Wyoming to 18.5 percent in Oklahoma and is 15.1 percent for the aquifer (table 4).

The volume of water in storage in the High Plains aquifer was estimated at about 3.2 billion acre-ft in 1980 (Gutentag and others, 1984), about 3.0 billion acre-ft in 2000 (McGuire and other, 2003), and about 2.9 billion acre-ft in 2009 (McGuire, 2011). The volume of water in storage in 2009 in the High Plains aquifer is re-estimated in this report at about

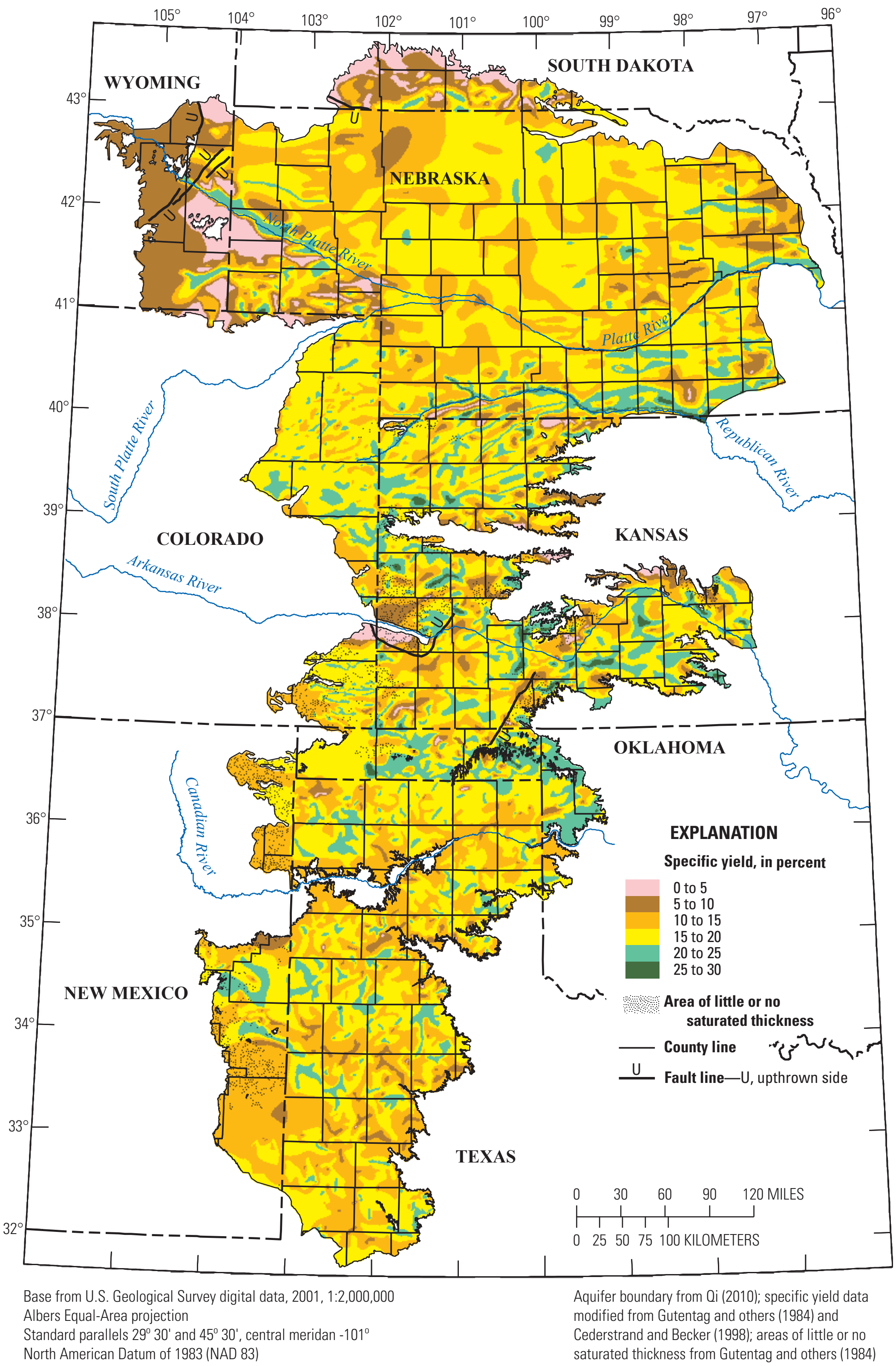


Figure 2. Specific yield of the High Plains aquifer.

Table 4. Area-weighted, average specific yield using average-mapped specific yield generated from a contour map of specific yield ranges of the High Plains aquifer, by State and in total, with and without areas of little or no saturated thickness.

State	Area-weighted, average specific yield, in percent[1]	
	Including areas of little or no saturated thickness[2]	Not including areas of little or no saturated thickness[2]
Colorado	16.3	16.3
Kansas	16.1	16.4
Nebraska	15.1	15.1
New Mexico	14.3	14.8
Oklahoma	18.4	18.5
South Dakota	9.1	9.1
Texas	15.3	15.3
Wyoming	8.1	8.1
High Plains aquifer	15.0	15.1

[1]Modified from Gutentag and others (1984); Cederstrand and Becker (1998).

[2]Delineated by Gutentag and others (1984).

3.0 billion acre-ft (table 5). Different methods were used to calculate water in storage for 1980, 2000, and 2009 in previous reports (Gutentag and others, 1984; McGuire and others, 2003; and McGuire, 2011) and in this report. Previously reported values for water in storage in 2000 (McGuire and others, 2003) were calculated using the average value associated with the mapped polygons and the average area-weighted specific yield of the aquifer (15.1 percent). Previously reported values for water in storage in 2009 (McGuire, 2011) were calculated using the average value associated with the mapped polygons of saturated thickness in 2000, Thiessen polygons (Thiessen, 1911) of water-level changes from 2000 to 2009, and the average area-weighted specific yield (15.1 percent) of the aquifer. In this report, water in storage for 2009 was calculated using a raster file of saturated thickness for 2009, and a raster file of average-mapped specific yield that was generated from a contour map of specific yield ranges (Gutentag and others, 1984; Cederstrand and Becker, 1998).

The volume of water in storage in 2009 by State, as calculated in this report, ranges from about 30 million acre-ft in New Mexico to 2,040 million acre-ft in Nebraska (table 5). The volume of water in storage in 2009 by county is listed in appendix 1. The volume of water in storage by county ranges from near zero in several counties underlain by the aquifer to 287 million acre-ft in Cherry County, Nebraska.

Table 5. Distribution of water in storage in the High Plains aquifer, 1980, 2000, and 2009, by State and in total, as calculated in this report and in previous reports.

State	Water in storage, in million acre-feet			
	Calculated in this report	Calculated in previous reports		
	Calculated using average-mapped specific yield generated from a contour map of specific yield ranges[1]	Calculated using area-weighted, average specific yield for the aquifer (15.1 percent)[2]		
	2009	[2]1980	[3]2000	[4]2009
Colorado	80	120	80	80
Kansas	260	320	270	260
Nebraska	2,040	2,130	2,000	1,980
New Mexico	30	50	40	30
Oklahoma	90	110	110	100
South Dakota	60	60	60	60
Texas	320	390	350	330
Wyoming	80	70	60	60
High Plains aquifer	2,960	3,250	2,970	2,900

[1]Gutentag and others (1984); Cederstrand and Becker (1998).

[2]Gutentag and others (1984).

[3]Modified from McGuire and others (2003).

[4]Modified from McGuire (2011).

Water-Level Changes and Changes in Water in Storage, 1980 to 1995

The map of water-level changes in the High Plains aquifer from 1980 to 1995 (fig. 3) is based on water-level data collected from 5,783 wells (table 1). Measured water-level changes from 1980 to 1995 ranged from a rise of about 48 ft in Nebraska to a decline of about 82 ft in New Mexico. Area-weighted, average water-level change from 1980 to 1995 for the aquifer was a decline of 2.0 ft; the area-weighted, average water-level change from 1980 to 1995 by State ranged from a decline of 6.6 ft in Kansas to a rise of 1.1 ft in Nebraska (table 6). McGuire and Sharpe (1997) calculated that the area-weighted, average water-level change from 1980 to 1995 for the aquifer was a decline of 2.4 ft (table 6). The difference in the values for the area-weighted, average water-level change from 1980 to 1995 in McGuire and Sharpe (1997) and in this report can be attributed to a difference in calculation methods. McGuire and Sharpe (1997) used Thiessen polygons (Thiessen, 1911) to calculate area-weighted, average water-level changes; in this report, an interpolated raster file of water-level changes was used in the calculation.

McGuire and Sharpe (1997) calculated that water in storage from 1980 to 1995 decreased by 40.2 million acre-ft (table 7). The change in water in storage in the High Plains aquifer from 1980 to 1995 calculated in this report was a decrease of about 36.0 million acre-ft (table 7). The difference in these values (4.2 million acre-ft or about 10 percent less depletion in this report) was caused by a difference in calculation methods. McGuire and Sharpe (1997) used Thiessen polygons (Thiessen, 1911) and the average area-weighted specific yield for the aquifer (15.1 percent) in their calculation. In this report, changes in water in storage were calculated using a raster file of water-level changes and a raster file of average-mapped specific yield generated from a contour map of specific yield ranges (Gutentag and others, 1984; Cederstrand and Becker, 1998).

Water-Level Changes and Changes in Water in Storage, 1995 to 2000

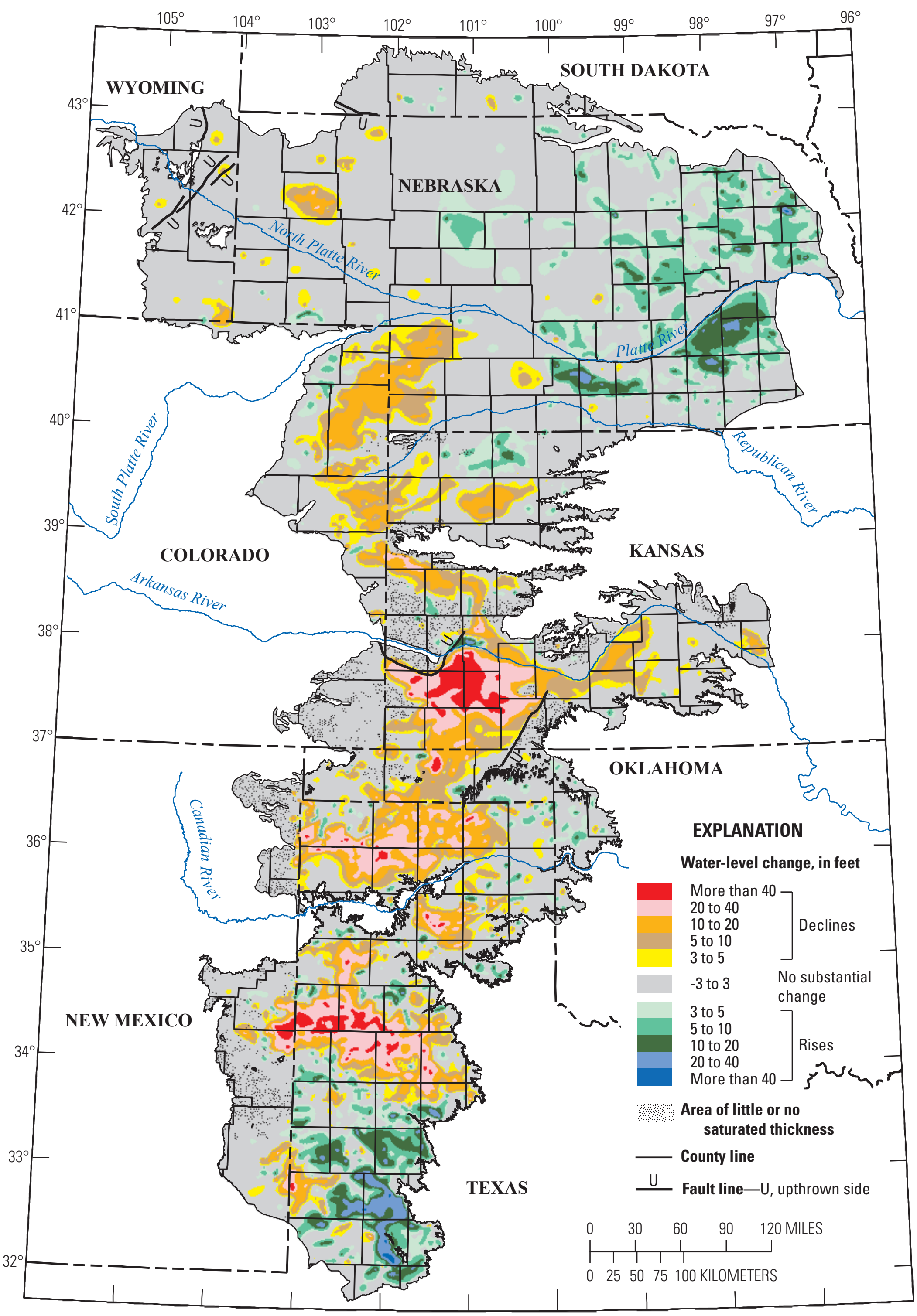
The map of water-level changes in the High Plains aquifer from 1995 to 2000 (fig. 4) is based on water-level data collected from 5,971 wells (table 1). Measured water-level changes from 1995 to 2000 ranged from a rise of about 26 ft in Texas to a decline of about 60 ft in Texas. The area-weighted, average water-level change from 1995 to 2000 for the aquifer was a decline of 1.3 ft; the area-weighted, average water-level change from 1995 to 2000 by State ranged from a decline of 4.7 ft in Texas to a rise of 0.8 ft in South Dakota (table 6). Previously reported area-weighted, average water-level change from 1995 to 2000 for the aquifer was a decline of 1.1 ft (McGuire and others, 1997; McGuire and Fischer, 1999a and 1999b; McGuire, 2001 and 2003; table 6). The difference in these values reflects a difference in calculation methods. Previously reported area-weighted, average water-level change from 1995 to 2000 (McGuire and others, 1997; McGuire and Fischer, 1999a and 1999b; McGuire, 2001 and 2003) was calculated using Thiessen polygons (Thiessen, 1911); in this report, an interpolated raster file of water-level changes was used in the calculation.

Previously reported change in water in storage for the High Plains aquifer from 1995 to 2000 was a decline of 17.6 million acre-ft (McGuire, 2011). The change in water in storage for the High Plains aquifer from 1995 to 2000 calculated in this report was a decline of 23.5 million acre-ft (table 7). The difference in these values (5.9 million acre-ft or about 33 percent more depletion in this report) is caused by a difference in calculation methods. Previously reported changes in water in storage from 1995 to 2000 were calculated using Thiessen polygons (Thiessen, 1911) and average area-weighted specific yield for the aquifer (15.1 percent). In this report, changes in water in storage were calculated using a raster file of water-level changes and a raster file of average-mapped specific yield generated from a contour map of specific yield ranges (Gutentag and others, 1984; Cederstrand and Becker, 1998).

Water-Level Changes and Changes in Water in Storage, 2000 to 2005

The map of water-level changes in the High Plains aquifer from 2000 to 2005 (fig. 5) is based on water-level data collected from 7,248 wells (table 1). Measured water-level changes from 2000 to 2005 ranged from a rise of about 17 ft in Oklahoma to a decline of about 44 ft in Texas. The area-weighted, average water-level change from 2000 to 2005 for the aquifer was a decline of 2.8 ft; the area-weighted, average water-level change from 2000 to 2005 by State ranged from a decline of 4.3 ft in Kansas to a decline of 0.5 ft in Oklahoma (table 6). The previously reported area-weighted, average water-level change from 2000 to 2005 for the aquifer was a decline of 3.4 ft (McGuire, 2003, 2004a; 2004b; 2007; table 6). The difference in these values is caused by differences in calculation methods. Previously reported area-weighted, average water-level changes from 2000 to 2005 (McGuire, 2003, 2004a; 2004b; 2007) was calculated using Thiessen polygons (Thiessen, 1911); this report uses an interpolated raster file of water-level changes for that calculation.

The previously reported change in water in storage from 2000 to 2005 was a decline of 55.4 million acre-ft (McGuire, 2011). The change in water in storage in the High Plains aquifer from 2000 to 2005 calculated in this report was a decline of 46.7 million acre-ft (table 7). The difference in these values (8.7 million acre-ft or about 16 percent less depletion in this report) is caused by differences in calculation methods. The previously reported changes in water in storage from 2000



Base from U.S. Geological Survey digital data, 2001, 1:2,000,000
Albers Equal-Area projection
Standard parallels 29° 30' and 45° 30', central meridan -101°
North American Datum of 1983 (NAD 83)

Aquifer boundary from Qi (2010); water-level change, 1980 to 1995, modified from McGuire and Sharpe (1997); areas of little or no saturated thickness from Gutentag and others (1984)

Figure 3. Water-level changes in the High Plains aquifer, 1980 to 1995.

Table 6. Distribution of area-weighted, average water-level changes in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, by State and in total, as calculated in this report and in previous reports.

State	Calculated in this report: Area-weighted, average water-level changes, in feet, calculated using an interpolated raster				Calculated in previous reports: Area-weighted, average water-level changes, in feet, calculated using Theissen polygons			
	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	[1]1980 to 1995	[2]1995 to 2000	[3]2000 to 2005	[4]2005 to 2009
Colorado	-3.0	-1.0	-2.9	-2.2	-4.2	-0.6	-3.8	-3.9
Kansas	-6.6	-1.6	-4.3	-2.4	-7.5	-0.9	-4.8	-2.2
Nebraska	1.1	0.3	-2.9	0.5	1.8	0.8	-3.8	0.5
New Mexico	-3.3	-1.9	-1.7	-0.9	-3.1	-3.8	-3.1	-3.2
Oklahoma	-2.1	-1.6	-0.5	-1.2	-2.8	-1.1	-0.7	-2.2
South Dakota	0.1	0.8	-0.7	-0.3	-0.6	2.5	-1.2	0.1
Texas	-4.3	-4.7	-2.7	-2.6	-4.8	-4.9	-3.2	-2.5
Wyoming	-0.2	0.1	-0.7	-0.4	-3.4	0	-2.2	-1.2
High Plains aquifer	-2.0	-1.3	-2.8	-1.0	-2.4	-1.1	-3.4	-1.4

[1]McGuire and Sharpe (1997).

[2]McGuire and others (1997); McGuire and Fischer (1999a and 1999b); McGuire (2001 and 2003).

[3]McGuire (2003, 2004a, 2004b, and 2007).

[4]McGuire (2009 and 2011).

Table 7. Distribution of changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, by State and in total, as calculated in this report and in previous reports.

[--, not calculated]

State	Calculated in this report: Changes in water in storage, in million acre-feet, calculated using interpolated water-level change raster and raster of average-mapped specific yield generated from a contour map of specific yield ranges[1]				Calculated in previous reports: Changes in water in storage, in million acre-feet, calculated using Theissen polygons of water-level-change results and area-weighted, average specific yield of the aquifer (15.1 percent)[2]			
	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	[3]1980 to 1995	[4]1995 to 2000	[4]2000 to 2005	[4]2005 to 2009
Colorado	-4.0	-1.4	-3.7	-2.9	-6.0	--	--	-4.4
Kansas	-17.4	-4.2	-11.6	-6.5	-22.0	--	--	-5.6
Nebraska	7.4	2.4	-18.8	3.0	10.9	--	--	2.8
New Mexico	-2.0	-1.1	-1.0	-0.5	-2.8	--	--	-1.8
Oklahoma	-1.8	-1.3	-0.4	-1.0	-2.0	--	--	-1.5
South Dakota	0.0	0.2	-0.2	-0.1	-0.3	--	--	0.1
Texas	-18.1	-18.1	-10.7	-10.1	-16.4	--	--	-9.1
Wyoming	-0.1	0.0	-0.3	-0.2	-2.6	--	--	-0.9
High Plains aquifer	-36.0	-23.5	-46.7	-18.3	-40.2	-17.6	-55.4	-20.4

[1]Modified from Gutentag and others (1984); Cederstand and Becker (1998).

[2]Gutentag and others (1984).

[3]Modified from McGuire and Sharpe (1997).

[4]Modified from McGuire (2011).

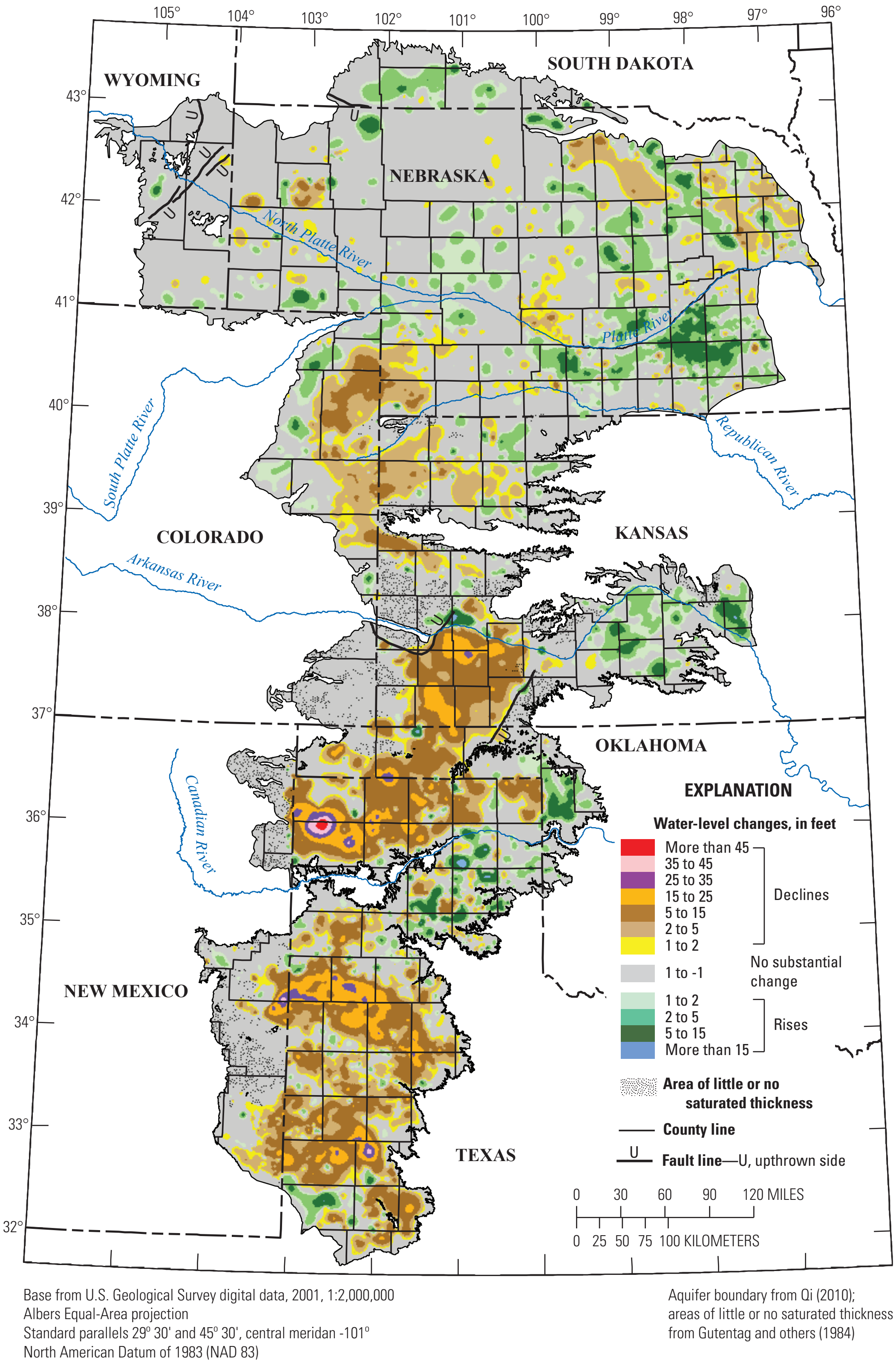


Figure 4. Water-level changes in the High Plains aquifer, 1995 to 2000.

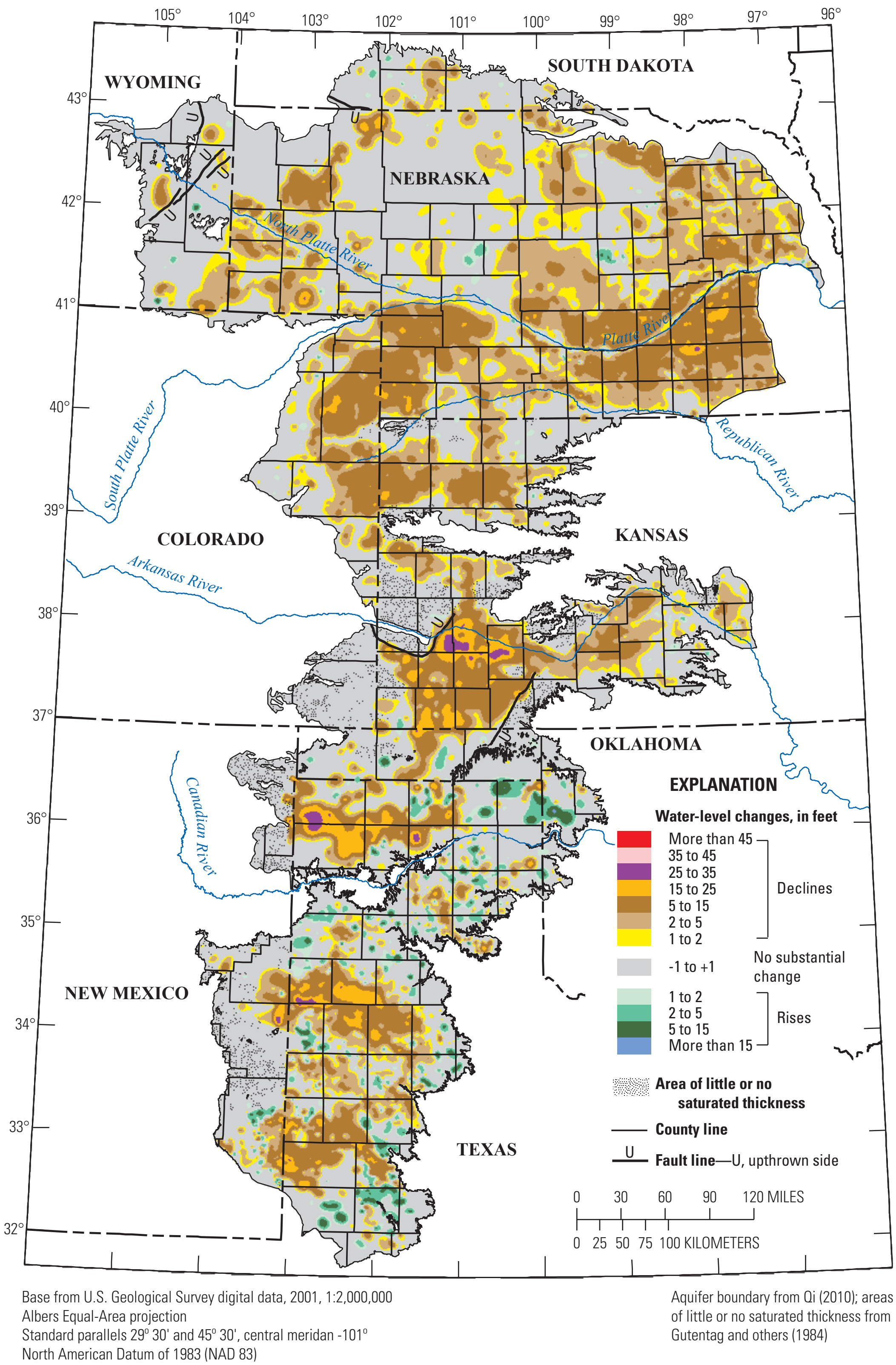


Figure 5. Water-level changes in the High Plains aquifer, 2000 to 2005.

to 2005 were calculated using Thiessen polygons (Thiessen, 1911) and the average area-weighted specific yield for the aquifer (15.1 percent). In this report, changes in water in storage were calculated using a raster file of water-level changes and a raster file of average-mapped specific yield generated from a contour map of specific yield ranges (Gutentag and others, 1984; Cederstrand and Becker, 1998).

Water-Level Changes and Changes in Water in Storage, 2005 to 2009

The map of water-level changes in the High Plains aquifer from 2005 to 2009 (fig. 6) is based on water-level data collected from 7,429 wells (table 1). Measured water-level changes from 2005 to 2009 ranged from a rise of about 32 ft in Oklahoma to a decline of about 45 ft in Texas. The area-weighted, average water-level change from 2005 to 2009 for the aquifer was a decline of 1.0 ft; the area-weighted, average water-level change from 2005 to 2009 by State ranged from a decline of 2.6 ft in Texas to a rise of 0.5 ft in Nebraska (table 6). The previously reported area-weighted, average water-level change from 2005 to 2009 for the aquifer was a decline of 1.4 ft (McGuire, 2009 and 2011; table 6). The difference in these values is caused by differences in calculation methods. The previously reported area-weighted, average water-level change from 2005 to 2009 (McGuire, 2009 and 2011) was calculated using Thiessen polygons (Thiessen, 1911); in this report, an interpolated raster file of water-level changes was used for that calculation.

The previously reported change in water in storage from 2005 to 2009 was a decline of 20.4 million acre-ft (McGuire, 2009 and 2011). The change in water in storage in the High Plains aquifer from 2005 to 2009 as calculated in this report was a decline of 18.3 million acre-ft (table 7). The difference in these values (2.1 million acre-ft or about 10 percent less depletion in this report) was caused by differences in calculation methods. The previously reported changes in water in storage from 2005 to 2009 were calculated using Thiessen polygons (Thiessen, 1911) and the aquifer average area-weighted specific yield (15.1 percent). In this report, changes in water in storage were calculated by using a raster file of water-level changes and a raster file of average-mapped specific yield generated from a contour map of specific yield ranges (Gutentag and others, 1984; Cederstrand and Becker, 1998).

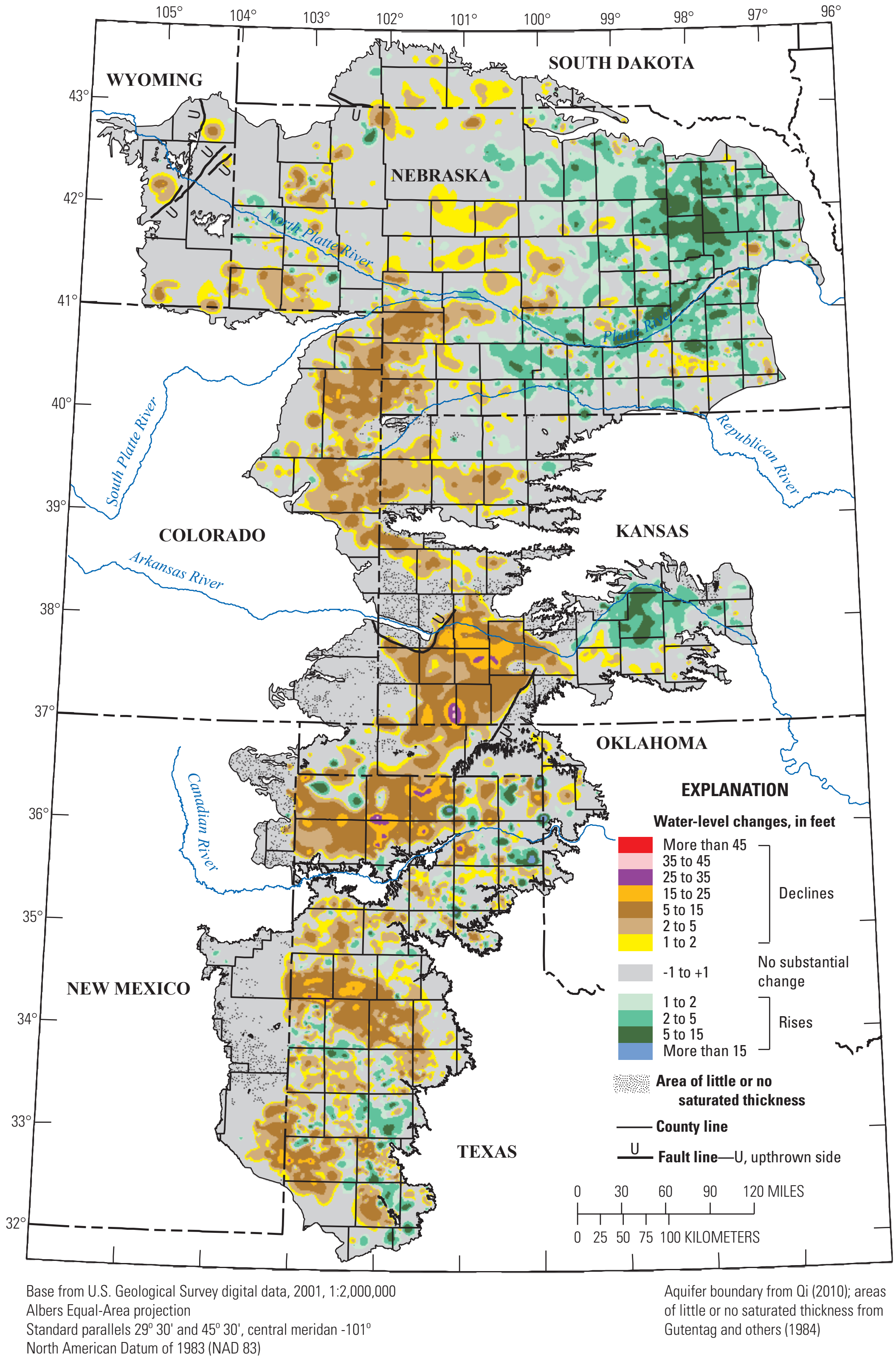


Figure 6. Water-level changes in the High Plains aquifer, 2005 to 2009.

Summary

The High Plains aquifer underlies about 112 million acres [about 175,000 square miles (mi^2)] in parts of eight States—Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. Water levels declined in parts of the High Plains aquifer soon after the onset of substantial irrigation with groundwater (about 1950). This report describes the volume of saturated material and drainable water in storage in the High Plains aquifer in 2009; water-level changes in the High Plains aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009; and change in the volume of drainable water in storage in the aquifer from 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009 using raster files with a cell size of about 62 acres. Water levels used in this report generally were measured in winter or early spring. At this time, irrigation wells typically were not pumping, and water levels generally had recovered from pumping during the previous irrigation season.

The volume of saturated material in the aquifer in 2009 was estimated from a saturated thickness map of the aquifer for 2009. The volume of saturated material in the aquifer in 2009 by State ranged from 200 million acre-ft in New Mexico to 13,200 million acre-ft in Nebraska. Water in storage in the High Plains aquifer in 2009 was calculated by multiplying the volume of saturated material in the aquifer by the average specific yield in defined areas of specific yield ranges. Average-mapped specific yield ranges from 2.5 to 27.5 percent. The average area-weighted specific yield using average-mapped specific yield by State ranges from 8.1 percent in Wyoming to 18.5 percent in Oklahoma and is 15.1 percent for the aquifer, not including the areas of little or no saturated thickness. The volume of water in storage in 2009 in the High Plains aquifer was estimated at about 3.0 billion acre-ft in this report.

The map of water-level changes in the High Plains aquifer from 1980 to 1995 was based on water levels from 5,783 wells. Area-weighted, average water-level change from 1980 to 1995 for the aquifer was a decline of 2.0 ft; the area-weighted, average water-level change from 1980 to 1995 by State ranged from a decline of 6.6 ft in Kansas to a rise of 1.1 ft in Nebraska. The change in water in storage in the High Plains aquifer from 1980 to 1995 calculated in this report was a decline of about 36.0 million acre-ft.

Water-level changes in the High Plains aquifer from 1995 to 2000 in this report were based on water levels measured in 5,971 wells. The area-weighted, average water-level change from 1995 to 2000 for the aquifer was a decline of 1.3 ft; the area-weighted, average water-level change from 1995 to 2000 by State ranged from a decline of 4.7 ft in Texas to a rise of 0.8 ft in South Dakota. The change in water in storage in the High Plains aquifer from 1995 to 2000 calculated in this report was a decline of 23.5 million acre-ft.

Water-level changes in the High Plains aquifer from 2000 to 2005 were based on water levels measured in 7,248 wells. The area-weighted, average water-level change from 2000 to 2005 for the aquifer was a decline of 2.8 ft; the area-weighted, average water-level change from 2000 to 2005 by State ranged from a decline of 4.3 ft in Kansas to a decline of 0.5 ft in Oklahoma. The change in water in storage in the High Plains aquifer from 2000 to 2005 calculated in this report was a decline of 46.7 million acre-ft.

Water-level changes in the High Plains aquifer from 2005 to 2009 were based on water levels measured in 7,429 wells. The area-weighted, average water-level change from 2005 to 2009 for the aquifer was a decline of 1.0 ft; the area-weighted, average water-level change from 2005 to 2009 by State ranged from a decline of 2.6 ft in Texas to a rise of 0.5 ft in Nebraska. The change in water in storage in the High Plains aquifer from 2005 to 2009 calculated in this report was a decline of 18.3 million acre-ft.

References Cited

Alley, W.M., Reilly, T.E., and Franke, O.L., 1999, Sustainability of ground-water resources: U.S. Geological Survey Circular 1186, 79 p. (Also available at *http://pubs.usgs.gov/circ/circ1186/*.)

Borman, R.G., and Meredith, T.S., 1983, Geology, altitude, and depth of the bedrock surface beneath the Ogallala Formation in the northern High Plains of Colorado: U.S. Geological Survey Hydrologic Atlas 669, 1 sheet, scale 1:500,000. (Also available at *http://pubs.er.usgs.gov/djvu/HA/ha_669_plt.djvu*.)

Borman, R.G., Meredith, T.S., and Bryn, S.M., 1984, Geology, altitude, and depth of the bedrock surface; altitude of the water table in 1980; and saturated thickness of the Ogallala aquifer in 1980 in the southern High Plains of Colorado: U.S. Geological Survey Hydrologic Atlas 673, 1 sheet, scale 1:500,000.

Cederstrand, J.R., and Becker, M.F., 1998, Digital map of specific yield for High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Open-File Report 98–414, accessed August 2011, at *http://water.usgs.gov/GIS/metadata/usgswrd/XML/ofr98-414.xml*.

Cunningham, W.L., and Schalk, C.W., comps., 2011, Groundwater technical procedures of the U.S. Geological Survey: U.S. Geological Survey Techniques and Methods 1–A1, 151 p. (Available only at *http://pubs.usgs.gov/tm/1a1/*.)

Environmental Systems Research Institute, 1992, Understanding GIS—the Arc/Info method: Redlands, Calif., Environmental Systems Research Institute, 450 p.

Environmental Systems Research Institute, variously dated, ArcDoc version 9.3: Redlands, Calif., Environmental Systems Research Institute instructions provided with software.

Gutentag, E.D., Heimes, F.J., Krothe, N.C., Luckey, R.R., and Weeks, J.B., 1984, Geohydrology of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–B, 63 p. (Also available at *http://pubs.er.usgs.gov/publication/pp1400B*.)

Hart, D.L., and McAda, D.P., 1985, Geohydrology of the High Plains aquifer in southeastern New Mexico: U.S. Geological Survey Hydrologic Atlas 679, 1 sheet, scale 1:1,000,000. (Also available at *http://pubs.usgs.gov/ha/679/plate-1.pdf*.)

Heimes, F.J., and Luckey, R.R., 1982, Method for estimating irrigation requirements from ground water in the High Plains in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Water-Resources Investigations Report 82–40, 64 p.

Houston, N.A., Garcia, C.A., and Strom, E.W., 2003, Selected hydrogeologic datasets for the Ogallala Aquifer, Texas: U.S. Geological Survey Open-File Report 2003–296, 1 CD-ROM.

Juracek, K.E., and Hansen, C.V., 1995, Digital maps of the extent, base, and 1991 potentiometric surface of the High Plains aquifer in Kansas: U.S. Geological Survey Open-File Report 95–758, accessed April 2001, at *http://www.kansasgis.org/catalog/index.cfm*.

Kansas Geological Survey, 2010, Wizard water well levels database: Kansas Geological Survey data, accessed September 2010, at *http://www.kgs.ku.edu/Magellan/WaterLevels/index.html*.

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p. (Also available at *http://pubs.usgs.gov/circ/1344/*.)

Luckey, R.R., and Becker, M.F., 1999, Hydrogeology, water use, and simulation of flow in the High Plains aquifer in northwestern Oklahoma, southeastern Colorado, southwestern Kansas, northeastern New Mexico, and northwestern Texas: U.S. Geological Survey Water-Resources Investigations Report 99–4104, 68 p. (Also available at *http://pubs.usgs.gov/wri/wri994104/pdf/wri994104.pdf*.)

Luckey, R.R., Gutentag, E.D., and Weeks, J.B., 1981, Water-level and saturated-thickness changes, predevelopment to 1980, in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–652, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.usgs.gov/ha/652/plate-1.pdf* and *http://pubs.usgs.gov/ha/652/plate-2.pdf*.)

Maupin, M.A., and Barber, N.L., 2005, Estimated withdrawals from principal aquifers in the United States, 2000: U.S. Geological Survey Circular 1279, 46 p. (Also available at *http://pubs.usgs.gov/circ/2005/1279/*.)

McGuire, V.L., 2001, Water-level changes in the High Plains aquifer, 1980 to 1999: U.S. Geological Survey Fact Sheet 029–01, 2 p. (Also available at *http://pubs.usgs.gov/fs/2001/fs-029-01/*.)

McGuire, V.L., 2003, Water-level changes in the High Plains aquifer, predevelopment to 2001, 1999 to 2000, and 2000 to 2001: U.S. Geological Survey Fact Sheet 078–03, 4 p. (Also available at *http://pubs.usgs.gov/fs/FS078-03/*.)

McGuire, V.L., 2004a, Water-level changes in the High Plains aquifer, predevelopment to 2002, 1980 to 2002, and 2001 to 2002: U.S. Geological Survey Fact Sheet 2004–3026, 6 p. (Also available at *http://pubs.usgs.gov/fs/2004/3026/*.)

McGuire, V.L., 2004b, Water-level changes in the High Plains aquifer, predevelopment to 2003 and 2002 to 2003: U.S. Geological Survey Fact Sheet 2004–3097, 6 p. (Also available at *http://pubs.usgs.gov/fs/2004/3097/*.)

McGuire, V.L., 2007, Water-level changes in the High Plains aquifer, predevelopment to 2005 and 2003 to 2005: U.S. Geological Survey Scientific Investigations Report 2006–5324, 7 p. (Also available at *http://pubs.usgs.gov/sir/2006/5324/*.)

McGuire, V.L., 2009, Water-level changes in the High Plains aquifer, predevelopment to 2007, 2005–06, and 2006–07: U.S. Geological Survey Scientific Investigations Report 2009–5019, 9 p., accessed August 2011, at *http://pubs.usgs.gov/sir/2009/5019/*.

McGuire, V.L., 2011, Water-level changes in the High Plains aquifer, predevelopment to 2009, 2007–08, and 2008–09, and change in water in storage, predevelopment to 2009: U.S. Geological Survey Scientific Investigations Report 2011–5089, 13 p., accessed August 2011, at *http://pubs.usgs.gov/sir/2011/5089/*.

McGuire, V.L., and Fischer, B.C., 1999a, Water-level changes, 1980 to 1997, and saturated thickness, 1996-97, in the High Plains aquifer: U.S. Geological Survey Fact Sheet 124–99, 4 p. (Also available at *http://ne.water.usgs.gov/ogw/hpwlms/graphics/97fs.pdf*.)

McGuire, V.L., and Fischer, B.C., 1999b, Water-level changes in High Plains aquifer, 1980-98: U.S. Geological Survey data, accessed August 2011, at *http://ne.water.usgs.gov/ogw/hpwlms/hpfs98.html.*

McGuire, V.L., Johnson, M.R., Schieffer, R.L., Stanton, J.S., Sebree, S.K., and Verstraeten, I.M., 2003, Water in storage and approaches to ground-water management, High Plains aquifer, 2000: U.S. Geological Survey Circular 1243, 51 p. (Also available at *http://pubs.usgs.gov/circ/2003/circ1243/*.)

McGuire, V.L., Stanton, C.P., and Fischer, B.C., 1997, Water-level changes in High Plains aquifer, 1980-96: U.S. Geological Survey data, accessed August 2011, at *http://ne.water.usgs.gov/ogw/hpwlms/hpfs96.html.*

McGuire, V.L., and Sharpe, J.B., 1997, Water-level changes in High Plains aquifer—Predevelopment to 1995: U.S. Geological Survey Water-Resources Investigations Report 97–4081, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.er.usgs.gov/djvu/WRI/wrir_97_4081_plt.djvu*.)

Qi, S.L., 2010, Digital map of aquifer boundary for the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Data Series 543, accessed April 2011, at *http://pubs.usgs.gov/ds/543/*.

Qi, S.L., Konduris, Alexandria, Litke, David W., and Dupree, Jean, 2002, Classification of irrigated land using satellite imagery, the High Plains aquifer, nominal date 1992: U.S. Geological Survey Water-Resources Investigations Report 02–4236, 35 p. (Also available at *http://pubs.usgs.gov/wri/wrir02-4236/pdf/wri02-4236.pdf*.)

Taylor, C.J., and Alley, W.M., 2001, Ground-water-level monitoring and the importance of long-term water-level data: U.S. Geological Survey Circular 1217, 68 p. (Also available at *http://pubs.usgs.gov/circ/circ1217/*.)

Texas Water Development Board, 2010, Groundwater database: Texas Water Development Board data, accessed December 2010, at *http://www.twdb.state.tx.us/groundwater/data/gwdbrpt.asp*.

Thelin, G.P., and Heimes, F.J., 1987, Mapping irrigated cropland from Landsat data for determination of water use from the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Professional Paper 1400–C, 38 p. (Also available at *http://pubs.usgs.gov/pp/1400c/report.pdf*.)

Thiessen, A.H., 1911, Precipitation averages for large areas: Monthly Weather Review, v. 39, p. 1,082–1,084.

U.S. Department of Agriculture, 1999, 1997 Census of agriculture, volume 1, geographic area series, part 51, United States: National Agricultural Statistics Service AC97–CD–VOL1–1B, CD–ROM.

U.S. Department of Agriculture, 2004, 2002 Census of agriculture, County level data: National Agriculture Statistics Service data, v. 1, chap. 2, accessed July 2006, at *http://www.agcensus.usda.gov/Publications/2002/index.asp*.

U.S. Geological Survey, 2008, Water use in the United States: U.S. Geological Survey groundwater-use data by county for 1985, 1990, 1995, 2000 and 2005, accessed December 2008, at *http://water.usgs.gov/watuse/.*

U.S. Geological Survey, 2011, National Water Information System: U.S. Geological Survey data, available at *http://waterdata.usgs.gov/nwis/gw*.

U.S. Geological Survey, 2012, High Plains Water-Level Monitoring Study web page, U.S. Geological Survey data, available at *http://ne.water.usgs.gov/ogw/hpwlms/data.html*.

Weeks, J.B., and Gutentag, E.D., 1981, Bedrock geology, altitude of base, and 1980 saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA–648, 2 sheets, scale 1:2,500,000. (Also available at *http://pubs.er.usgs.gov/usgspubs/ha/ha648*.)

Appendix 1

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Colorado										
Baca	08009	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.8
Bent	08011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cheyenne	08017	-3.0	-1.8	-1.8	-2.3	-0.4	-0.2	-0.2	-0.3	4.4
Elbert	08039	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kiowa	08061	-0.8	0.7	-0.3	0.0	0.0	0.0	0.0	0.0	0.1
Kit Carson	08063	-4.7	-1.6	-4.1	-3.7	-1.1	-0.4	-1.0	-0.9	12.9
Larimer	08069	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Las Animas	08071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Lincoln	08073	0.1	0.7	-0.1	-0.3	0.0	0.1	0.0	0.0	2.2
Logan	08075	1.3	1.2	-1.1	-0.5	0.1	0.1	-0.1	0.0	1.2
Phillips	08095	-6.7	-1.9	-5.4	-3.8	-0.5	-0.1	-0.4	-0.3	7.8
Prowers	08099	-0.5	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	1.0
Sedgwick	08115	-1.6	0.4	-1.8	-0.9	-0.1	0.0	-0.1	0.0	3.4
Washington	08121	-0.7	0.5	-1.3	-1.0	-0.1	0.1	-0.2	-0.2	6.0
Weld	08123	-0.4	0.1	-0.4	-0.2	0.0	0.0	0.0	0.0	0.3
Yuma	08125	-7.5	-3.6	-6.9	-4.5	-1.8	-0.9	-1.7	-1.1	32.7
Kansas										
Barber	20007	0.0	0.7	-0.4	0.0	0.0	0.0	0.0	0.0	0.6
Barton	20009	0.0	0.7	-1.6	1.8	0.0	0.0	-0.1	0.1	3.2
Cheyenne	20023	-1.2	-1.4	-2.2	-1.4	-0.1	-0.1	-0.2	-0.1	6.2
Clark	20025	-0.4	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.5
Comanche	20033	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Decatur	20039	3.3	1.0	-2.0	0.1	0.3	0.1	-0.2	0.0	3.9
Edwards	20047	-6.4	1.9	-5.0	1.1	-0.4	0.1	-0.3	0.1	6.3
Ellis	20051	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ellsworth	20053	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finney	20055	-15.6	-3.7	-12.6	-10.1	-1.5	-0.4	-1.1	-0.9	13.5
Ford	20057	-5.9	-0.2	-3.9	-3.1	-0.5	0.0	-0.4	-0.3	6.0
Gove	20063	0.0	0.4	-1.4	-0.4	0.0	0.0	-0.1	0.0	1.3
Graham	20065	0.4	0.6	-0.8	0.4	0.0	0.0	-0.1	0.0	3.0
Grant	20067	-40.1	-8.3	-8.8	-6.1	-2.0	-0.4	-0.4	-0.3	7.9
Gray	20069	-19.1	-6.9	-12.2	-11.2	-1.8	-0.7	-1.2	-1.1	9.9
Greeley	20071	-5.2	-0.9	-2.4	-1.6	-0.2	0.0	-0.1	-0.1	1.7
Hamilton	20075	-17.5	-1.6	-4.7	-3.4	-0.2	0.0	0.0	0.0	0.7
Harper	20077	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Harvey	20079	-3.6	5.3	-1.8	0.6	-0.1	0.2	-0.1	0.0	4.1
Haskell	20081	-42.1	-13.3	-13.2	-12.3	-2.3	-0.7	-0.7	-0.7	11.1
Hodgeman	20083	0.3	0.1	-0.4	0.0	0.0	0.0	0.0	0.0	0.6

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Kansas—Continued										
Jewell	20089	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	0.0	0.0
Kearny	20093	-14.0	-3.8	-10.1	-7.7	-0.7	-0.2	-0.5	-0.4	6.2
Kingman	20095	-0.2	0.6	-0.1	-0.1	0.0	0.0	0.0	0.0	3.5
Kiowa	20097	-2.8	0.5	-2.1	-0.5	-0.2	0.0	-0.2	0.0	5.6
Lane	20101	-1.8	0.5	-1.1	-1.1	-0.1	0.0	0.0	0.0	1.3
Logan	20109	-0.3	-0.2	-0.5	-0.3	0.0	0.0	0.0	0.0	0.9
McPherson	20113	0.0	1.1	-1.4	0.5	0.0	0.0	-0.1	0.0	2.2
Marion	20115	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meade	20119	-15.5	-4.6	-8.5	-7.1	-0.9	-0.3	-0.5	-0.4	15.1
Morton	20129	-5.5	-2.2	-1.8	-1.4	-0.3	-0.1	-0.1	-0.1	5.1
Ness	20135	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.1
Norton	20137	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.6
Pawnee	20145	-2.5	0.8	-2.8	2.3	-0.1	0.0	-0.1	0.1	2.2
Phillips	20147	0.0	0.1	-0.1	0.3	0.0	0.0	0.0	0.0	0.7
Pratt	20151	-1.6	2.3	-2.5	0.6	-0.2	0.2	-0.2	0.1	12.5
Rawlins	20153	1.8	-0.2	-1.2	-0.1	0.2	0.0	-0.1	0.0	6.1
Reno	20155	-0.4	1.3	-0.7	1.5	0.0	0.1	-0.1	0.2	10.8
Republic	20157	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rice	20159	0.0	1.1	-0.5	2.0	0.0	0.0	0.0	0.1	2.5
Rooks	20163	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rush	20165	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scott	20171	-4.0	-0.1	-3.0	-0.9	-0.2	0.0	-0.2	-0.1	2.4
Sedgwick	20173	-1.5	2.5	-0.8	0.2	0.0	0.1	0.0	0.0	2.5
Seward	20175	-14.0	-7.5	-8.6	-10.0	-1.0	-0.5	-0.6	-0.7	21.2
Sheridan	20179	-3.9	-0.9	-5.3	-1.9	-0.4	-0.1	-0.5	-0.2	6.0
Sherman	20181	-3.6	-3.0	-6.8	-3.3	-0.4	-0.4	-0.8	-0.4	11.8
Smith	20183	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stafford	20185	-1.6	2.1	-3.5	4.9	-0.1	0.2	-0.3	0.5	12.6
Stanton	20187	-21.8	-2.9	-8.3	-5.2	-1.0	-0.1	-0.4	-0.2	3.7
Stevens	20189	-21.6	-12.6	-12.5	-12.5	-1.6	-0.9	-0.9	-1.0	22.0
Sumner	20191	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Thomas	20193	-4.9	-1.7	-4.8	-2.2	-0.6	-0.2	-0.6	-0.3	9.4
Trego	20195	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Wallace	20199	-14.0	-5.5	-5.2	-4.5	-0.5	-0.2	-0.2	-0.2	1.9
Wichita	20203	-5.7	-1.2	-2.4	-2.3	-0.4	-0.1	-0.1	-0.1	2.2
Nebraska										
Adams	31001	1.7	1.2	-7.0	0.2	0.1	0.1	-0.5	0.0	12.5
Antelope	31003	2.9	2.0	-4.1	4.8	0.3	0.2	-0.4	0.5	31.0

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Nebraska—Continued										
Arthur	31005	0.0	0.1	-0.7	-0.2	0.0	0.0	-0.1	0.0	52.1
Banner	31007	-0.3	-0.1	-2.6	-0.3	0.0	0.0	-0.1	0.0	4.6
Blaine	31009	1.1	0.1	-0.9	0.4	0.1	0.0	-0.1	0.0	40.7
Boone	31011	3.4	0.6	-3.1	5.0	0.2	0.0	-0.2	0.3	19.7
Box Butte	31013	-5.5	-1.1	-5.5	-2.0	-0.6	-0.1	-0.6	-0.2	26.4
Boyd	31015	0.0	0.0	0.0	-0.2	0.0	0.0	0.0	0.0	0.0
Brown	31017	0.0	0.3	-2.0	0.8	0.0	0.0	-0.3	0.1	58.9
Buffalo	31019	1.3	1.5	-8.0	1.7	0.1	0.1	-0.7	0.1	23.5
Burt	31021	2.0	-0.8	-1.5	0.8	0.0	0.0	0.0	0.0	0.1
Butler	31023	3.4	-0.4	-8.5	2.6	0.1	0.0	-0.3	0.1	5.2
Cedar	31027	1.8	0.9	-0.9	0.9	0.1	0.0	0.0	0.0	2.8
Chase	31029	-6.9	-2.0	-7.7	-2.8	-0.6	-0.2	-0.6	-0.2	16.0
Cherry	31031	0.4	0.0	-0.5	-0.1	0.2	0.0	-0.3	0.0	287.2
Cheyenne	31033	0.4	0.9	-3.4	-1.2	0.0	0.1	-0.3	-0.1	13.9
Clay	31035	6.5	4.8	-8.6	0.9	0.4	0.3	-0.5	0.1	10.5
Colfax	31037	3.9	-1.2	-3.8	0.4	0.1	0.0	-0.1	0.0	3.9
Cuming	31039	6.7	-0.4	-2.4	1.1	0.3	0.0	-0.1	0.1	3.9
Custer	31041	0.6	-0.2	-3.6	-0.2	0.2	0.0	-1.0	-0.1	143.7
Dawes	31045	-0.2	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	11.4
Dawson	31047	3.1	-1.0	-4.9	1.7	0.3	-0.1	-0.5	0.2	43.3
Deuel	31049	0.3	0.5	-1.6	0.1	0.0	0.0	-0.1	0.0	4.2
Dixon	31051	2.9	-1.1	-1.2	1.8	0.0	0.0	0.0	0.0	0.1
Dodge	31053	3.0	-0.1	-2.5	1.1	0.1	0.0	-0.1	0.1	4.8
Douglas	31055	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dundy	31057	-4.5	-2.7	-7.5	-3.2	-0.4	-0.2	-0.7	-0.3	11.4
Fillmore	31059	2.6	4.4	-6.8	1.4	0.2	0.3	-0.4	0.1	12.7
Franklin	31061	0.2	0.4	-2.3	0.1	0.0	0.0	-0.2	0.0	5.5
Frontier	31063	-1.1	0.4	-2.6	2.1	-0.1	0.0	-0.3	0.2	19.4
Furnas	31065	0.4	-0.4	-1.8	0.7	0.0	0.0	-0.2	0.1	3.1
Gage	31067	1.0	1.4	-3.0	1.3	0.0	0.0	0.0	0.0	0.2
Garden	31069	-0.1	0.0	-0.7	-0.2	0.0	0.0	-0.1	0.0	54.0
Garfield	31071	3.1	1.3	-0.4	0.5	0.2	0.1	0.0	0.0	32.7
Gosper	31073	7.3	2.6	-2.8	1.6	0.3	0.1	-0.1	0.1	12.7
Grant	31075	0.2	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	80.6
Greeley	31077	6.1	1.9	-2.0	1.2	0.3	0.1	-0.1	0.1	19.5
Hall	31079	3.8	2.2	-8.1	2.9	0.2	0.1	-0.4	0.2	10.7
Hamilton	31081	11.8	4.9	-10.6	2.5	0.7	0.3	-0.6	0.1	12.7
Harlan	31083	0.4	0.9	-2.5	1.3	0.0	0.1	-0.2	0.1	4.9

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Nebraska—Continued										
Hayes	31085	-0.1	-0.3	-4.2	-0.5	0.0	0.0	-0.3	0.0	14.9
Hitchcock	31087	0.0	-0.2	-1.2	-0.3	0.0	0.0	-0.1	0.0	4.9
Holt	31089	1.6	-0.9	-2.7	2.1	0.3	-0.2	-0.6	0.4	74.4
Hooker	31091	4.9	0.6	-0.1	-1.0	0.4	0.0	0.0	-0.1	63.2
Howard	31093	3.1	-0.2	-2.9	2.3	0.1	0.0	-0.2	0.1	12.5
Jefferson	31095	0.7	1.7	-4.0	0.0	0.0	0.0	-0.1	0.0	3.5
Kearney	31099	3.8	1.8	-6.6	1.4	0.2	0.1	-0.4	0.1	14.9
Keith	31101	-0.7	0.5	-2.2	-1.5	-0.1	0.1	-0.3	-0.1	22.8
Keya Paha	31103	1.0	1.6	-2.3	0.4	0.0	0.1	-0.1	0.0	5.6
Kimball	31105	0.0	0.2	-2.3	-1.9	0.0	0.0	-0.2	-0.1	8.3
Knox	31107	2.3	0.2	-1.6	0.7	0.1	0.0	0.0	0.0	2.2
Lincoln	31111	-0.1	0.6	-2.9	-0.6	0.0	0.2	-0.7	-0.2	105.5
Logan	31113	0.9	0.4	-1.7	-0.8	0.1	0.0	-0.1	0.0	34.4
Loup	31115	0.9	0.8	-1.0	0.9	0.0	0.0	-0.1	0.0	29.7
McPherson	31117	1.4	1.5	-0.2	-0.8	0.1	0.1	0.0	-0.1	63.6
Madison	31119	5.0	0.2	-2.4	4.5	0.3	0.0	-0.1	0.3	13.1
Merrick	31121	0.5	-0.2	-5.0	3.4	0.0	0.0	-0.2	0.2	6.6
Morrill	31123	-0.2	-0.2	-1.8	-0.3	0.0	0.0	-0.2	0.0	28.4
Nance	31125	3.4	0.4	-2.8	2.3	0.1	0.0	-0.1	0.1	5.1
Nuckolls	31129	1.0	0.4	-2.0	0.4	0.1	0.0	-0.1	0.0	2.2
Perkins	31135	-7.9	0.3	-7.8	-5.0	-0.7	0.0	-0.6	-0.4	18.6
Phelps	31137	8.0	2.4	-4.6	1.9	0.5	0.1	-0.3	0.1	15.5
Pierce	31139	5.1	-0.9	-3.2	3.6	0.3	0.0	-0.2	0.2	11.1
Platte	31141	3.0	0.4	-5.4	3.3	0.2	0.0	-0.4	0.2	9.4
Polk	31143	9.6	0.2	-8.4	1.4	0.4	0.0	-0.4	0.1	9.2
Red Willow	31145	0.2	-0.2	-2.5	0.0	0.0	0.0	-0.2	0.0	4.2
Rock	31149	2.0	-0.6	-2.9	1.7	0.2	-0.1	-0.3	0.2	52.1
Saline	31151	1.3	0.9	-4.8	0.5	0.1	0.1	-0.2	0.0	6.4
Saunders	31155	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scotts Bluff	31157	0.0	-0.2	-2.9	0.8	0.0	0.0	-0.1	0.0	6.6
Seward	31159	5.2	1.1	-6.8	0.9	0.2	0.0	-0.2	0.0	7.3
Sheridan	31161	-0.5	0.7	-2.0	-0.2	-0.1	0.1	-0.4	0.0	82.9
Sherman	31163	2.9	0.3	-2.3	0.7	0.1	0.0	-0.1	0.0	20.5
Sioux	31165	0.0	-0.3	-0.5	0.2	0.0	0.0	-0.1	0.0	43.6
Stanton	31167	3.9	-0.9	-3.6	2.6	0.1	0.0	-0.1	0.1	4.5
Thayer	31169	0.9	0.3	-3.6	0.3	0.0	0.0	-0.2	0.0	6.2
Thomas	31171	1.1	0.4	-0.3	-1.4	0.1	0.0	0.0	-0.1	44.1
Thurston	31173	3.3	0.4	-0.3	0.6	0.0	0.0	0.0	0.0	0.0

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Nebraska—Continued										
Valley	31175	4.6	2.4	0.3	1.8	0.2	0.1	0.0	0.1	27.8
Washington	31177	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wayne	31179	3.5	-1.1	-2.2	2.7	0.1	0.0	-0.1	0.1	4.6
Webster	31181	1.3	0.0	-3.1	0.8	0.1	0.0	-0.2	0.1	3.9
Wheeler	31183	2.7	0.9	-1.9	3.8	0.2	0.1	-0.1	0.2	27.0
York	31185	10.5	2.4	-10.8	2.0	0.6	0.1	-0.7	0.1	15.4
New Mexico										
Chaves	35005	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.3
Curry	35009	-6.6	-2.3	-2.0	-0.4	-0.9	-0.3	-0.3	-0.1	6.3
DeBaca	35011	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eddy	35015	0.0	0.0	-1.3	0.0	0.0	0.0	0.0	0.0	0.0
Guadalupe	35019	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Harding	35021	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Lea	35025	-1.2	-1.9	-1.5	-1.9	-0.2	-0.4	-0.3	-0.4	17.2
Quay	35037	-0.1	0.2	-0.7	0.1	0.0	0.0	0.0	0.0	1.4
Roosevelt	35041	-6.4	-3.0	-2.2	-0.1	-0.8	-0.4	-0.3	0.0	3.4
Union	35059	-2.2	-1.4	-2.5	-0.8	-0.1	-0.1	-0.1	0.0	2.3
Oklahoma										
Beaver	40007	0.1	-0.2	0.0	-0.3	0.0	0.0	0.0	-0.1	21.8
Beckham	40009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cimarron	40025	-1.9	-2.2	-0.4	-0.9	-0.3	-0.3	-0.1	-0.1	9.3
Dewey	40043	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ellis	40045	1.4	2.9	1.5	0.1	0.2	0.4	0.2	0.0	13.2
Harper	40059	0.7	0.3	-0.1	-0.4	0.0	0.0	0.0	0.0	0.9
Roger Mills	40129	0.3	0.5	0.3	-0.1	0.0	0.0	0.0	0.0	1.8
Texas	40139	-8.0	-6.3	-2.5	-3.7	-1.7	-1.4	-0.5	-0.8	39.5
Woodward	40153	0.5	1.2	-0.1	-0.3	0.0	0.1	0.0	0.0	4.1
South Dakota										
Bennett	46007	0.3	2.0	-1.6	-0.4	0.0	0.1	-0.1	0.0	30.7
Gregory	46053	0.0	1.1	-0.8	0.0	0.0	0.0	0.0	0.0	0.3
Jackson	46071	0.0	0.1	-0.8	-0.2	0.0	0.0	0.0	0.0	2.5
Mellette	46095	0.3	0.9	-1.2	0.0	0.0	0.0	0.0	0.0	0.0
Shannon	46113	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	10.4
Todd	46121	0.0	0.7	-0.3	-0.6	0.0	0.1	0.0	-0.1	15.6
Tripp	46123	0.0	0.0	-0.6	0.0	0.0	0.0	0.0	0.0	1.6
Texas										
Andrews	48003	2.3	0.9	0.5	-1.3	0.3	0.1	0.0	-0.2	3.2
Armstrong	48011	-1.9	1.4	-0.2	-0.1	-0.1	0.1	0.0	0.0	3.6

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Texas—Continued										
Bailey	48017	-4.6	-4.8	-1.9	-1.5	-0.4	-0.4	-0.2	-0.1	4.6
Borden	48033	0.6	0.0	-0.3	0.2	0.0	0.0	0.0	0.0	0.1
Briscoe	48045	-3.4	-1.2	0.2	-0.1	-0.1	0.0	0.0	0.0	1.4
Carson	48065	-11.9	0.2	-1.6	-0.9	-1.1	0.0	-0.2	-0.1	14.4
Castro	48069	-23.2	-12.0	-9.3	-7.0	-2.3	-1.2	-0.9	-0.7	7.6
Cochran	48079	2.2	-3.7	-2.1	-1.6	0.2	-0.3	-0.2	-0.1	3.9
Collingsworth	48087	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Crosby	48107	-1.7	-4.6	0.0	-1.4	-0.1	-0.3	0.0	-0.1	4.8
Dallam	48111	-8.9	-8.4	-8.0	-4.4	-1.5	-1.4	-1.3	-0.8	16.4
Dawson	48115	17.6	-7.3	-3.1	-1.5	1.4	-0.6	-0.3	-0.1	4.5
Deaf Smith	48117	-7.7	-3.1	-0.4	-2.0	-1.2	-0.5	-0.1	-0.3	9.0
Dickens	48125	-3.4	-0.5	1.0	-0.2	0.0	0.0	0.0	0.0	0.1
Donley	48129	0.9	0.8	-0.9	0.0	0.1	0.1	-0.1	0.0	4.3
Ector	48135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Floyd	48153	-11.1	-5.1	-1.2	-1.5	-1.2	-0.5	-0.1	-0.2	7.7
Gaines	48165	1.5	-8.9	-6.4	-4.6	0.2	-1.3	-0.9	-0.7	6.2
Garza	48169	7.1	-1.1	-1.2	0.1	0.1	0.0	0.0	0.0	0.2
Glasscock	48173	6.9	-1.5	-0.6	1.6	0.2	0.0	0.0	0.0	0.6
Gray	48179	-3.3	1.8	0.0	0.1	-0.3	0.2	0.0	0.0	11.2
Hale	48189	-22.3	-10.8	-7.4	-5.7	-2.4	-1.1	-0.8	-0.6	6.4
Hall	48191	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hansford	48195	-16.6	-6.8	-3.6	-9.5	-1.7	-0.7	-0.4	-0.9	19.7
Hartley	48205	-9.1	-14.8	-8.6	-5.8	-1.5	-2.4	-1.4	-1.0	18.6
Hemphill	48211	0.3	0.5	-0.7	1.8	0.0	0.0	-0.1	0.2	15.7
Hockley	48219	1.2	-3.1	-2.3	-1.2	0.1	-0.3	-0.2	-0.1	3.6
Howard	48227	4.5	-5.4	0.4	0.5	0.3	-0.3	0.0	0.0	2.2
Hutchinson	48233	-7.9	-4.5	-4.1	-4.3	-0.6	-0.4	-0.3	-0.3	7.0
Lamb	48279	-16.1	-7.7	-6.0	-5.0	-1.8	-0.9	-0.7	-0.6	6.6
Lipscomb	48295	0.4	-4.1	1.7	-0.1	0.0	-0.4	0.2	0.0	22.8
Lubbock	48303	0.3	-3.3	-1.6	-0.7	0.1	-0.3	-0.1	-0.1	5.2
Lynn	48305	9.2	-3.0	-1.1	1.8	0.7	-0.3	-0.1	0.1	3.4
Martin	48317	12.0	-3.4	1.4	-2.0	1.1	-0.3	0.1	-0.2	5.9
Midland	48329	4.6	-2.8	-0.5	0.7	0.2	-0.1	0.0	0.0	1.9
Moore	48341	-15.0	-7.1	-4.4	-8.8	-1.3	-0.6	-0.4	-0.7	6.9
Motley	48345	-0.6	-0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.1
Ochiltree	48357	-10.1	-3.7	-0.2	-2.6	-1.0	-0.4	0.0	-0.2	21.1
Oldham	48359	0.7	-0.1	0.3	-1.0	0.0	0.0	0.0	-0.1	1.7
Parmer	48369	-24.8	-12.6	-8.4	-7.5	-2.6	-1.3	-0.9	-0.8	6.6

Table 1-1. Area-weighted, average water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009, and water in storage in the High Plains aquifer, 2009, by county, within State.—Continued

[FIPS, Federal Information Processing Standard; ft, feet; acre-ft, acre-feet]

County	FIPS state and county code	Area-weighted, average water-level change, in ft				Changes in water in storage, in million acre-ft				Water in storage, 2009, in million acre-ft
		1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	1980 to 1995	1995 to 2000	2000 to 2005	2005 to 2009	
Texas—Continued										
Potter	48375	-0.9	0.0	0.3	0.0	0.0	0.0	0.0	0.0	1.8
Randall	48381	-0.5	-0.5	0.4	-1.1	0.0	0.0	0.0	-0.1	4.2
Roberts	48393	-2.1	2.6	0.1	-2.4	-0.2	0.2	0.0	-0.2	22.2
Sherman	48421	-17.6	-12.1	-5.3	-9.6	-1.7	-1.2	-0.5	-0.9	15.2
Swisher	48437	-4.9	-3.2	-1.4	-1.4	-0.5	-0.3	-0.2	-0.1	4.8
Terry	48445	7.0	-8.0	-5.3	-0.3	0.5	-0.6	-0.4	0.0	3.8
Wheeler	48483	0.3	0.9	-0.4	-0.3	0.0	0.1	0.0	0.0	8.2
Yoakum	48501	3.8	-5.6	-4.9	-2.2	0.3	-0.4	-0.3	-0.1	3.2
Wyoming										
Albany	56001	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Converse	56009	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Goshen	56015	-0.1	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	24.2
Laramie	56021	-0.5	0.1	-1.4	-0.6	-0.1	0.0	-0.2	-0.1	28.0
Niobrara	56027	-0.3	0.0	-0.5	-0.5	0.0	0.0	0.0	0.0	11.5
Platte	56031	-0.1	0.2	-0.7	-0.5	0.0	0.0	-0.1	0.0	14.7

Publishing support provided by:
Rolla Publishing Service Center

For more information concerning this publication, contact:
Director, USGS Nebraska Water Science Center
5231 South 19th Street
Lincoln, Nebraska 68512
(402) 328–4100

Or visit the Nebraska Water Science Center Web site at:
http://ne.water.usgs.gov/

USGS

McGuire and others—**Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-Level Changes** —SIR 2012–5177