Nebraska Statewide Groundwater-Level Monitoring Report

2016

Aaron R. Young, Mark E. Burbach, Leslie M. Howard, Michele M. Waszgis, R. Matt Joeckel and Susan Olafsen Lackey

Conservation and Survey Division
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Nebraska Water Survey Paper Number 84

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The Conservation and Survey Division of the University of Nebraska–Lincoln is the agency designated by statute to investigate and interpret the geologically related natural resources of the State, to make available to the public the results of these investigations, and to assist in the development and conservation of these resources. It consists of program areas in geology, water, soils, and remote sensing-geographic information systems.

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Website: nebraskamaps.unl.edu

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FORWARD

Nebraska water issues of interest, 2015-2016

A forward by R. Matt Joeckel, Nebraska State Geologist and Associate Director for Conservation and Survey Division

The term "groundwater" has come to be all but synonymous with Nebraska. Nearly three-quarters of the volume of the High Plains aquifer lies beneath the State, and groundwater maintains our streams, our ecosystems, our people, and our vitally important agricultural economy. Although Nebraska's total groundwater resource is vast, it is also quite vulnerable to changes induced by natural processes and by humankind, necessitating a long-term commitment to wise management through informed decision making. Monitoring, studying, and reporting are the essential basis for such management and, ultimately, for meeting the myriad challenges presented by change.

The personnel of the Conservation and Survey Division (CSD) are pleased to support wise groundwater management through the issuance of this report, a yearly continuation of a long-running series of water-resources reports and maps published by CSD. The information provided herein should be used to inform, educate, and guide the citizens of Nebraska regarding water resources. All Nebraskans need water. Therefore, we must all partner in management as informed citizens.

Trends and Events

Annual precipitation surpluses of 8 to 16 inches (203-406 mm) occurred in eastern Nebraska in 2015 and surpluses of 4-8 inches (102-203 mm) occurred in the Panhandle; almost all of the remainder of the State registered normal precipitation to surpluses of as much as 4 inches (102 mm). Drought was a minor issue for but a few weeks in March-July and November 2015. In contrast to the previous year, 2016 saw annual precipitation deficits of nearly 4 inches (102 mm) in areas of southern Nebraska. Significant precipitation deficits also occurred in parts of the Panhandle and southwestern Nebraska. Precipitation surpluses of nearly 4 inches (102 mm), however, were registered in north central Nebraska. Drought remained a minor issue overall in Nebraska until June 21, 2016, after which drought was reported continuously, attaining a maximum of 13.43% of the state, mainly in the central and southwestern areas, at the end of the year.

A particularly large ice jam developed on the Platte River in January 2015, which despite concerns and a preliminary plans for the use of explosives, broke up under warming weather (Bergin, 2015). During May 2015, high flow stages and localized flooding occurred on the North Platte River above Lake McConaughy, and on the South Platte River as far downstream as North Platte, Nebraska resulting from upstream snowmelt and spring rainfall. Major flooding occurred on the Little Blue River in Thayer and Jefferson counties during May 2015 and additional high-stage flow events occurred in the following month (Joeckel et al., 2016). High-stage flows also occurred on the North Platte River in the Scottsbluff area during May 2016, cresting just below major flood stage on the 29th of that month (national Weather Service, undated).

Water Quality

UNL researchers published a major compilation and analysis of the linkage between groundwater nitrate and uranium contamination of US aquifers, calculating high ($r \geq 0.75$) spatial correlations between uranium and nitrate concentrations for data from the North Platte, South Platte, and Platte River Valleys, parts of northeastern Nebraska, and parts of other states that overlie the High Plains aquifer (Nolan and Weber, 2015).

Management, Regulation, and Litigation

In February 2015 the U.S. Supreme Court handed down a decision on Kansas v. Nebraska et al. assessing the State of Nebraska a $5.5 million payment for the overuse of irrigation water on the Republican River, a much smaller figure than had originally been requested by the State of Kansas. President Barack Obama vetoed a bill approving construction of the Keystone XL Pipeline extension across Nebraska in February 2015, and TransCanada asked for a suspension of its permit application in November of the same year. Concerns about the pipeline's potential impacts on surface water and groundwater in Nebraska had been voiced for several years prior to these outcomes. The Clean Water Rule: Definition of "Waters of the United States" (2015), which is intended to protect streams and wetlands, was published by the Environmental Protection Agency and the U.S. Army Corps of Engineers in June 2015 and it went into effect in the following August (The Federal Register, 2015).

The Nebraska Public Power District, Niobrara River Basin Alliance, and the Nebraska Game and Parks Commission (NGPC) negotiated the Niobrara River Memorandum of Understanding, which transfers Spencer Dam and associated surface-water rights to the constituent Natural Resources Districts and to NGPC, in 2015 (Anonymous, undated). Legislative Bill 1038, which allows such a transfer of water rights by amending the Revised Statutes of Nebraska, was approved by the Governor in 2016 (Nebraska Legislature, undated—a).

Central Nebraska Public Power and Irrigation District initiated its E67 Telemetry Project, a precision, remote monitoring of surface-water withdrawals from the E67 Pipeline Canal, and increased the total number of measurement sites to 51 (Central Nebraska Public Power and Irrigation District, 2016).

The Atomic Safety and Licensing Board (ASLB) held a hearing for the renewal of the operational license of Cameco Corporation's Crow Butte Mine near Crawford during late August 2015 (Rempp, 2015), at which concerns about both surface water and groundwater were raised. Near the end of 2016, the second of two partial rulings by the ASLB concluded that mining operations in Nebraska were not responsible for elevated uranium levels in waters on the Pine Ridge Indian Reservation in South Dakota. Nevertheless, the ruling also indicated that the Nuclear Regulatory Commission had not meet requirements in assessing the future impacts of the potential onsite surface application of wastewater from the mining operation, citing the impacts that wastewater selenium could have on wildlife (Rempp, 2016).

In 2015, the Nebraska Oil and Gas Conservation Commission (NOGCC) granted permission for a Colorado company to dispose of hydraulic-fracturing wastewater through an abandoned oil well in Sioux County into deep bedrock strata. Landowners in the area appealed the decision in the Cheyenne County District Court in 2016, resulting in a ruling stating that the NOGCC had exceeded its authority (North, 2016a, b). In parallel, Legislative Bill 1082, which changes and amends sections of prior statutes regarding the powers and duties of the NOGCC relative to injection well operations, was passed by the Nebraska Legislature and approved by the Governor in March 2016 (Nebraska Legislature, undated—b). Legislative Bill 1070, which also pertained to the NOGCC was introduced but indefinitely postponed during 2016 (Nebraska Legislature, undated—c).

The approval of plans for a major wholesale poultry operation in Fremont raised concerns about water use, wastewater discharge, and the potential contamination of surface waters by nitrates, phosphates, and pathogens; a lawsuit was filed in July 2016 by Nebraska Communities United over actions taken by that city (Associated Press, 2016).

Note: A synopsis of precipitation data was provided by Al Dutcher, Associate State Climatologist, Nebraska State Climate Office, School of Natural Resources, UN-L and a synopsis of drought was provided by Brian Fuchs of the National Drought Mitigation Center.

INTRODUCTION

Groundwater-level information is valuable to citizens and stakeholders for understanding water resource availability and making informed management decisions.

This report is a statewide synthesis of groundwater-level monitoring programs in Nebraska. It is a continuation of the series of annual reports and maps produced by the CSD of the University of Nebraska in cooperation with the U.S. Geological Survey (USGS) since the 1950's. Groundwater-level monitoring began in Nebraska in 1930 in an effort to survey the State's groundwater resources and observe changes in its availability on a continuing basis. The CSD and USGS cooperatively developed, maintained, and operated an observation well network throughout the State. These two agencies were responsible for collecting, storing, and making this information available to the citizens.

Although CSD and USGS still occupy a central role in the statewide groundwater-level monitoring program, other agencies have assumed the responsibilities of building and maintaining observation networks and measuring water levels. The CSD and USGS continue to operate some of the original observation wells, but today the majority of measurements are made by agencies such as the Natural Resources Districts (Fig.1), U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, and Public Power and Irrigation Districts. Because these agencies are located throughout the State, they are able to implement groundwater-level monitoring programs using local field staff, landowner contacts, taxing and regulatory authority, and first-hand knowledge of local conditions. Collectively, these agencies have developed an extensive network of observation wells throughout the State.

The CSD plays a vital role in providing technical expertise to these agencies as they develop and implement groundwater-level monitoring plans. The CSD evaluates the adequacy and accuracy of the water-level data and provides the statewide assessment of groundwater-level changes across many of the State's aquifers (Figs. 2-3).

The CSD has long provided technical services to stakeholders by integrating groundwater-level change data with multiple data sets in order to:

1) Determine the amount of groundwater in storage and its availability for use.
2) Assess the water-supply outlook by determining changes in the volume of groundwater in storage.
3) Identify areas in which changes in groundwater levels may have an economic impact.
4) Assist state and local agencies in the formulation and administration of resource-management programs.
5) Determine or estimate the rate and direction of groundwater movement, specific yield of aquifers, base flow of streams, sources and amounts of groundwater recharge, and locations and amounts of groundwater discharge.
6) Assess the validity of hydrogeologic interpretations and the assumptions used in developing models of groundwater systems.

The need for this information has increased tremendously over the past few years, yet the resources available for fulfilling this need have decreased. The CSD strives to meet this challenge by focusing on fundamental data, building collaborative relationships with the agencies that depend on the information, and providing scientifically accurate information in a timely manner.

Introduction continued on page 7

Figure 1. Nebraska Natural Resources Districts

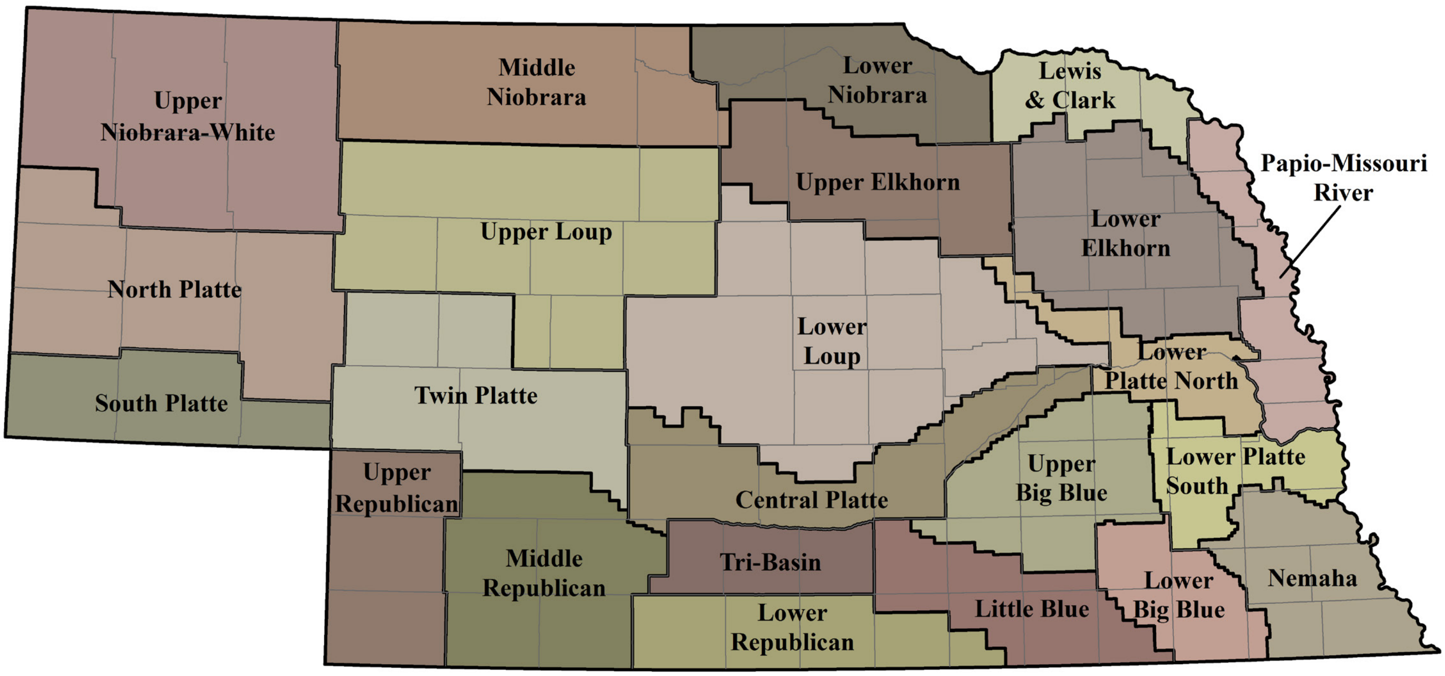
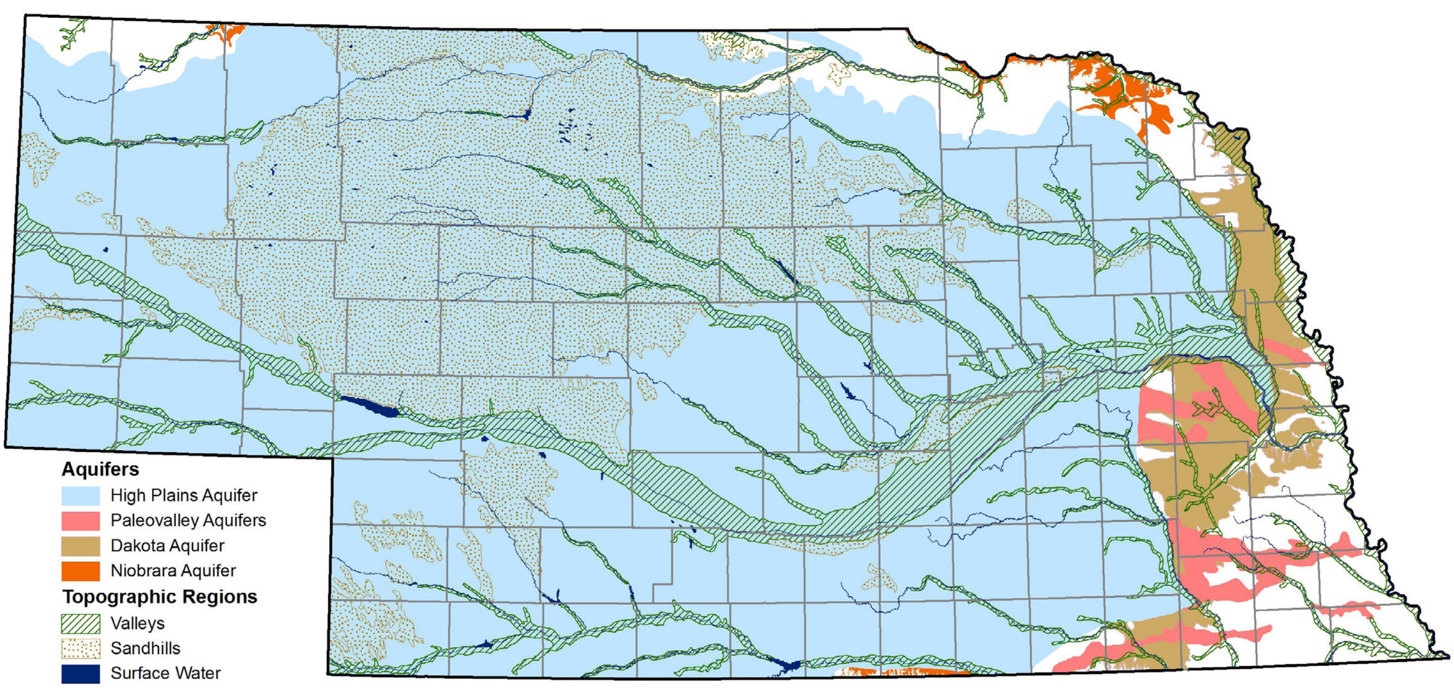


Figure 2. Important Aquifers and Topographic Regions of Nebraska



Note: In some areas, the aquifer units shown here may contain little or no saturated thickness.

Figure 3. Generalized Geologic and Hydrostratigraphic Framework of Nebraska

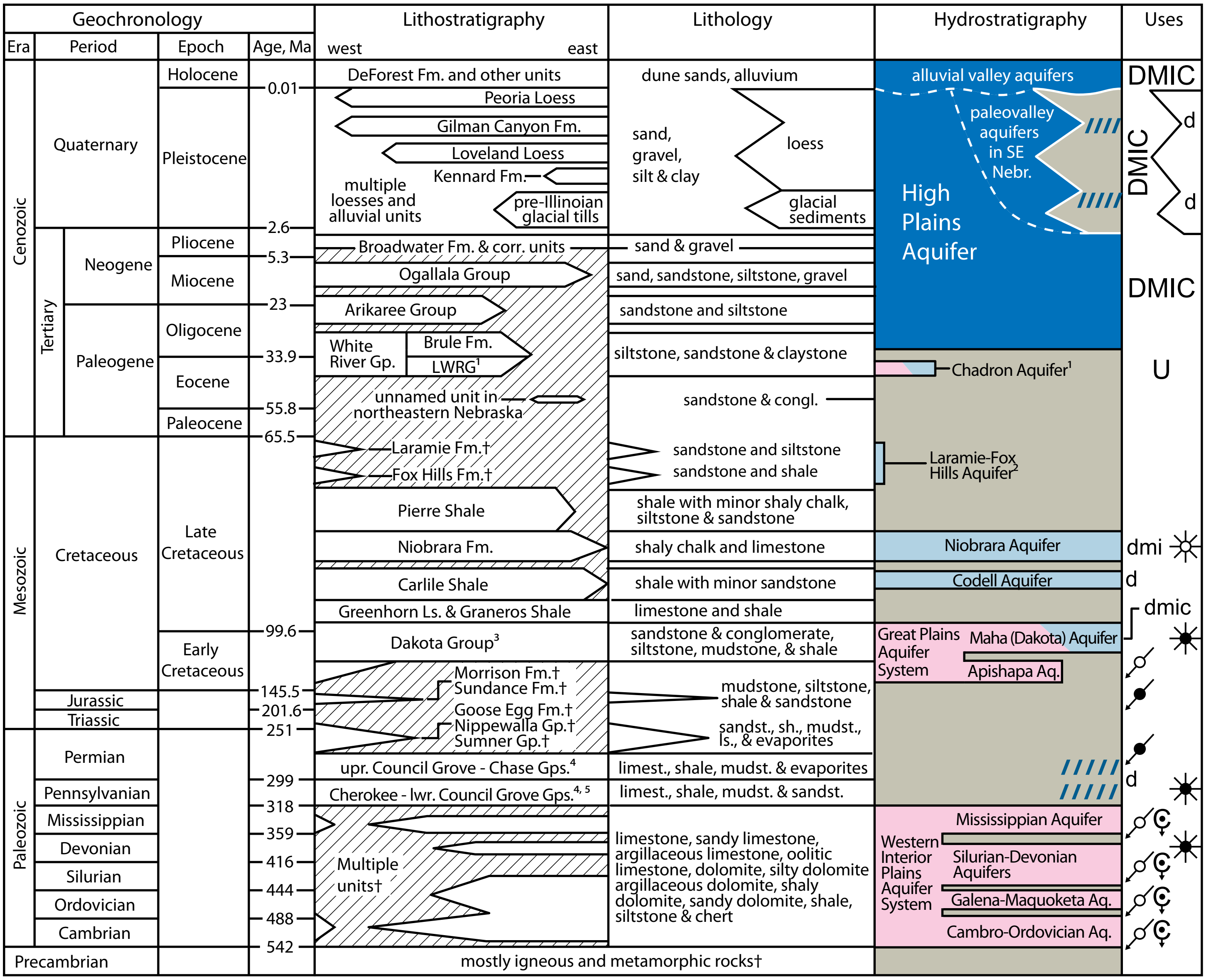


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

Hydrostratigraphic characteristics and water quality

- primary aquifers with good quality water
- secondary aquifers with good quality water
- secondary aquifers with generally poor quality water
- //// aquitards with local low-yield aquifers
- aquitards

[1] lower White River Group - includes Chamberlain Pass and Chadron Formations according to some authors; "Chadron Aquifer" historically refers to aquifer in lower White River Group

[2] important aquifer in Colorado, but present in Nebraska only in extreme southwestern Panhandle

[3] Dakota Formation in adjacent states

[4] includes correlative units with different names in northwest Nebraska

[5] Cherokee, Marmaton & Pleasanton Groups are not exposed in Nebraska

†present only in subsurface

Groundwater uses and related aspects

D	major domestic use	I	major irrigation use
d	minor domestic use	i	minor irrigation use
M	major municipal use	C	major commercial/industrial use
m	minor municipal use	c	minor commercial/industrial use

- units used for wastewater injection
- units with potential use for wastewater injection
- U unit mined for uranium by in-situ leaching (Dawes Co.)
- unit with potential use for carbon sequestration
- unit producing petroleum or natural gas
- unit with natural gas potential

From Korus and Joeckel, 2011

Purpose and Methods

This report summarizes changes in Nebraska's groundwater levels over periods of 1, 5, and 10 years prior to 2016, as well as from 1981 to 2016, predevelopment to 1981 and predevelopment to 2016. Nineteen eighty-one was selected as a fixed year, as groundwater-level declines in many parts of the state reached a maximum in 1981. These changes are depicted in maps that delineate regional trends on a statewide basis. Although localized conditions may vary considerably, the maps presented in this report provide an overview of the general locations, magnitudes, and extents of rises and declines. The reader should use figures 1 – 4 to locate NRDs, rivers, aquifers, and counties mentioned in the text.

The 1-, 5-, and 10-year changes are presented in the spring 2015 to spring 2016, spring 2011 to spring 2016, and spring 2006 to spring 2016 maps, respectively. Groundwater levels measured from thousands of wells throughout the State in spring 2016 (Fig. 5) were compared to levels measured in the same wells in the spring of the earlier year. For the 1-, 5-, and 10-year change maps, contours were generated using computer interpolation. These contours were incorporated into the final maps in areas where the principal aquifer is continuous, is in relatively good hydraulic connection over large areas, and where data density is relatively high. In areas not meeting the above conditions, the computer-generated contours were manually edited on maps at a scale of 1:500,000 in order to conform to hydrogeologic boundaries that prevent the flow of groundwater. Such boundaries include 1) areas where relatively impermeable bedrock units outcrop or exist in the shallow subsurface, such as southeastern Nebraska and in areas of Scotts Bluff County, 2) valley boundaries in eastern Nebraska where alluvial aquifers are a major source of groundwater but upland areas between them lack a primary aquifer, and 3) areas where the High Plains Aquifer is separated by deeply entrenched parts of the Niobrara, Republican, and Platte River valleys. For the spring 1981 to spring 2016 map, computer interpolation was impractical because data was sparse in many areas. Contours were therefore drawn manually with knowledge of the major hydrogeologic boundaries listed above.

For the predevelopment to spring 2016 and predevelopment to spring 1981 maps, water levels from wells measured in 2016 and 1981 were compared to estimated predevelopment water levels in the same wells. An estimated predevelopment water level is the approximate average water level at a well site prior to any development that significantly affects water levels. Predevelopment water levels for most of the State are the estimated water levels that generally occurred before the 1930s, 1940s, or early to mid-1950s. These dates, which vary throughout Nebraska, generally depend on the beginning dates of intensive use of groundwater for irrigation. Typically all available water-level data collected prior to or during the early stages of groundwater development are used to estimate predevelopment water levels. Contours were drawn manually with the aid of previously existing maps for similar time periods and with knowledge of major hydrogeologic boundaries.

Areas of sparse data are shown with a hatched pattern on all maps. A computer point density interpolation was used to determine the number of observation points within a 6 mile (10 kilometer) search radius. Areas of sparse data were defined as areas with zero observation points within the search radius.

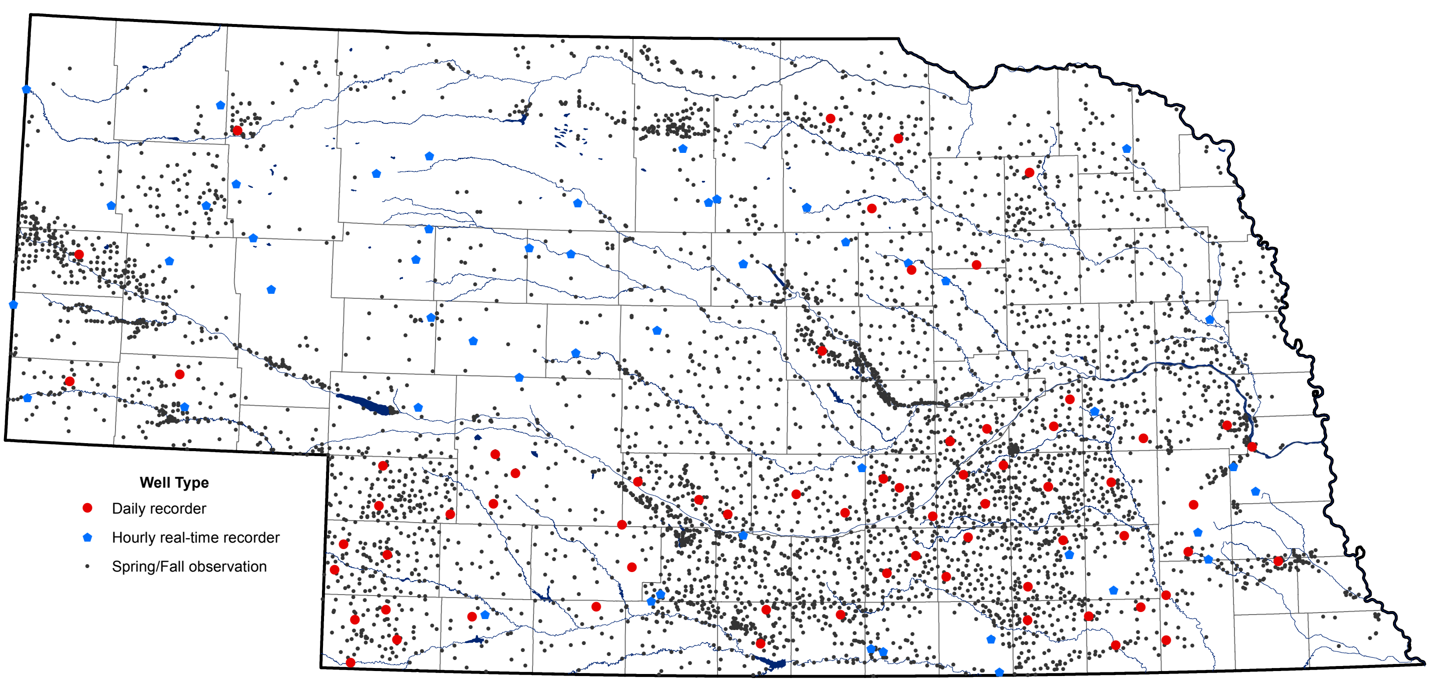
Precipitation maps were prepared by comparing total precipitation over the time period of interest to the 30-year normal provided by the National Climate Data Center. The 30-year normal currently in use is based on average annual precipitation from 1981 to 2010. A precipitation surface is generated using the inverse distance weighted interpolation method in ArcGIS with a 500 meter cell size. The resulting surface is classified with a defined interval of ten percent and contoured. The resulting contours are smoothed and then converted to polygons.

Factors Causing Groundwater-Level Changes

Long-term groundwater-level changes are a reflection of the changing balance between recharge to, discharge from, and storage in an aquifer. If recharge and discharge are in balance, such as they were before widespread irrigation development, groundwater levels are generally steady because the amount of water stored in the aquifer does not change. Minor changes in groundwater levels may occur due to natural variations in precipitation and streamflow, but generally the system is in equilibrium. If, however, the rate of recharge exceeds the rate of discharge over a long period, the amount of water stored in the aquifer increases and groundwater levels rise. Conversely, if the rate of discharge exceeds the rate of recharge for a long period, the amount of water in storage is depleted and groundwater levels decline. The magnitudes, locations, and rates of groundwater-level changes are controlled by many factors, including: the aquifer's storage properties, permeability, and saturated thickness; the locations, rates, and pumping schedules of wells; the locations and rates

Figure 4. Counties, Major Cities, and Streams of Nebraska

Figure 5. Location of Observation Wells by Type



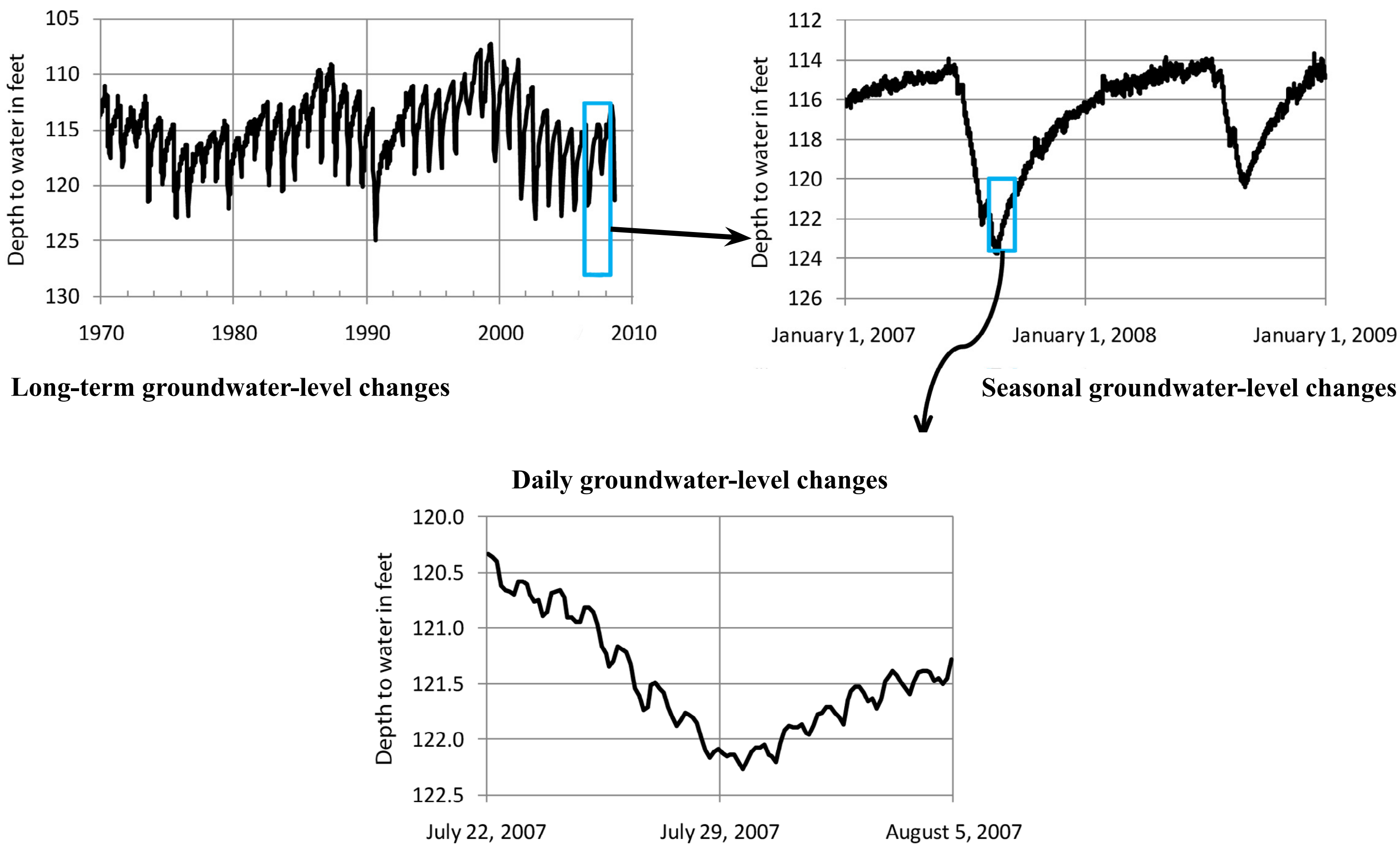
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln of artificial recharge areas; and the degree of hydraulic connection between the aquifer and surface water bodies.

It is a common misconception that the rate of recharge from precipitation can be used as a "safe yield" or "sustainable limit" on the rate of groundwater extraction from an aquifer (Bredehoeft, 1997). This idea is too simplistic. The aquifer properties and all sources of recharge and discharge must be taken into consideration. Recharge is provided primarily by precipitation, but also by irrigation return flow and seepage from canals, reservoirs, and streams. Discharge occurs as baseflow to streams and lakes, evapotranspiration, and groundwater pumping. Groundwater levels, therefore, respond to a variety of natural and anthropogenic factors affecting recharge and discharge and are controlled largely by the physical properties of the aquifer. Limiting groundwater extraction to a rate equal to or less than the rate of recharge from precipitation will not prevent depletion of the aquifer. In fact, groundwater "mining" is prone to occur to one degree or another in any heavily pumped aquifer. A holistic, adaptive approach to groundwater management based on hydrologic mass balance is more appropriate. These strategies are discussed by several authors (e.g. Sophocleous, 1997, 2000; Alley and Leake, 2004; Maimone, 2004; Korus and Burbach, 2009a).

Groundwater-level changes can be observed at many different temporal scales (Fig. 6). Changes may occur over several minutes or hours in response to pumping, floods, or earthquakes. Long-term changes may occur due to the cumulative effects of pumping over many irrigation seasons, prolonged droughts or periods of high rainfall, or seepage from man-made water bodies. Similarly, groundwater levels can be observed at multiple spatial scales. For example, groundwater levels decline around the immediate vicinity of an individual well during pumping, but also from the cumulative effects of many irrigation wells pumped over many irrigation seasons at the scale of an entire regional aquifer. Groundwater levels rise along the banks of a stream during a flood, but may also rise significantly over an entire drainage basin during a prolonged wet period. The temporal and spatial scales of observation must be taken into account when using the maps presented in this report.

The maps presented in this report were generally created at a scale of 1:500,000. They are intended to identify regional trends at medium and long-term time scales throughout the entire state of Nebraska. As such, these changes chiefly reflect the interplay between precipitation, groundwater pumping, and artificial recharge from reservoirs and canals.

Figure 6. Example of Groundwater-Level Changes at Different Temporal Scales



Based on data from Plymouth Recorder well, Jefferson County

CHANGES IN GROUNDWATER LEVELS, SPRING 2015 TO SPRING 2016

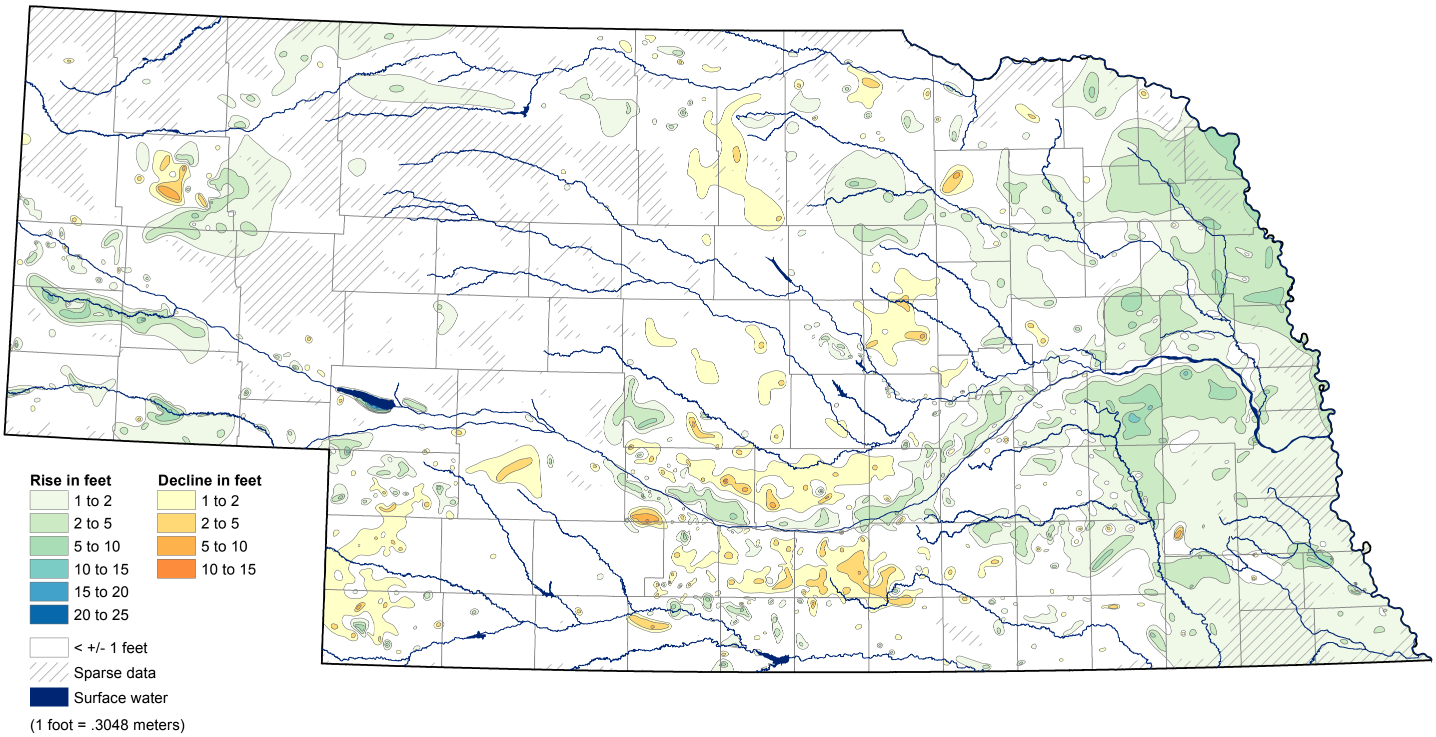
Following a year of above average precipitation, water levels in Nebraska rose an average of 0.69 feet statewide.

In the spring of 2016, a total of 4,993 monitoring wells were measured throughout the state of Nebraska (Fig. 5). Of those wells, 35% recorded groundwater-level declines compared to the spring of 2015, with 12% experiencing a decline of greater than one foot (Fig. 7). Groundwater-level rises were recorded in 64% of wells measured, with 32% of wells recording a rise greater than one foot. Approximately 1% of wells had neither rises nor declines from the spring of 2015 to the spring of 2016. On average, water levels in wells throughout Nebraska rose by 0.69 feet. Precipitation totals varied throughout the state during 2015, with values ranging from as little as 80% to as much as 170% of the 30-year average (Fig. 8). With the exception of localized areas in Central Nebraska, most of Nebraska received near average too much above average precipitation from January 2015-January 2016.

Areas of above and below average precipitation correspond well to groundwater-level changes from the spring of 2015 to spring of 2016. Areas with much above average precipitation receive more water for recharge, and more importantly require less groundwater for irrigation, thus usually resulting in a modest regional groundwater-level rise. The inverse is also true for areas of below average precipitation. Between spring 2015 and spring 2016 groundwater-level changes generally followed this model. Most rises were associated with much above average precipitation in the Panhandle and Eastern Nebraska. Notable rises took place in these regions with rises up to 15 feet, and much of the eastern one third of Nebraska experiencing rises of at least one foot. Other more localized rises in central Nebraska are the result of above average precipitation during the growing season and above average flows on the Platte River. Wells in Southern Dundy County used as part of the Rock Creek Republican River Augmentation project were not actively being pumped when spring water levels were taken as they were in 2015. As a result, water levels have recovered from a pumping level, and show an increase of 5-10 feet from 2015 pumping levels.

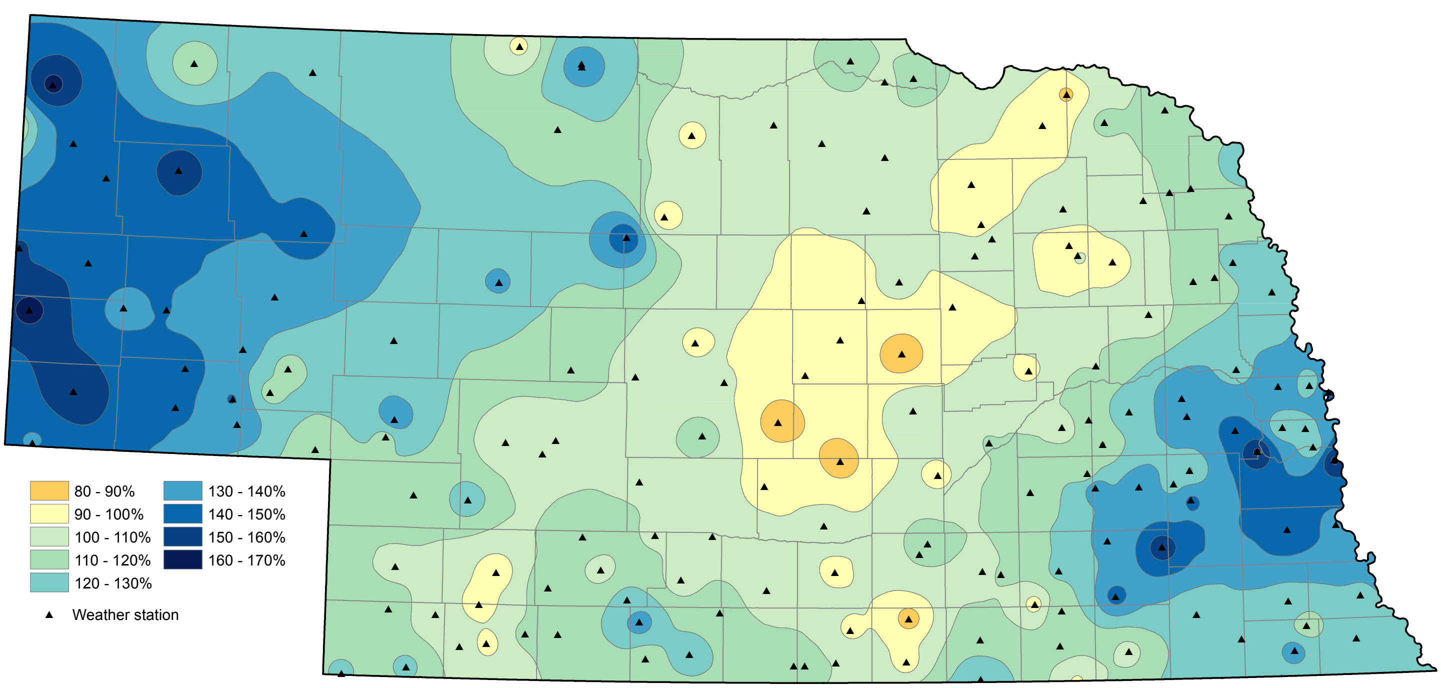
Groundwater-level declines of one to ten feet occurred locally throughout central Nebraska and Box Butte County. Declines were generally associated with areas of near or below average precipitation. Despite above average precipitation in Box Butte County, groundwater levels continue to decline due to irrigation pumping.

Figure 7. Groundwater-Level Changes in Nebraska - Spring 2015 to Spring 2016



Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln

Figure 8. Percent of Normal Precipitation - January 2015 to January 2016



Sources: National Climate Data Center, Asheville, North Carolina; High Plains Regional Climate Center, University of Nebraska–Lincoln

CHANGES IN GROUNDWATER LEVELS, SPRING 2011 TO SPRING 2016

Groundwater level changes from 2011-2016 generally illustrate persisting drawdowns following the drought of 2012.

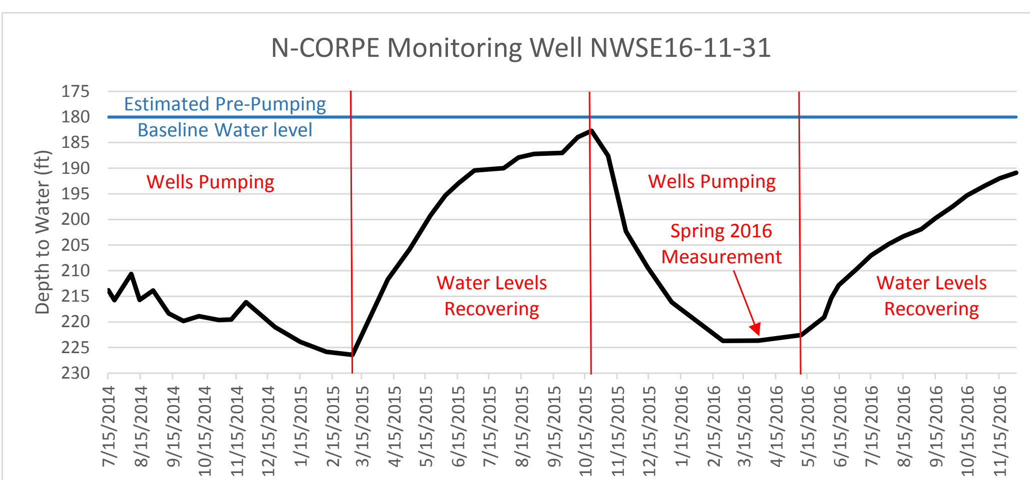
The five-year groundwater-level change map was developed based on 4,411 wells which were measured in 2011 and 2016. Of these wells, 73% recorded declines, 57% of all wells recorded declines of greater than one foot. Approximately 0.5% of wells recorded no change from spring 2011 to spring 2016. Over this five-year period, groundwater-levels declined on average 1.80 feet throughout Nebraska. Significant groundwater declines occurred throughout most of Nebraska during this five-year period (Fig. 10). Most of the eastern two thirds of Nebraska recorded groundwater-level declines from 1-10 feet, with declines greater than 15 feet locally. Generally, areas of decline in eastern Nebraska had total precipitation percentages from 70-100% of the 30-year average for the five-year period 2011-2016. Most groundwater-level declines were the result of heavy irrigation pumping and extreme drought conditions during the 2012 and early 2013 growing season.

Of the 4,411 wells measured, 27% of wells recorded water-level rises, while 14% of all wells recorded rises of greater than one foot from spring 2011 to spring 2016. The Panhandle and northwestern portion of the Sand Hills received higher than average precipitation, particularly in 2015. Modest groundwater level rises were recorded through much of these regions, with the exception of Box Butte County, where water levels continue to decline at a rate of approximately one foot per year.

The five-year period between spring 2011 and spring 2016 had swings in precipitation from years with record low precipitation, to years with much above average precipitation. Total precipitation for the five-year period was near the 30-year average for much of Nebraska (Fig. 11). Water levels were at a relative high level through much of Nebraska following record wet years from 2009-2011 (cf. Korus et. al. 2012, pg. 14, 15). Beginning with the record setting drought of 2012, reduced recharge to aquifers, combined with the much greater demand for irrigation water in 2012 and 2013 buffered many of the groundwater-level rises recorded in previous years. Although many of the declines resulting from 2012 still persist in central Nebraska, recent years with much above average rainfall have allowed water levels to return to or exceed pre-drought levels in the southern half of the Panhandle, and in eastern Nebraska in portions of Butler, Lancaster, Saunders, Dodge and Burt Counties.

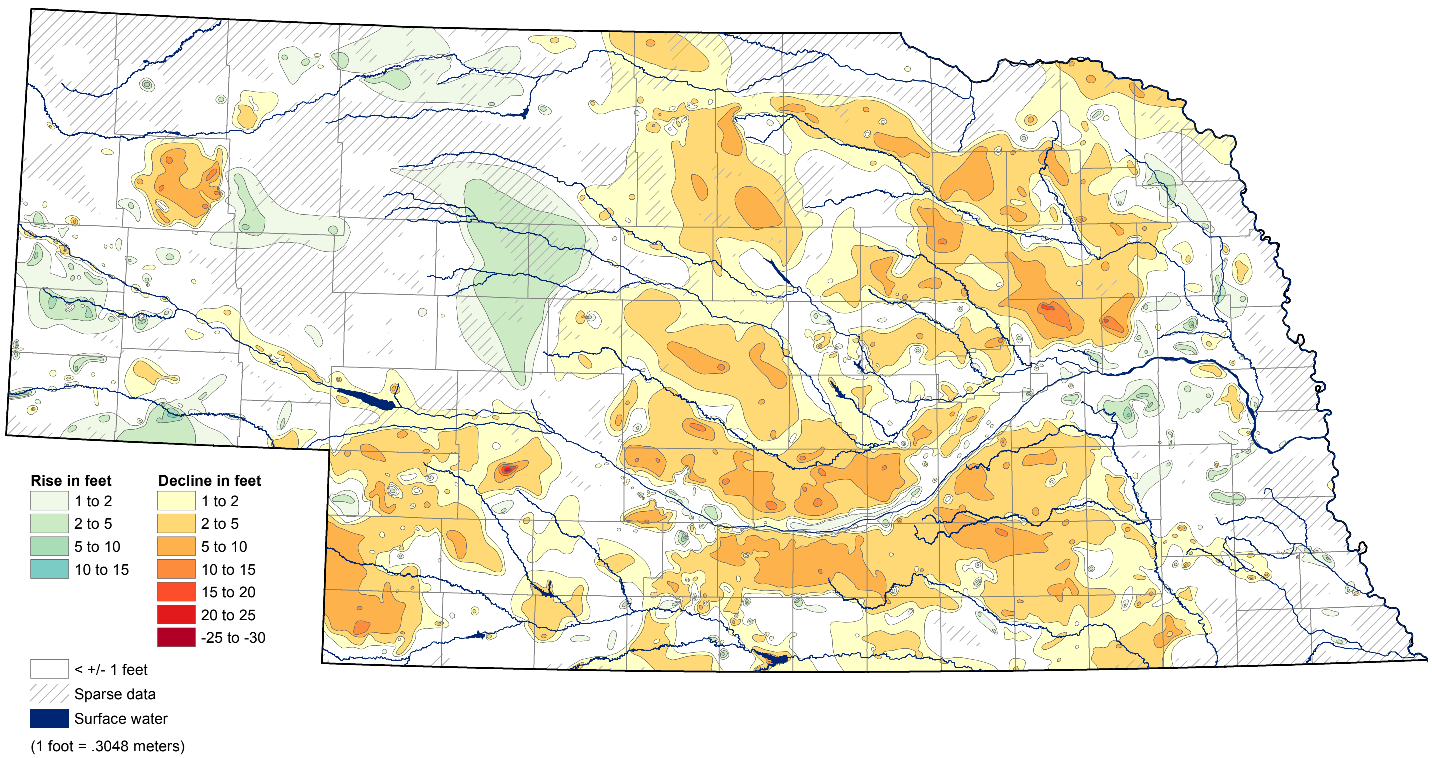
Declines in south central Lincoln County of 25-30 feet resulted from pumping associated with Republican River augmentation project, also known as the N-CORPE Project. Wells in this area were pumped from April 2014 through February 2015 (Fig. 9). Pumping resumed in November 2015, and continued until May of 2016. Spring 2016 measurements were taken while nearby wells were pumping continuously for approximately six months. Therefore, the declines associated with these wells are pumping levels, and show exaggerated declines. When pumps are turned off, water levels will recover to a static level such as what was measured in the fall of 2015. The net groundwater level decline for this area is the difference between the baseline pre-pumping measurement value, and the recovered water level post pumping. Actual net water-level declines in this area as of the fall of 2015, following the recovery of water levels in the well is approximately 3 feet.

Figure 9. Hydrograph from an Observation Well in the N-CORPE Well Field, Lincoln County, Nebraska



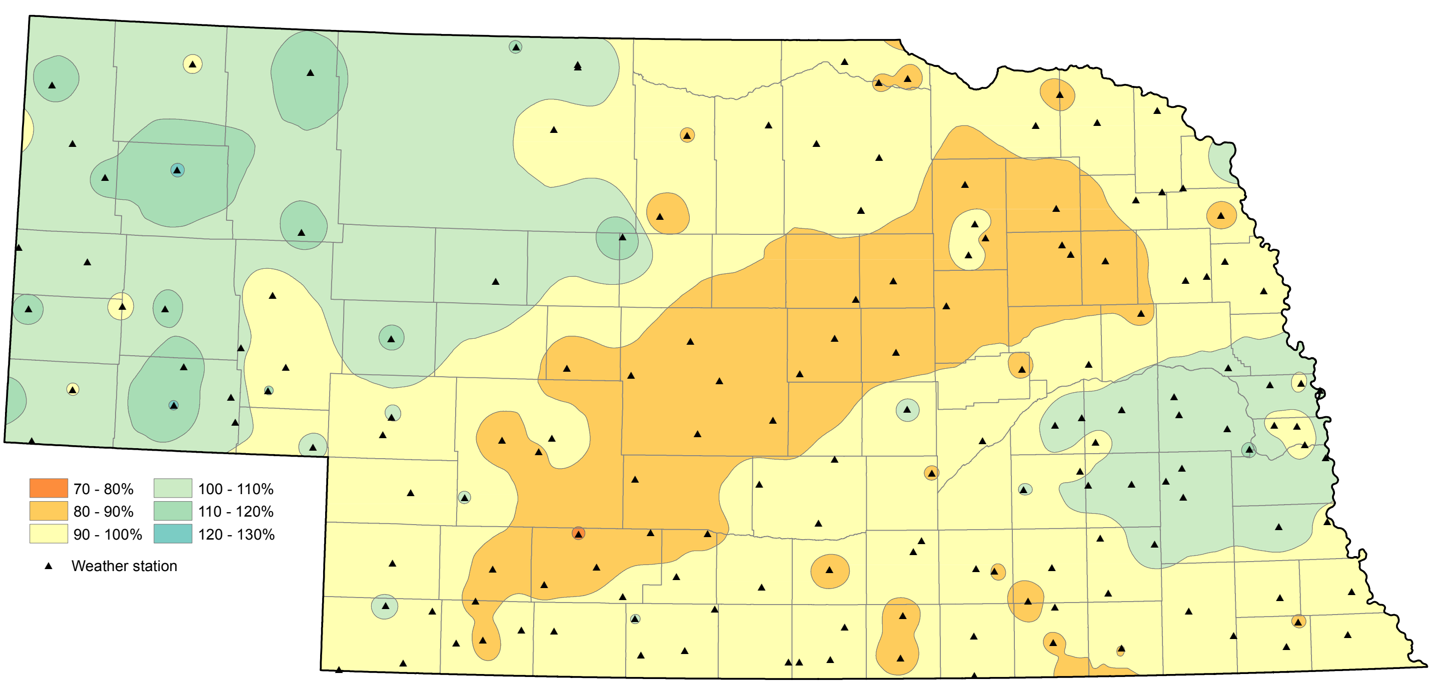
Sources: Twin Platte NRD; Olsson Associates, Lincoln, Nebraska

Figure 10. Groundwater-Level Changes in Nebraska - Spring 2011 to Spring 2016



Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District

Figure 11. Percent of Normal Precipitation - January 2011 to January 2016



Sources: National Climate Data Center, Asheville, North Carolina; High Plains Regional Climate Center, University of Nebraska–Lincoln

CHANGES IN GROUNDWATER LEVELS, SPRING 2006 TO SPRING 2016

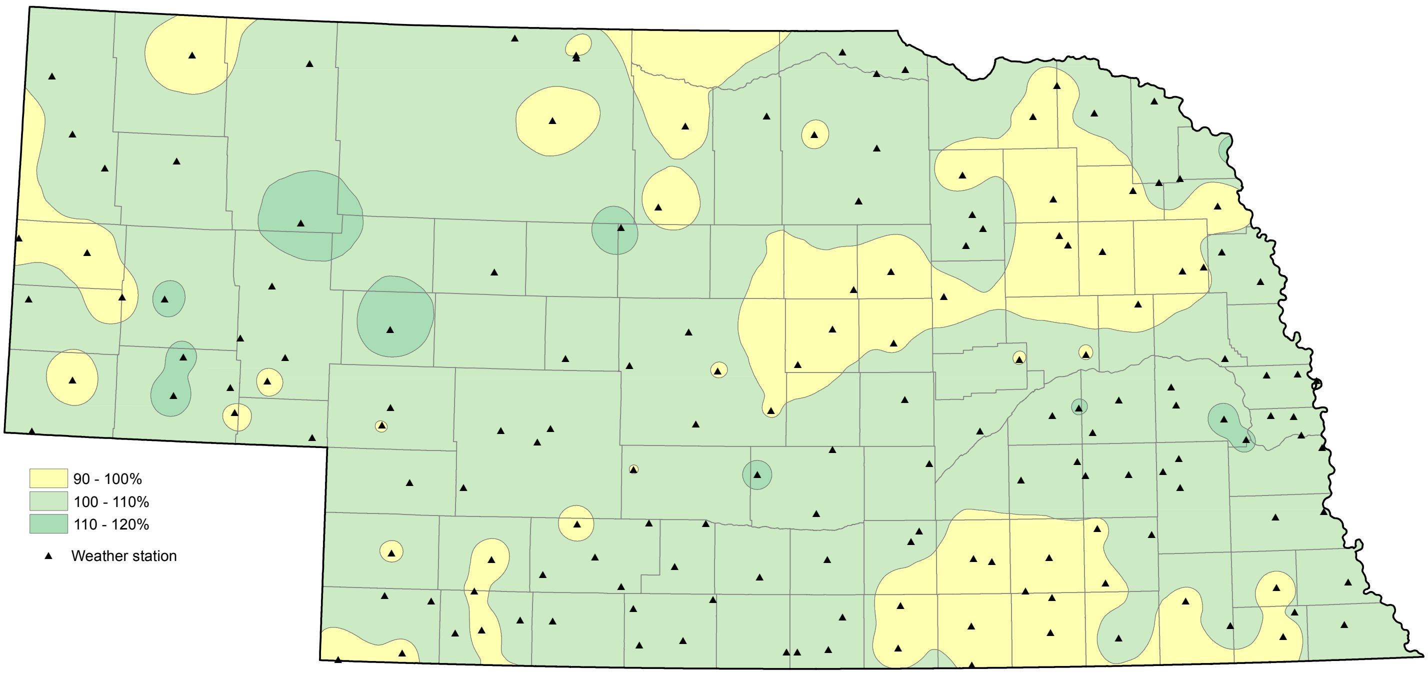
Despite major swings in climate conditions and record setting drought, modest groundwater level rises were recorded throughout much of Nebraska.

Climate conditions from the spring of 2006 to the spring of 2016 varied from record setting drought, to periods of much above average precipitation. Much of the Midwest, and all of Nebraska were in a period of drought from 2000 to about 2007. During this time, groundwater-level declines were recorded throughout the state of Nebraska (Burbach, 2007). Precipitation returned to above-normal levels for the years between 2007 and early 2012, causing groundwater levels to return to pre-drought levels in much of eastern and central Nebraska. However, spring of 2012 through the spring of 2013 was the driest year on record for the state of Nebraska, resulting in groundwater-level declines which eliminated many of the groundwater-level rises associated with the wet years between 2007 and early 2012. For most of Nebraska, precipitation values returned to near the long-term averages in late 2013 and 2014. The Panhandle and eastern Nebraska experienced much above average precipitation from 2015-2016. Due to swings in climate conditions, the average precipitation for the 10-year period from 2005 to 2015 was near the 30-year normal for most of the state despite persistent drought conditions in 2012 and early 2013 (Fig. 12).

Much of Nebraska recorded modest groundwater-level rises from the spring of 2006-spring 2016 (Fig. 13). Of 4,338 wells measured consecutively in the spring of 2006 and spring of 2016, 62% recorded groundwater-level rises, with 46% rising more than one foot. Despite the extreme drought conditions experienced during 2012, groundwater levels continue to rise from the relative low water levels experienced in the drought from 2000-2007. Water levels rose in many other localized areas of Nebraska due to a variety of factors. Increased flows in rivers, streams, and canals for a number of consecutive years resulted in rising groundwater-levels mainly along the Platte River and some of its tributaries. Higher water levels in numerous reservoirs in Nebraska resulted in water level rises of more than 10 feet in localized areas surrounding the reservoirs. Near to above-average precipitation for most of the Nebraska between 2013 and 2015 reduced the need for irrigation pumping and increased recharge to aquifers, leading to groundwater-level rises for much of Nebraska.

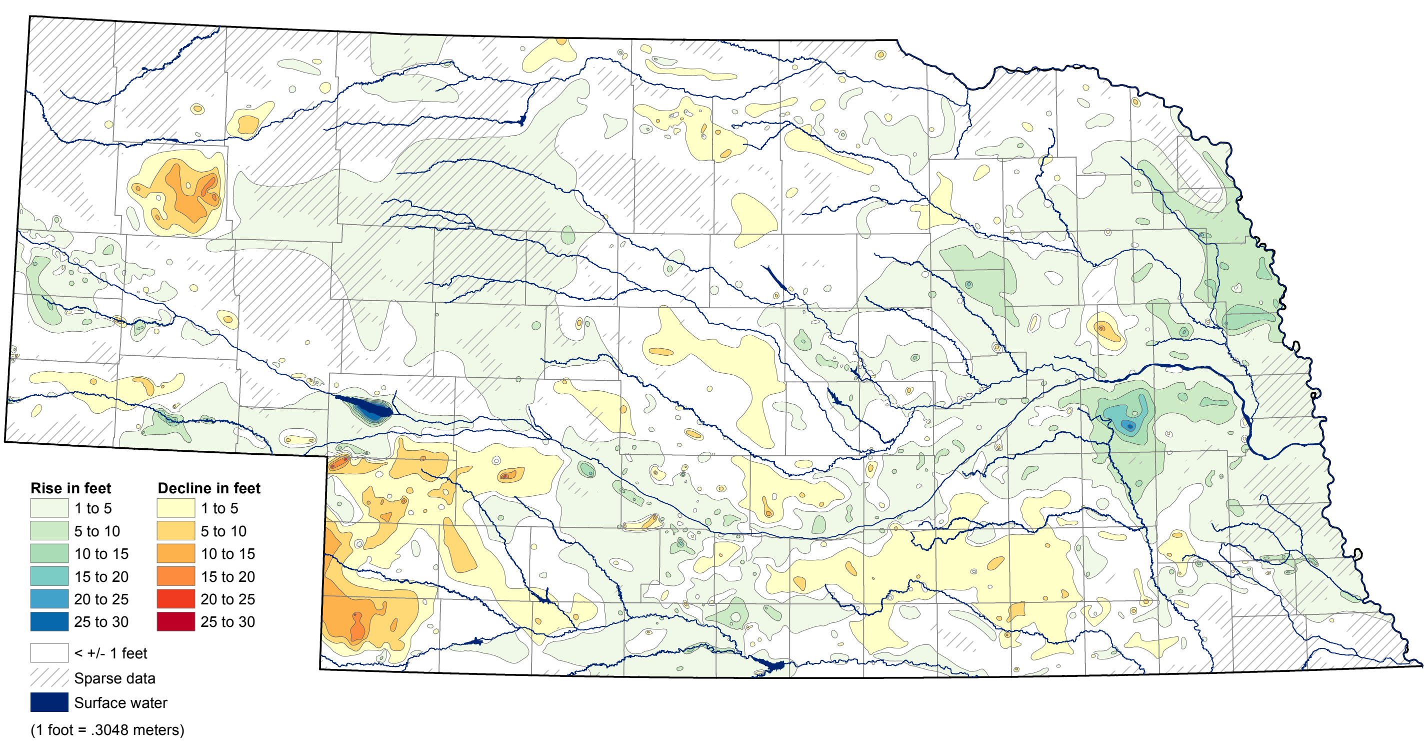
Groundwater-level declines were recorded in 38% of wells measured in Nebraska, with 26% experiencing declines of greater than one foot. Despite near-average precipitation for the state between 2006 and 2016, groundwater levels in some parts of the state continue to decline. Major areas of groundwater-level decline include the south central/southeast region, Chase Dundy and Perkins Counties, as well as Box Butte and Colfax Counties. Declines of more than 5 feet occurred over much of these regions, with declines of more than 20 feet occurring in parts of Box Butte, Perkins, Dundy and Colfax Counties. Water-level declines in these counties are largely the result of drawing large quantities of irrigation water from deep aquifers with little or no connection to surface water. Near-normal precipitation in south central/southeast Nebraska, combined with a high density of irrigation wells per section have resulted in declines of 1-5 feet for much of the region. Other localized areas of groundwater-level declines occurred throughout the state, which may have resulted from a combination of factors including increased irrigation water withdrawals or reduced recharge from near-normal to slightly below-normal precipitation on a regional scale.

Figure 12. Percent of Normal Precipitation - January 2006 to January 2016



Sources: National Climate Data Center, Asheville, North Carolina;
High Plains Regional Climate Center, University of Nebraska–Lincoln

Figure 13. Groundwater-Level Changes in Nebraska - Spring 2006 to Spring 2016



Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 2016

Long-term groundwater-level changes in Nebraska primarily reflect aquifer depletion in areas of dense irrigation development and increases in storage due to seepage from canals and reservoirs.

Spring 2016 groundwater levels continue to indicate long-term declines and rises in certain areas of Nebraska (Fig. 14). With a few exceptions, areas of significant groundwater-level declines generally correspond to areas where irrigation well density is high and aquifers are deep and have little or no connection to surface water (Fig. 15). The greatest measured decline from predevelopment to 2016 was 120.14 feet, in Box Butte County just north of the city of Alliance. Regions of notable groundwater-level declines from predevelopment to spring 2016 occurred in Box Butte County, the southwestern part of the State near Chase, Perkins, and Dundy Counties, and in the Panhandle. A large area of lesser declines occurred in the southeast corner of the High Plains aquifer in southeast to south central Nebraska. The largest rises occurred in Gosper, Phelps, and Kearney Counties; areas where canals and surface irrigation systems exist.

The predevelopment groundwater levels used in Chase, Perkins, and Dundy Counties are representative of the approximate average water levels prior to 1953. Available data indicate that, as a result of intensive use of groundwater for irrigation, a general trend of declining water levels began in about 1966. Predevelopment water levels used to develop the groundwater-level change map in Box Butte County are the approximate average water levels prior to 1938. Intensive groundwater development for irrigation since 1950 has caused water levels to decline 5 to more than 110 feet from predevelopment levels (Fig. 14). Records from recorder wells in both areas indicate that rates of decline have been more or less steady despite changes in groundwater management practices, water use allocations, and fluctuations in the amount of annual precipitation (see Korus and Burbach, 2009b; and forthcoming section).

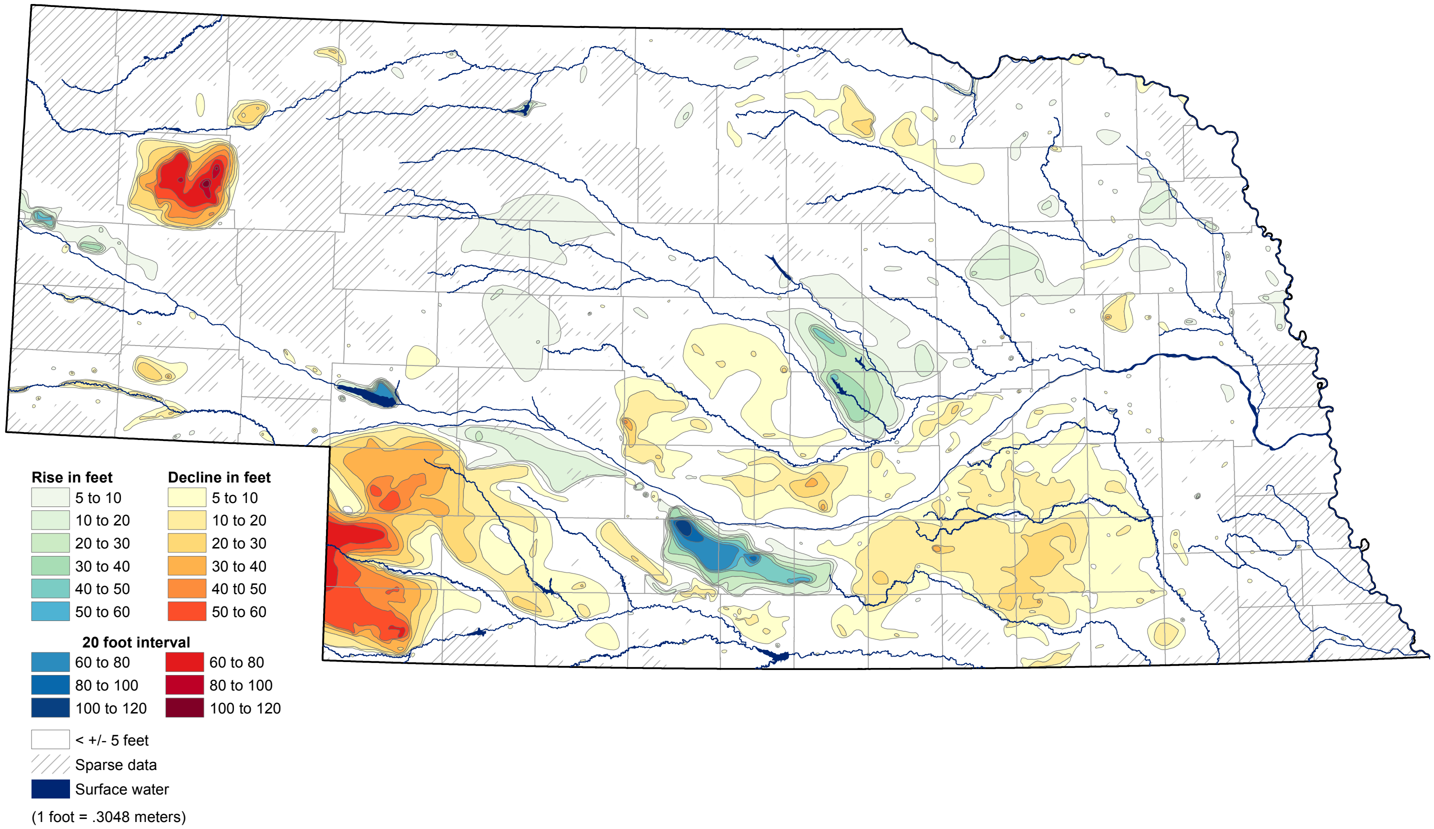
A large portion of southeast to south central Nebraska has experienced long-term groundwater-level declines since predevelopment (Fig. 14). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this region have declined more than 10 feet, and in some areas more than 30 feet, from predevelopment.

Parts of other regions that experienced relatively large areas of decline include areas between the Platte and Loup/South Loup Rivers; Republican River Valley; localized areas throughout the Panhandle; and parts of Holt and Colfax Counties. Irrigation well density is high in some, but not all, of these areas. Other factors such as aquifer characteristics, rates of recharge, and irrigation scheduling could be contributing to the declines.

Groundwater-level rises from predevelopment generally occurred in areas of surface irrigation systems. Storage of water in Lake McConaughy began in 1941, and seepage losses caused water-level rises of as much as 60 feet in nearby observation wells (Ellis and Dreeszen, 1987). Water levels generally stabilized by about 1950 and since then have fluctuated in response to changes in reservoir levels and precipitation (Johnson and Pederson, 1984). Water released from storage in Lake McConaughy is subsequently diverted from the Platte River near Sutherland west of North Platte, and then flows through the Tri-County Canal and a series of reservoirs toward Dawson, Gosper, Phelps, and Kearney Counties, where it has been used for irrigation since 1941. Deep percolation of water from these irrigation-distribution systems and from excess water applied to crops has raised groundwater levels more than 100 feet (Fig. 14). Groundwater levels have also risen in association with seepage from Sutherland Reservoir, Lake Maloney, and their associated canals in eastern Keith and central Lincoln Counties. Rises of as much as 60 feet in southern Sioux, Scotts Bluff, and western Morrill Counties are also associated with irrigation canal systems.

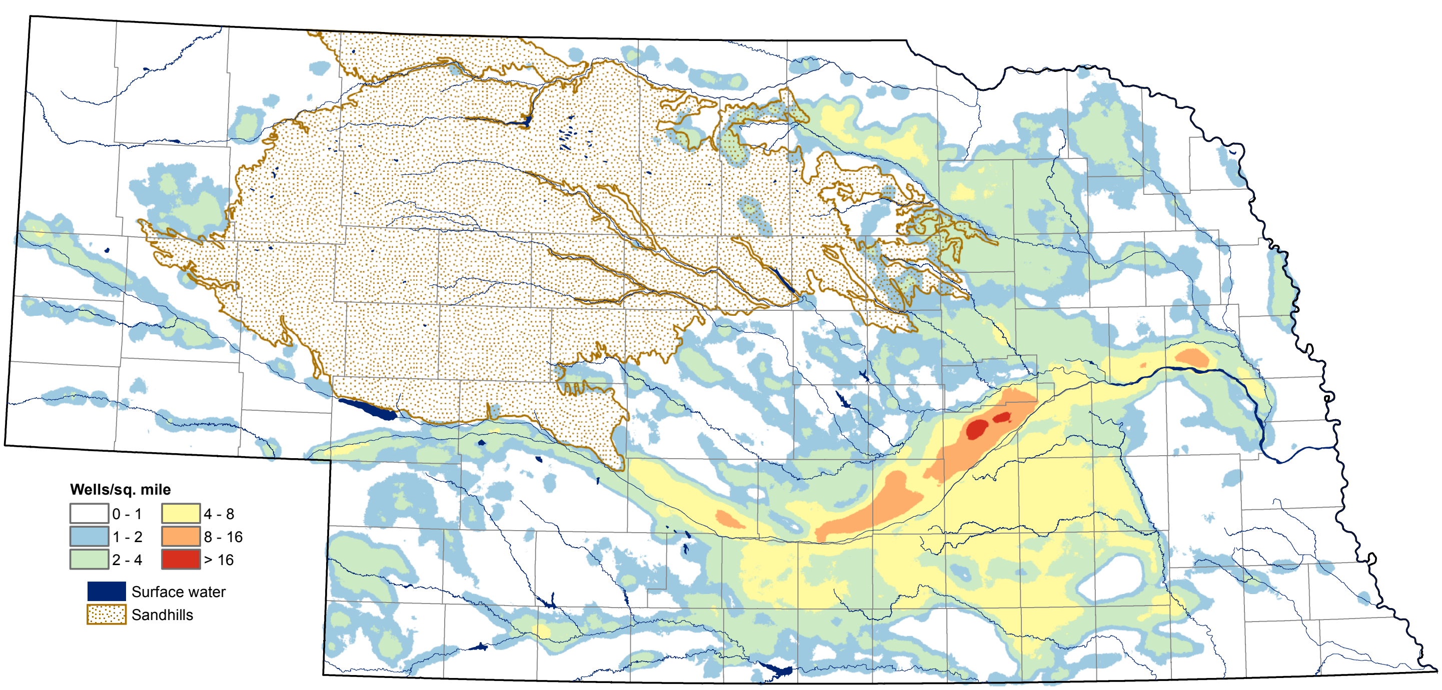
Groundwater-level rises of 10 to more than 50 feet occurred in portions of central Nebraska (Fig. 14). The highest water-level rises occurred in Valley, Sherman, and Howard Counties as the result of seepage from irrigation canals, Sherman and Davis Creek Reservoirs, and deep percolation of irrigation water applied to crops.

Figure 14. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2016



Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District

Figure 15. Density of Active Registered Irrigation Wells - December 2016



Source: Nebraska Department of Natural Resources

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 1981 AND SPRING 1981 TO SPRING 2016

Prior to 1981, groundwater levels were declining in nearly all areas of the State. After 1981, however, markedly different changes occurred in the east compared to the west.

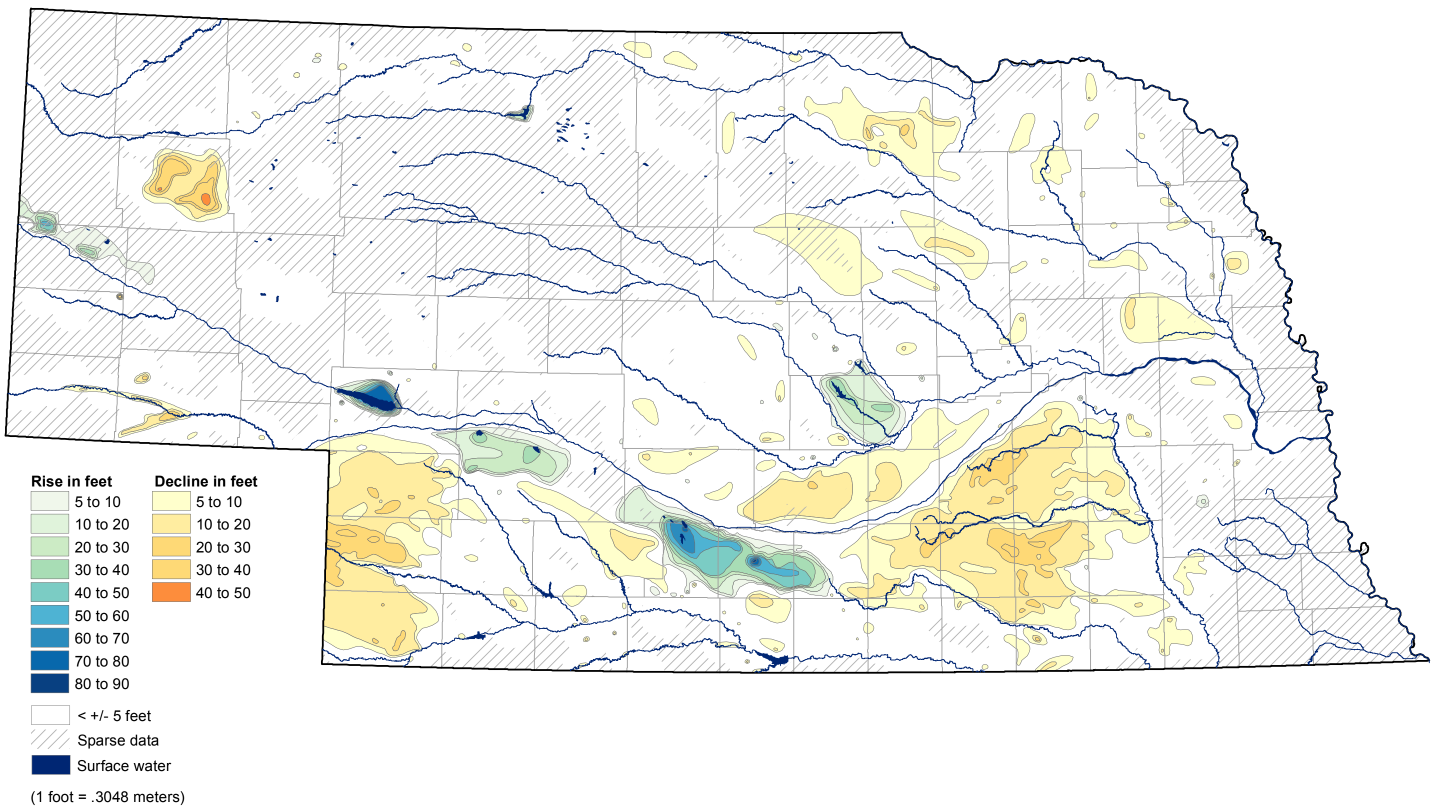
Groundwater-level changes from predevelopment to spring 1981 reflect the responses of aquifers to the development of groundwater and surface water irrigation systems in Nebraska. Areas of significant groundwater-level declines generally corresponded to areas of dense irrigation well development (cf. Johnson and Pederson, 1981). Declines were generally equal in magnitude in eastern and western areas (Fig. 16). The largest areas in which declines occurred were in Box Butte County in the Panhandle, Chase, Perkins, and Dundy Counties in the southwest, south central/southeast Nebraska, Platte River Valley, central Nebraska, and northeast portion of the Sand Hills. Declines exceeded 40 feet in Box Butte County in the Panhandle, and 30 feet in Chase County in the southwest, and Clay and Fillmore Counties in the south central/southeast. Declines occurred in smaller areas of the Republican River drainage as well as the northeast. Almost all groundwater-irrigated areas of Nebraska experienced declines associated with groundwater withdrawals. Such declines are a necessary response of the aquifer to development according to laws of hydrologic mass balance (see Korus and Burbach, 2009a).

Groundwater-level rises from predevelopment to spring 1981 were associated with irrigation canal systems and reservoirs (Fig. 16). The rise in southern Sioux and northern Scotts Bluff Counties was associated with seepage from the Interstate Canal System, among numerous smaller systems, and excess water applied to crops beginning in the early 20th century. The rise in these counties exceeded 50 feet in some areas. The rise in Cherry County was associated with seepage from Merritt Reservoir beginning in the mid-1960s and exceeded 20 feet immediately adjacent to the reservoir. Seepage from Lake McConaughy beginning in 1941 caused groundwater levels to rise more than 100 feet by 1981. Reservoirs and canals south of the Platte River, which are used for hydroelectric power production and irrigation, provided seepage that caused groundwater-levels to rise from eastern Keith County to western Kearney County (see discussion in previous section). Water levels began rising in this area after 1941 and had nearly reached their maximum by 1981. In Howard and Sherman Counties, groundwater levels began rising in 1963 due to seepage from Sherman Reservoir, its irrigation-distribution system, and deep percolation of irrigation water applied to crops. Rises of 10 to more than 30 feet occurred in in this area by 1981.

Compared to the changes discussed above, a much different pattern of groundwater-level changes has emerged in Nebraska since 1981 (Fig. 17). In central and eastern Nebraska, areas in which declines had occurred from predevelopment to 1981 experienced rises of 5 to more than 20 feet from 1981 to 2016. This pattern of pre-1981 decline and post-1981 recovery is observed in many wells, including the Hastings Recorder well, which has a continuous record dating to the mid-1930's, and the Aurora Recorder well, which dates to the mid-1950's (Fig. 18). Although some areas in south central/southeast Nebraska still have a net rise in groundwater levels compared to spring 1981, post spring 1981 water level recovery in this region reached a maximum in the spring of 2012. Since the spring of 2012, water levels in many areas have been trending back toward, or in some areas have declined below 1981 levels. Since 2012, water levels in this region fluctuate on a year to year basis, due to this fluctuation, it is difficult to predict the trend of future water-level changes in this region. These declines may be a temporary response of the aquifer to increased pumping and decreased recharge due to extreme drought, or they may be the beginning of a declining trend in response to long-term climate trends.

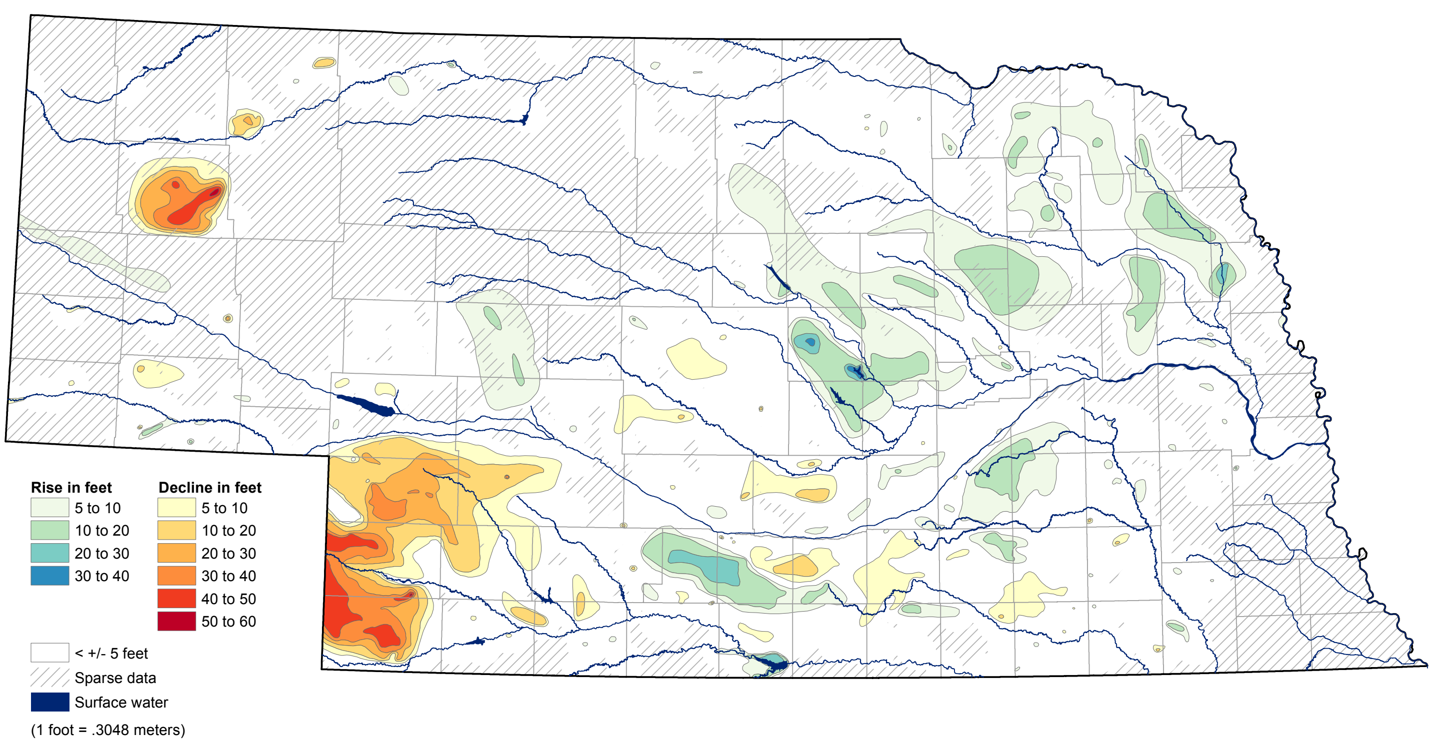
Declines in south central/southeast Nebraska reached a maximum in 1981 and had recovered such that declines in some areas are now less than 5-10 feet compared to predevelopment levels (Figs 14, 16, 17). Groundwater levels in most of this area, however, remain below predevelopment levels. It is hypothesized that the post-1981 recovery of groundwater levels in central and eastern Nebraska resulted from a combination of factors, including (1) reduced groundwater withdrawals during several long periods of above-average precipitation, (2) increased irrigation efficiencies that resulted in reduced pumping rates and volumes, and (3) stabilization of groundwater-levels as the aquifer equilibrated to the new hydrological conditions imposed on it by irrigation development decades earlier (see Korus and Burbach, 2009a). Another possible explanation for these rises may be related to increasing rates of recharge. In some areas, a shallow water table aquifer is separated from the primary aquifer by a confining layer. Irrigation during the first several decades after development was primarily by means of flooding along rows of crops. This method resulted in over-application and deep percolation, which thereby recharged the shallow aquifer. Evidence for this phenomenon is shown in the

Figure 16. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 1981



Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District

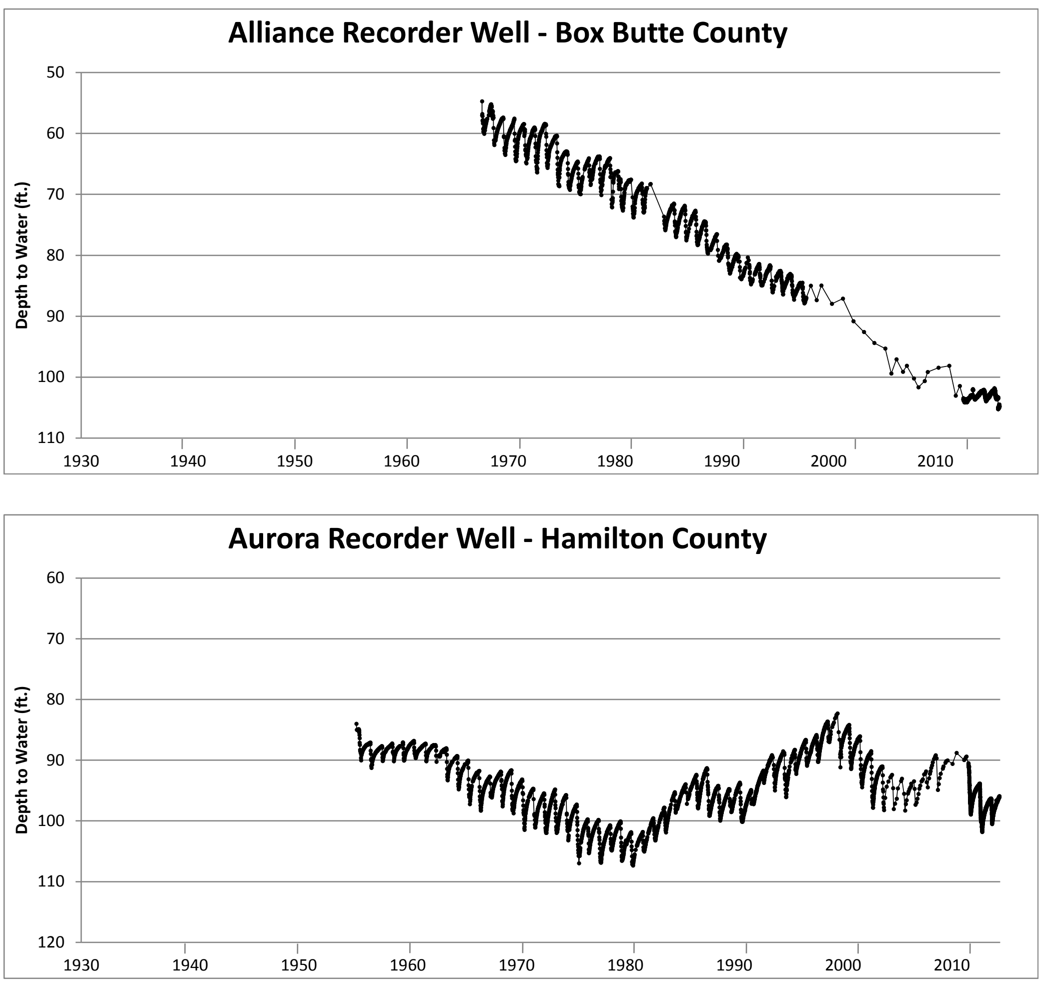
Figure 17. Groundwater-Level Changes in Nebraska - Spring 1981 to Spring 2016

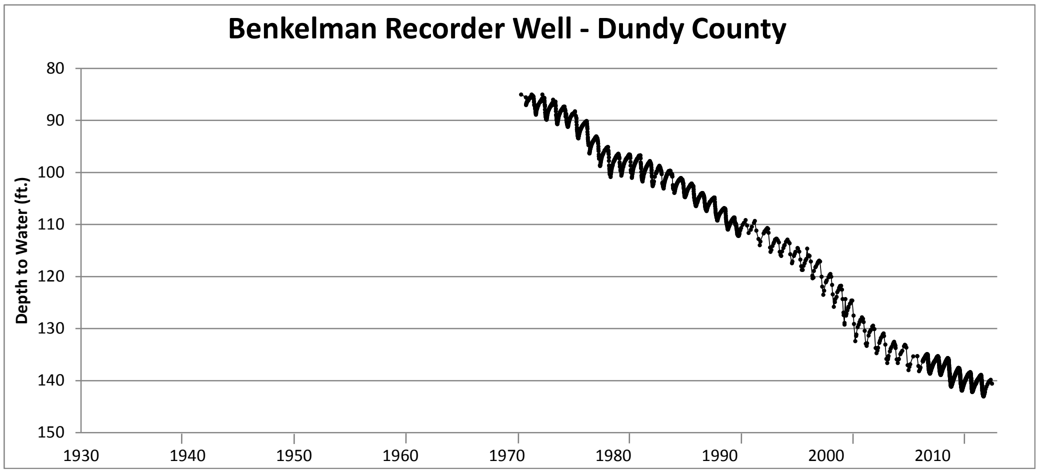


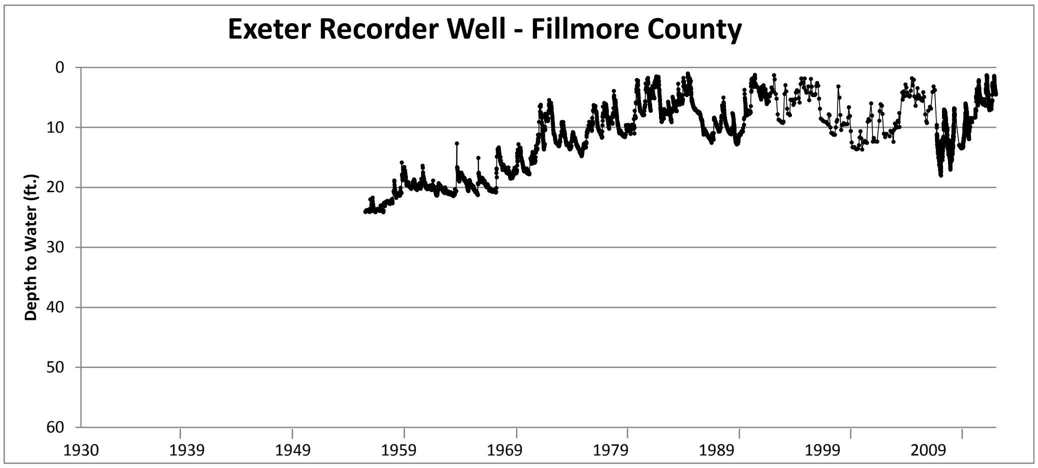
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District hydrograph for the Exeter Recorder Well, which is screened in the shallow aquifer (Fig. 18). The steady rise from 1956 to 1981 in this well corresponds to the steady decline observed in nearby wells that are screened in the deep aquifer. This excess water may have served as a source of new recharge to the primary aquifer in areas where the confining layer is sufficiently permeable.

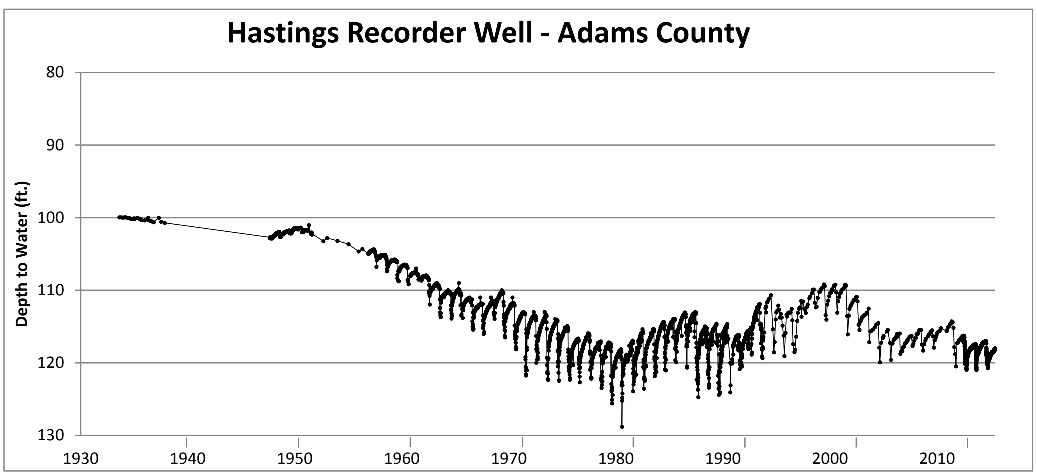
In contrast to the groundwater-level rises in the east, levels continued to decline in parts of western Nebraska from 1981 to 2016 (Fig. 17). The Alliance, Benkelman, and Imperial Recorder wells show declines of 50 - 60 feet in just 50 years, an average of about 1 foot per year (Fig. 18). Brief periods of unchanging or rising groundwater levels occurred, but the rates of decline were steady overall despite changes in groundwater management practices, water use allocations, and fluctuations in the amount of annual precipitation over the past 30 years. The pattern of long-term groundwater-level decline over a large region, such as southwest Nebraska or Box Butte County, is a normal response of an aquifer to irrigation development. Such declines reflect the release of water from storage in the aquifer and the adjustment of the water table to new hydrological stresses (see Korus and Burbach, 2009a). These declines will stabilize only if groundwater withdrawals do not exceed the total yield of the aquifer, which is a function of its hydrogeological characteristics as well as its sources and rates of replenishment.

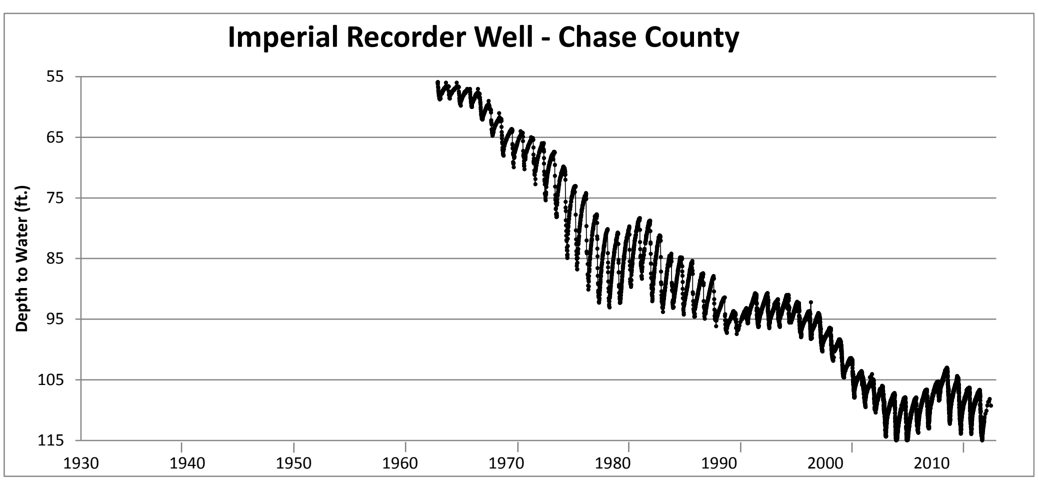
Figure 18. Groundwater-Level Hydrographs Typical of Southeast and Southwest Nebraska




Benkelman Recorder Well - Dundy County
Depth to Water (ft.)
80
90
100
110
120
130
140
150
1930
1940
1950
1960
1970
1980
1990
2000
2010


Exeter Recorder Well - Fillmore County
Depth to Water (ft.)
0
10
20
30
40
50
60
1930
1939
1949
1959
1969
1979
1989
1999
2009


Hastings Recorder Well - Adams County
Depth to Water (ft.)
80
90
100
110
120
130
1930
1940
1950
1960
1970
1980
1990
2000
2010


Imperial Recorder Well - Chase County
Depth to Water (ft.)
55
65
75
85
95
105
115
1930
1940
1950
1960
1970
1980
1990
2000
2010

Useful Groundwater Resources

Online Resources

Online CSD resources are available at: go.unl.edu/groundwater

The Nebraska Real-Time Groundwater-Level Network
The network consists of 58 observation wells located throughout Nebraska. The wells take automated hourly readings, which are updated on the website in real-time.

Historic Nebraska Statewide Groundwater-Level Monitoring Reports
Recent reports, including the current issue, are available as PDFs for download. Water-level change maps are available for download beginning with 1954 through the maps included in this report.

Other Online Resources

Other groundwater information is available from the following websites and agencies:

Nebraska Natural Resources Districts
http://nrdnet.org/find-your-nrd.php

United States Geologic Survey, Nebraska Water Science Center
http://ne.water.usgs.gov

References

Alley, W.M., and Leake S.A., 2004, The Journey from Safe Yield to Sustainability. Ground Water, v. 42, p. 12-16.

Anonymous, undated. Niobrara River Memorandum of Understanding. Know the Facts. [http://www.lnnrd.org/uploads/3/4/1/8/34181013/niobrara_mou_factsheet_final.pdf]. Accessed January 4, 2017.

Associated Press, 2016. "Fremont sued over actions taken to aid Costco chicken plant." Lincoln Journal Star. 26 July 2016. [URL http://journalstar.com/news/state-and-regional/nebraska/fremont-sued-over-actions-taken-to-aid-costco-chicken-plant/article_b8ed5626-1f3a-5360-8b8c-820383924588.html].

Bergin, N., 2015. "Blasting on Platte is called off." Lincoln Journal Star. 29 January 2015. [URL http://journalstar.com/news/local/blasting-on-platte-is-called-off/article_a291787b-6b9a-5e19-9d5d-d171fcf2df63.html]. Accessed January 4, 2017

Bredehoeft, J.D., 1997, Safe Yield and the Water Budget Myth. Ground Water, v. 35, p. 929.

Burbach, M.E., 2006, Groundwater-Level Changes in Nebraska, Spring 2000 to Spring 2006. University of Nebraska-Lincoln Conservation and Survey Division, Water Survey Map 63.

Burbach, M.E., 2007, Groundwater-Level Changes in Nebraska, Spring 2000 to Spring 2007. University of Nebraska-Lincoln Conservation and Survey Division, Water Survey Map 74.

Cady, R.C., and Scherer O.J., 1946, Geology and Ground-Water Resources of Box Butte County, Nebraska. US Geological Survey, Water Supply Paper 969, 99 p.

Central Nebraska Public Power and Irrigation District, 2016. "E67 Telemetry Project begins second year." Web blog post. [URL http://www.cnppid.com/e67-telemetry-project-begins-second-year/]. Accessed January 4, 2017.

"Clean Water Rule: Definiton of 'Waters of the United States,'" 2015. Federal Register 80, No. 124 (29 June 2015):37054-37127.

Ellis, M.J., and Dreeszen, V.H., 1987, Groundwater Levels in Nebraska, 1986. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 62, 68 p.

Joeckel, R.M., Tucker, S.T., and McMullin, J.D., 2016. Morphosedimentary features from a major flood on a small, lower-sinuosity, single-thread river: The unknown quantity of overbank deposition, historical-change context, and comparisons with a multichannel river. Journal of Sedimentary Research 343:18-37.

Johnson, M.S., and Pederson, D.T., 1981, Groundwater Levels in Nebraska, 1980. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 51, 65 p.

Johnson, M.S., and Pederson, D.T., 1984, Groundwater Levels in Nebraska, 1983. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 57, 67 p.

Kansas v. Nebraska et al., 574 U. S. ____ (2015). No. 126. Supreme Court of the United States.

Korus, J.T., and Burbach, M.E., 2009a, Analysis of Aquifer Depletion Criteria with Implications for Groundwater Management, Great Plains Research, v. 19, p. 187-200.

Korus, J.T., and Burbach, M.E., 2009b, Nebraska Statewide Groundwater-Level Monitoring Report 2009. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 76, 38 p.

Korus, J.T., Burbach, M.E., Howard, L.M., Joeckel, R.M. 2010, Nebraska Statewide Groundwater-Level Monitoring Report 2010: University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 77, 20 p.

Korus, J.T., and Joeckel, R.M., 2011, Generalized Geologic and Hydrostratigraphic Framework of Nebraska 2011, ver. 2. Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Geologic Maps and Charts (GMC) 38.

Maimone, M., 2004, Defining and Managing Sustainable Yield. Ground Water, v. 42, p. 809-814.

National Weather Service, undated. North Platte River at Scottsbluff. [URL http://water.weather.gov/ahps2/hydrograph.php?gage=sbrn1&wfo=cys].

Nebraska Legislature, undated—a. LB1038 - Change provisions relating to vegetation and natural resources. [URL http://nebraskalegislature.gov/bills/view_bill.php?DocumentID=28892].

Nebraska Legislature, undated—b. LB1082 - Change provisions relating to the Nebraska Oil and Gas Conservation Commission and provide for a periodic well fluid analysis, report, and notice as prescribed. [URL http://nebraskalegislature.gov/bills/view_bill.php?DocumentID=28893]

Nebraska Legislature, undated—c. LB1070 - Change powers and duties of the Nebraska Oil and Gas Conservation Commission to require liability insurance and restrict permits as prescribed. [http://nebraskalegislature.gov/bills/view_bill.php?DocumentID=28937]

Nolan, J., and Weber, K.A., 2015. Nitrate contamination in major U.S. aquifers linked to nitrate. Environmental Science and Technology Letters 2015, 2:215-220.

North, I., 2016a. “Sioux County landowners argue fracking case in district court.” Scottsbluff StarHerald 23 May 2016. [URL http://www.starherald.com/news/local_news/sioux-county-landowners-argue-fracking-case-in-district-court/article_b596bbda-f4e3-56f9-a2dc-cb214b16f647.html].

North, I., 2016b. “Attorney General declines to appeal fracking case.” Scottsbluff StarHerald 26 July 2016. [URL http://www.starherald.com/news/local_news/attorney-general-declines-to-appeal-fracking-case/article_8eed39cb-e182-59c8-ae68-11bc95eec283.html].

Rempp, K., 2015. “Hearings begin on objections to Crow Butte uranium mining.” The Chadron Record. 25 August 2015. [URL http://rapidcityjournal.com/news/local/communities/chadron/]. Accessed January 4, 2017.

Rempp, K., 2016. “Federal board rules on Crow Butte disputes.” The Chadron Record. 27 December 2016. [URL http://rapidcityjournal.com/news/local/communities/chadron/]. Accessed January 4, 2017.

Sophocleous, M.A., 1997, Managing Water Resources Systems: Why “Safe Yield” is not Sustainable. Ground Water, v. 35, p. 561.

Sophocleous, M.A., 1998, On the Elusive Concept of Safe Yield and the Response of Interconnected Stream-Aquifer Systems to Development. In Perspectives on Sustainable Development of Water Resources in Kansas, ed. M.A. Sophocleous, p. 6-85. Kansas Geological Survey Bulletin 239. KGS, Lawrence, KS.

Sophocleous, M.A., 2000, From Safe Yield to Sustainable Development of Water Resources–the Kansas Experience. Journal of Hydrology, v. 235, p. 27-43.

Groundwater-Level Changes in Nebraska Map Series
Available online at http://snr.unl.edu/data/water/groundwatermaps.asp

Reports Containing Water-level Information

Year	Publication and Number	Author(s) and year published
pre 1954	U.S.G.S. Open-File Rpt. 54-138	Keech, C.F.; Case, R.L., 1954
1954	U.S.G.S. Open-File Rpt. 55-80	Keech, C.F.; Case, R.L., 1955
1955	U.S.G.S. Open-File Rpt. 56-70	Keech, C.F., 1956
1956	U.S.G.S. Open-File Rpt. 57-61	Keech, C.F., 1957
1957	Nebraska Water Survey Paper 4*	Keech, C.F., 1958
1958	Nebraska Water Survey Paper 5*	Keech, C.F., 1959
1959	Nebraska Water Survey Paper 6	Keech, C.F., 1960
1960	Nebraska Water Survey Paper 9	Keech, C.F., 1961
1961	Nebraska Water Survey Paper 12	Keech, C.F.; Hyland, J.B., 1962
1962	Nebraska Water Survey Paper 13	Emery, P.A.; Malhoit, M.M., 1963
1963	Nebraska Water Survey Paper 14	Emery, P.A.; Malhoit, M.M., 1964
1964	Nebraska Water Survey Paper 17	Emery, P.A.; Malhoit, M.M., 1965
1965	Nebraska Water Survey Paper 18	Emery, P.A.; Malhoit, M.M., 1966
1966	Nebraska Water Survey Paper 20*	Keech, C.F., 1967
1967	Nebraska Water Survey Paper 23	Keech, C.F., 1968
1968	Nebraska Water Survey Paper 24*	Keech, C.F.; Svoboda, G.R., 1969
1969	Nebraska Water Survey Paper 26*	Keech, C.F., 1970
1970	Nebraska Water Survey Paper 28*	Keech, C.F., 1971
1971	Nebraska Water Survey Paper 33	Keech, C.F., 1972
1972	Nebraska Water Survey Paper 34	Ellis, M.J., 1973
1973	Nebraska Water Survey Paper 36	Ellis, M.J., 1974
1974	Nebraska Water Survey Paper 40*	Ellis, M.J., 1975
1975	Nebraska Water Survey Paper 43*	Ellis, M.J.; Pederson, D.T., 1976
1976	Nebraska Water Survey Paper 44	Ellis, M.J.; Pederson, D.T. 1977
1977	Nebraska Water Survey Paper 45	Ellis, M.J.; Pederson, D.T., 1978
1978	Nebraska Water Survey Paper 49	Pederson, D.T.; Johnson, M.S., 1979
1979	Nebraska Water Survey Paper 50*	Johnson, M.S.; Pederson, D.T., 1980
1980	Nebraska Water Survey Paper 51	Johnson, M.S.; Pederson, D.T., 1981
1981	Nebraska Water Survey Paper 52	Johnson, M.S.; Pederson, D.T., 1982
1982	Nebraska Water Survey Paper 56	Johnson, M.S.; Pederson, D.T., 1983
1983	Nebraska Water Survey Paper 57	Johnson, M.S.; Pederson, D.T., 1984
1984	Nebraska Water Survey Paper 59	Ellis, M.J.; Pederson, D.T., 1985
1985	Nebraska Water Survey Paper 61	Ellis, M.J.; Pederson, D.T., 1986
1986	Nebraska Water Survey Paper 62	Ellis, M.J.; Dreeszen, V.H., 1987
1987	Nebraska Water Survey Paper 65	Ellis, M.J.; Wigley, P.B, 1988
1988	Nebraska Water Survey Paper 66	Ellis, M.J.; Steele, G.V.; Wigley, P.B., 1989
1989	Nebraska Water Survey Paper 67	Ellis, M.J.; Steele, G.V.; Wigley, P.B., 1990
1990	Nebraska Water Survey Paper 69	Steele, G.V.; Wigley, P.B., 1991
1991	Nebraska Water Survey Paper 71	Steele, G.V.; Wigley, P.B., 1992
1992	Nebraska Water Survey Paper 72	Steele. G.V.; Wigley, P.B., 1994
1994	Nebraska Water Survey Paper 74	Chen, A.H.; Wigley, P.B., 1996
1996	Nebraska Water Survey Paper 75	Chen, A.H.; Khisty, M.J., 1999
2009	Nebraska Water Survey Paper 76	Korus, J.T.; Burbach, M.E. 2009
2010	Nebraska Water Survey Paper 77	Korus, J.T.; Burbach, M.E.; Howard, L.M.; Joeckel, R.M.,2010
2011	Nebraska Water Survey Paper 79	Korus, J.T.; Burbach, M.E.; Howard, L.M.; 2011
2012	Nebraska Water Survey Paper 80	Young, A.R.; Burbach, M.E.; Korus, J.T.; Howard, L.M.; 2012
2013	Nebraska Water Survey Paper 81	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2013
2014	Nebraska Water Survey Paper 82	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2014
2015	Nebraska Water Survey Paper 83	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2015
2016	Nebraska Water Survey Paper 84	Young, A.R.; Burbach, M.E.; Howard, L.M.; Waszgis M.M.; Joeckel R.M.; Lackey, S.O., 2017

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