Nebraska Statewide Groundwater-Level Monitoring Report

2014

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Nebraska Water Survey Paper Number 82

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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.

The division is authorized to enter into agreements with federal and state agencies to engage in cooperative surveys and investigations of the State. Publications of the division and the cooperating agencies are available through the Conservation and Survey Division, 101 Hardin Hall, University of Nebraska–Lincoln, Lincoln, NE 68583-0961. Contact the address above, phone: (402) 472-3471, or e-mail snrsales@unl.edu. The Conservation and Survey Division web site is: http://snr.unl.edu/csd/.

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Nebraska's proud tradition of natural-resources stewardship is particularly apparent in the case of groundwater. Groundwater is inextricably linked to the State's rich heritage; it also maintains our agricultural economy and provides steady flows to some of the Nation's most admired natural streams. The groundwater resources that lie beneath Nebraska are indeed vast, but they are also vulnerable: even small changes in groundwater levels can have profound impacts.

We are proud to present this report, which is a continuation of the series of water resources reports and maps published by the Conservation and Survey Division (CSD) of the School of Natural Resources. The information provided herein can be used to inform, educate, and guide the citizens of Nebraska as we enter new and challenging times regarding water resources.

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.

Figure 1. Nebraska Natural Resources Districts

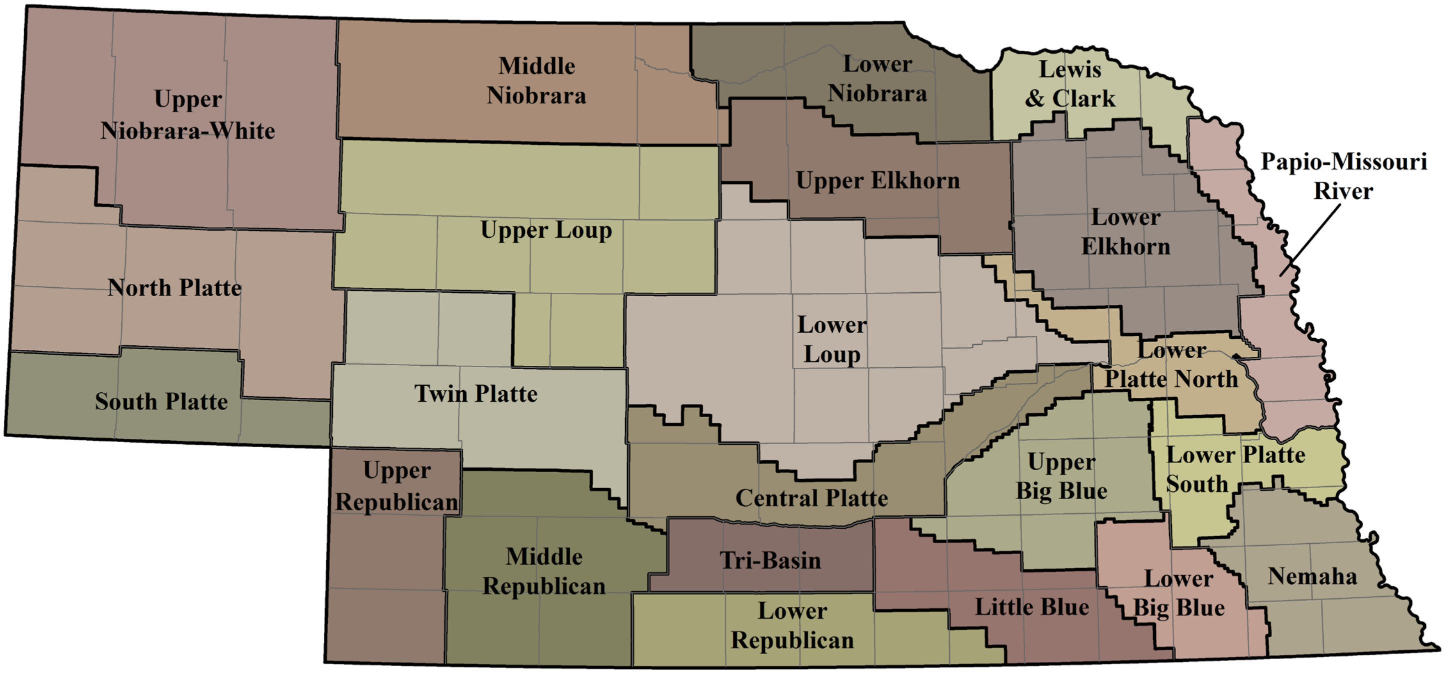
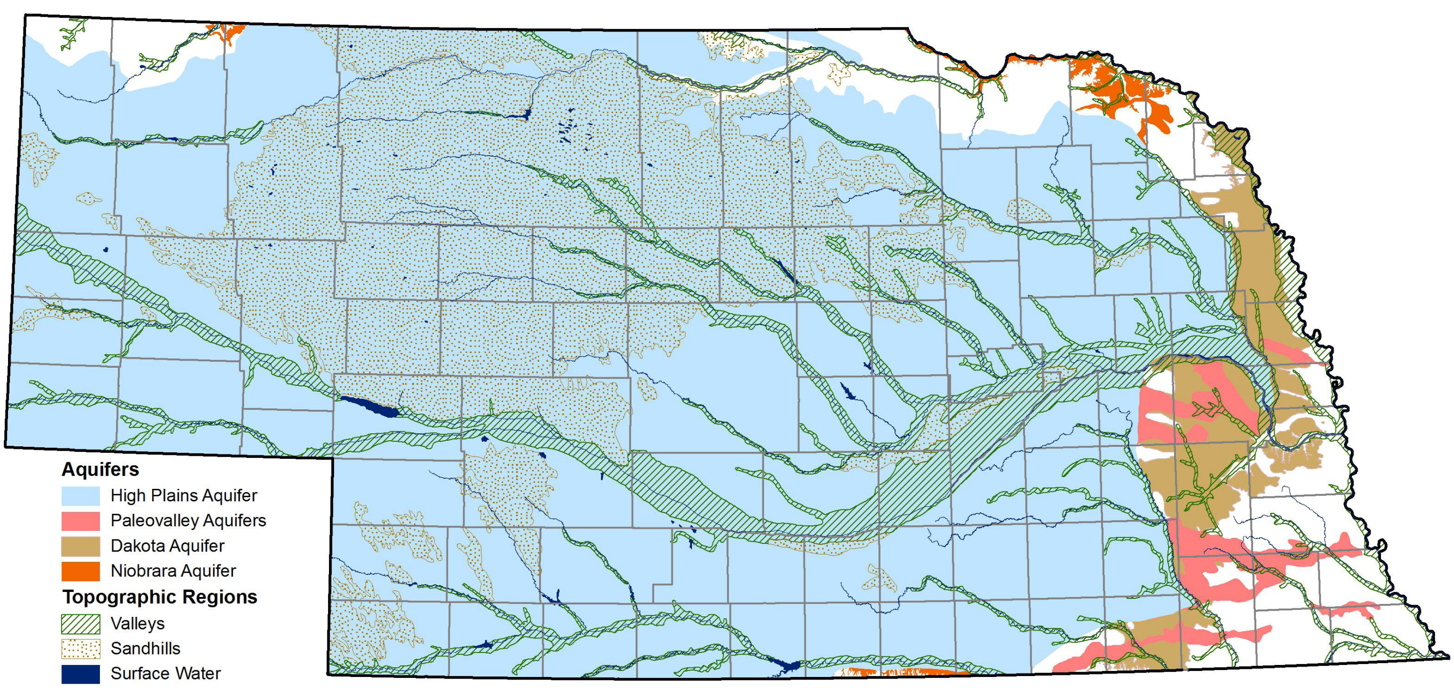


Figure 2. Important Aquifers and Topographic Regions of Nebraska



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

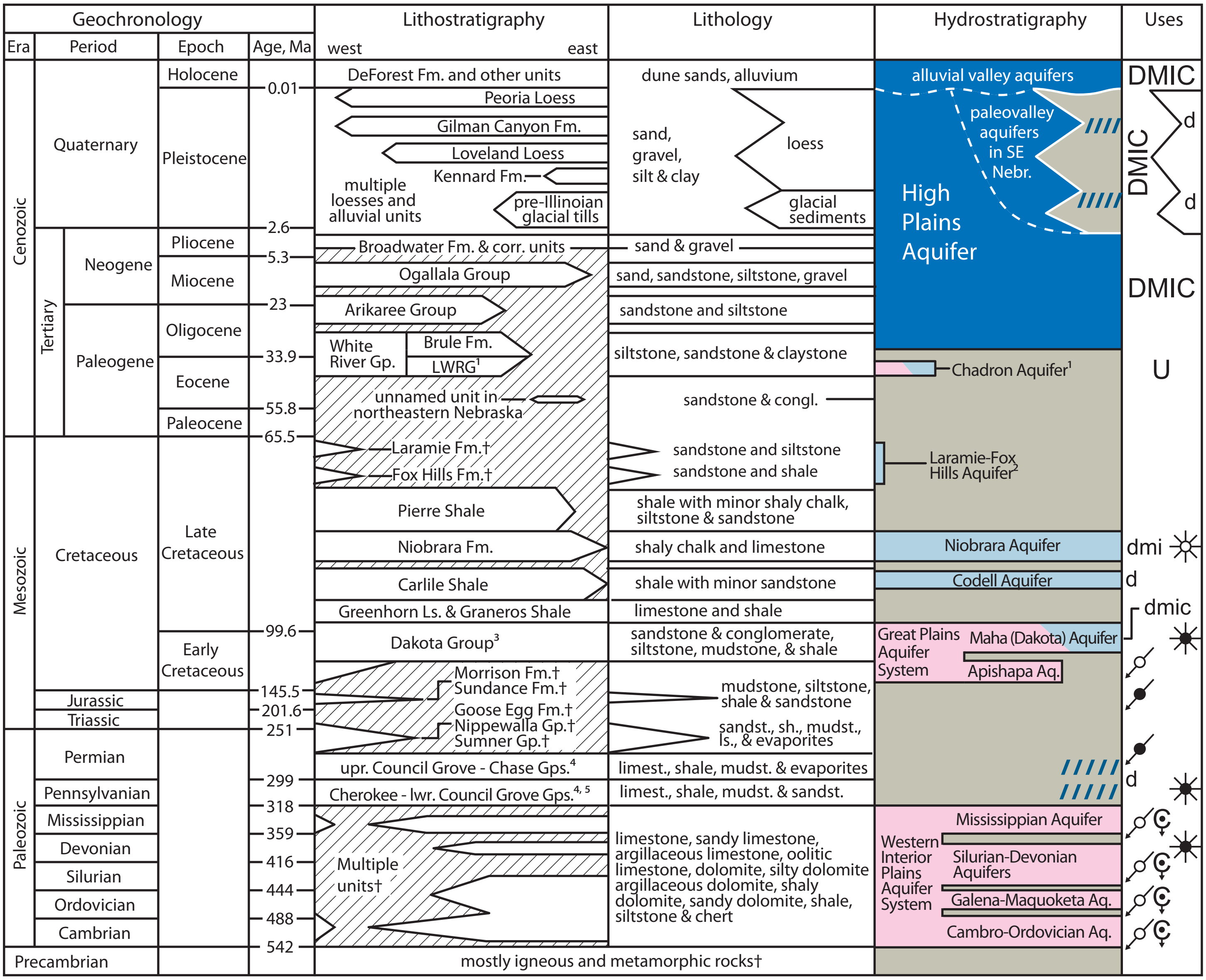


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

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
d minor domestic use

I major irrigation use
i minor irrigation use

M major municipal use
m minor municipal use

C major commercial/industrial 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 2014, as well as from 1981 to 2014, predevelopment to 1981, and predevelopment to 2014. Nineteen eighty-one was selected as a fixed year, as groundwate-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 2013 to spring 2014, spring 2009 to spring 2014, and spring 2004 to spring 2014 maps, respectively. Groundwater levels measured from thousands of wells throughout the State in spring 2014 (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 2014 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 2014 and predevelopment to spring 1981 maps, water levels from wells measured in 2014 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.

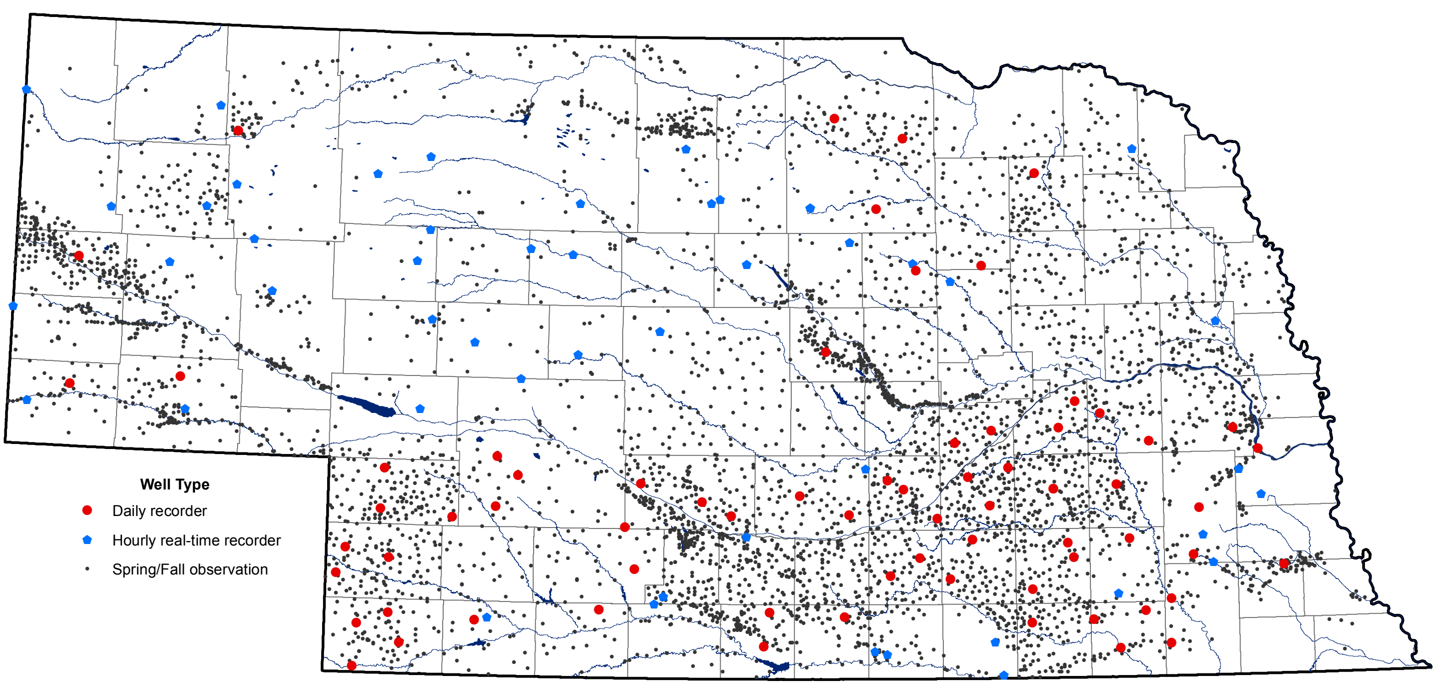
Precipitation maps were prepared by comparing total precipitation over the time period of interest to the 30-year normal provided by the National Climate Data Center. The 30-year normal currently in use is based on average annual precipitation from 1981 to 2010. A precipitation surface is generated using 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 manually 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 of artificial recharge areas; and the degree of hydraulic connection between the aquifer and surface water bodies.

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

Figure 5. Location of Observation Wells by Type



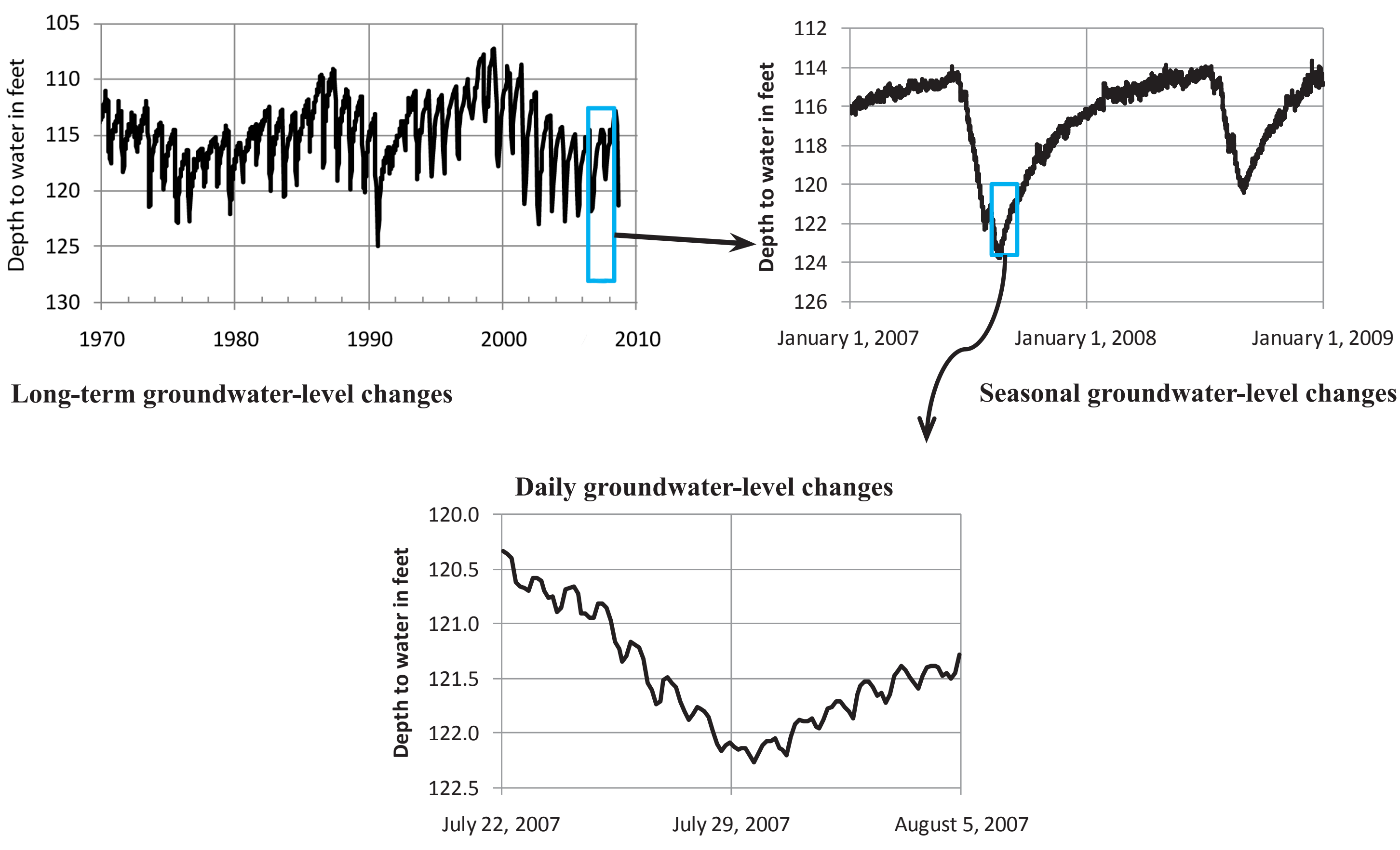
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln

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

RECENT DROUGHT IN NEBRASKA

Throughout 2013, drought conditions continued to improve, compared to extreme drought conditions experienced in 2012.

During 2012, Nebraska experienced a severe drought causing major economic and physical impacts for the state. Severe drought conditions persisted into the 2013 growing season, although overall drought conditions were much less severe than 2012. The persistent drought conditions in 2013, particularly in the southern half of the state, dramatically increased the demand for irrigation water. For weather stations in Nebraska, precipitation values for 2013 were on average 1.32 inches below normal, compared to 10.34 inches below normal for 2012 (NCDC, HPRCC).

Drought severity is ranked by the US Drought Monitor using a drought severity index, ranging from Abnormally Dry (D0) to Exceptional Drought (D4). Explanations of categories are explained in Figure 7. Figure 8 represents the percent area of Nebraska included in drought categories during the period of drought from August 2011 to October 2014. For the majority of Nebraska, precipitation values for the first half of 2012 were normal to slightly dryer than normal. Beginning in June 2012, precipitation rates throughout the state began to decrease dramatically, and the portion of the state included in the worst categories of drought (D3 and D4) began to rapidly increase. The percentage of the state included in the worst two categories of drought peaked in October of 2012 at 98% with little improvement until May 2013. Figure 9 shows drought conditions in Nebraska at the peak of the growing season in July 2013. By October 2013, drought conditions began to improve across Nebraska, with drought conditions across the state mostly subsiding by September 2014.

Based on High Plains Regional Climate Center (HPRCC) data, the average annual temperature for 2013 was generally 1-2 degrees below normal, compared to 1-5 degrees above normal in 2012. More importantly from a groundwater standpoint, average temperatures in spring 2013 (Mar-May) were 2 to 8 degrees below normal, compared to temperatures ranging from 2 to 10 degrees above normal for spring 2012. The early onset of higher temperatures in 2012 caused the growing season to begin at least a month before normal. Early vegetation growth coupled with below normal precipitation values beginning in late May 2012 quickly depleted soil moisture reserves, greatly increasing the need for supplemental irrigation throughout the 2012 growing season. In the spring of 2013, the later onset of growing conditions preserved available soil moisture. Near-normal precipitation values early in 2013 helped to replenish depleted soil moisture, thus reducing the need for supplemental irrigation during 2013.

Drought has both a direct and indirect impact on groundwater levels. In Nebraska, some observation wells are screened in portions of aquifers that are not affected by human use, including irrigation pumping or other high capacity wells. Therefore, water level changes in these wells are the result of reduced recharge, largely resulting from reduced precipitation. These wells generally continued to decline up to 1 foot in 2013, in addition to the 2-4 foot decline experienced during 2012. Parts of the Sand Hills saw rises in similar wells through 2012 and most of 2013. However, this is the result of a lag period between short-term changes in climate, and longer-term changes in groundwater levels.

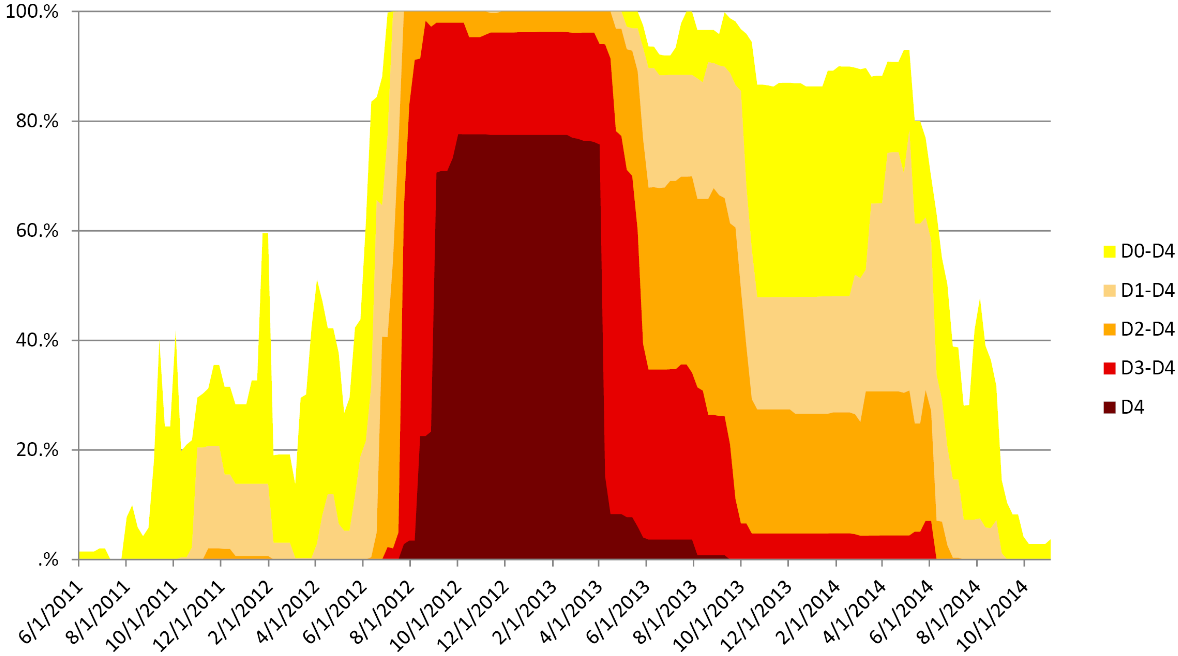
Water levels in these wells began to decline in early 2014. The major impact of drought on groundwater levels comes in the form of increased demand for irrigation water due to a decrease in precipitation. From the spring of 2013 to the spring of 2014 observation wells in Nebraska experienced an average decline of 0.5 feet, compared to the all-time greatest average decline of 2.55 feet recorded in spring 2013. Although reduced recharge to aquifers from reduced precipitation contributed to these declines, in most cases the contribution was minor. With continued below-average precipitation for parts of Nebraska in 2013, the demand for irrigation water was higher than years of normal precipitation.

Figure 7. Descriptions of Drought Categories

Category	Description	Possible Impacts
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies

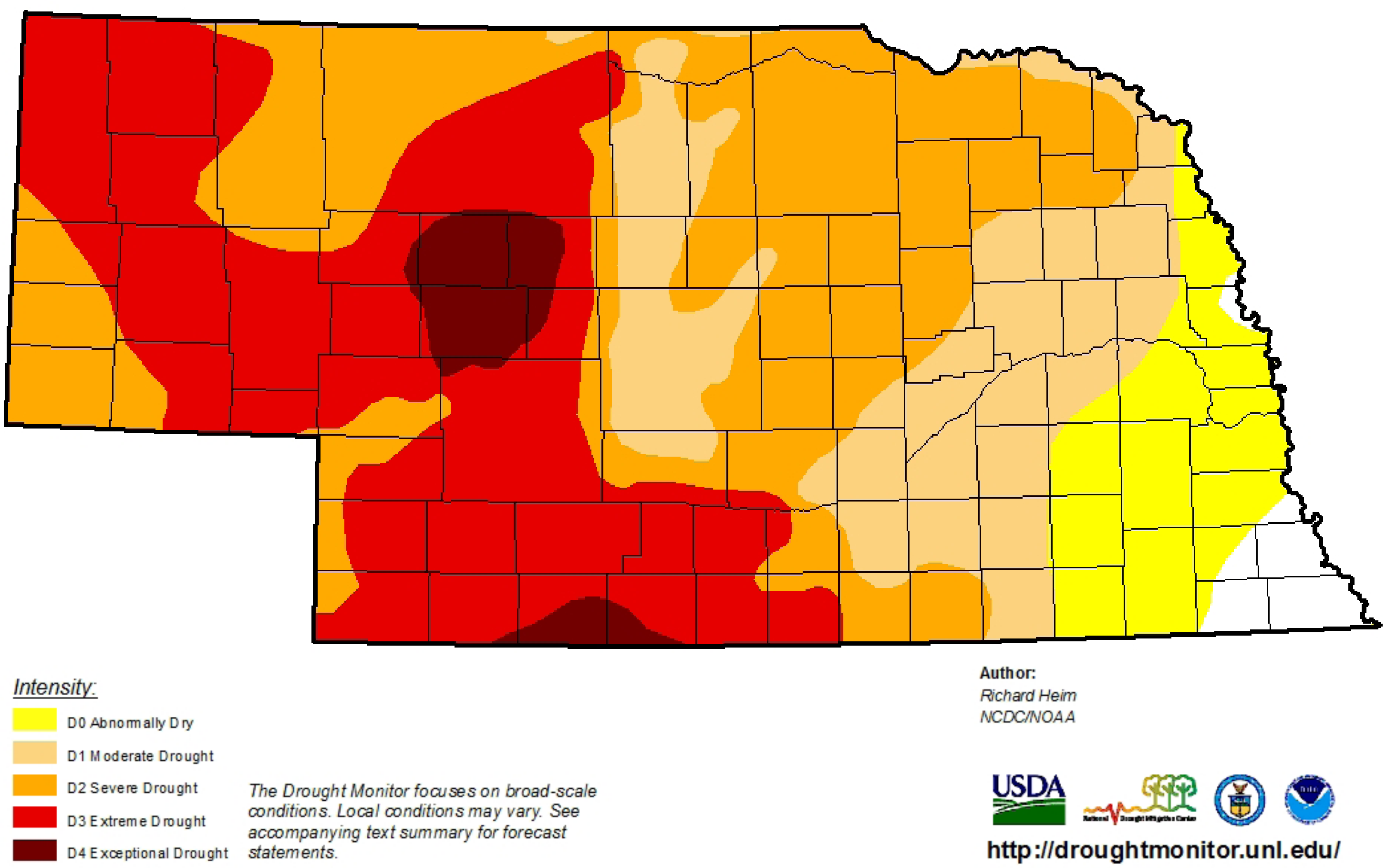
The U.S. Drought Monitor is jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. Map courtesy of NDMC-UNL.

Figure 8. Drought Severity Index by Percent Area in Nebraska



Source: Modified from U.S. Drought Monitor

Figure 9. Nebraska Drought Monitor, July 16, 2013



Source: U.S. Drought Monitor

CHANGES IN GROUNDWATER LEVELS, SPRING 2013 TO SPRING 2014

Groundwater levels continue to decline in Nebraska following two years of persistent drought.

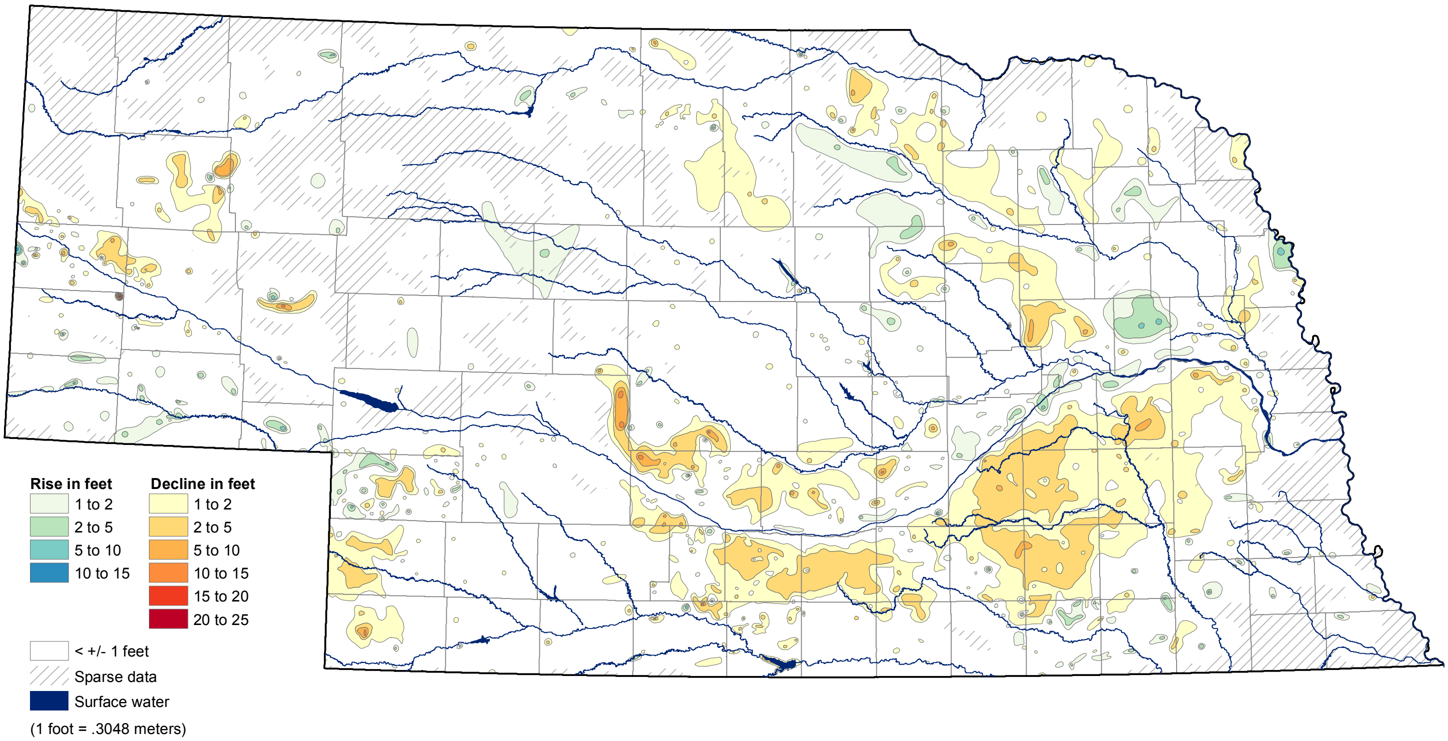
In the spring of 2014, a total of 4,770 monitoring wells were measured throughout the state of Nebraska (Fig. 5). Of those wells, 64% recorded groundwater-level declines compared to the spring of 2013, with 33% experiencing a decline greater than one foot (Fig. 10). Groundwater-level rises were recorded in 35% of wells measured, with only 12% of wells recording a rise greater than one foot. Approximately 1% of wells had neither rises nor declines from the spring of 2013 to the spring of 2014. Precipitation totals varied significantly throughout the state during 2013, with values ranging from as little as 50% of normal to as much as 150% of normal (Fig. 11). Generally, the northwest part of the State received precipitation values much above normal, with the southwest portion of the State receiving precipitation values much below normal.

Generally, regional changes in groundwater levels in Nebraska are representative of trends in precipitation (c.f. Young et. al. 2012). 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. The Spring 2013 to Spring 2014 changes, however, do not necessarily follow this typical model. During 2012, Nebraska experienced the driest year ever recorded for the State, and subsequently some of the largest one-year groundwater-level declines ever recorded. Even though many parts of the state received near-average precipitation during 2013, groundwater levels continued to decline for many of these areas. There are a number of factors which may have led to this outcome, including; a) a time lag in the movement of water through the aquifer, resulting in a delayed response to the drought of 2012 and early 2013, b) precipitation falling with heavy duration over a short timeframe, thus causing runoff rather than infiltration, and c) precipitation events occurring during the non-growing season, requiring heavy pumping of groundwater for irrigation.

Regional groundwater-level declines of 1-5 feet were recorded for much of the southern third of Nebraska to the east of Lincoln County. Other significant areas of groundwater-level declines took place in parts of Rock and Brown Counties, as well as to the areas to the north and south of the Elkhorn River in eastern Nebraska. Other more localized declines took place throughout the State due largely to localized changes in pumping. A modest decline was recorded in central Dundy County near the Republican River Augmentation project, however, these readings were taken while pumping of the augmentation wells was taking place, possibly causing an exaggerated decline in this area. Other declines in Perkins, Dundy, and Chase Counties are likely the result of increased pumping due to below average precipitation.

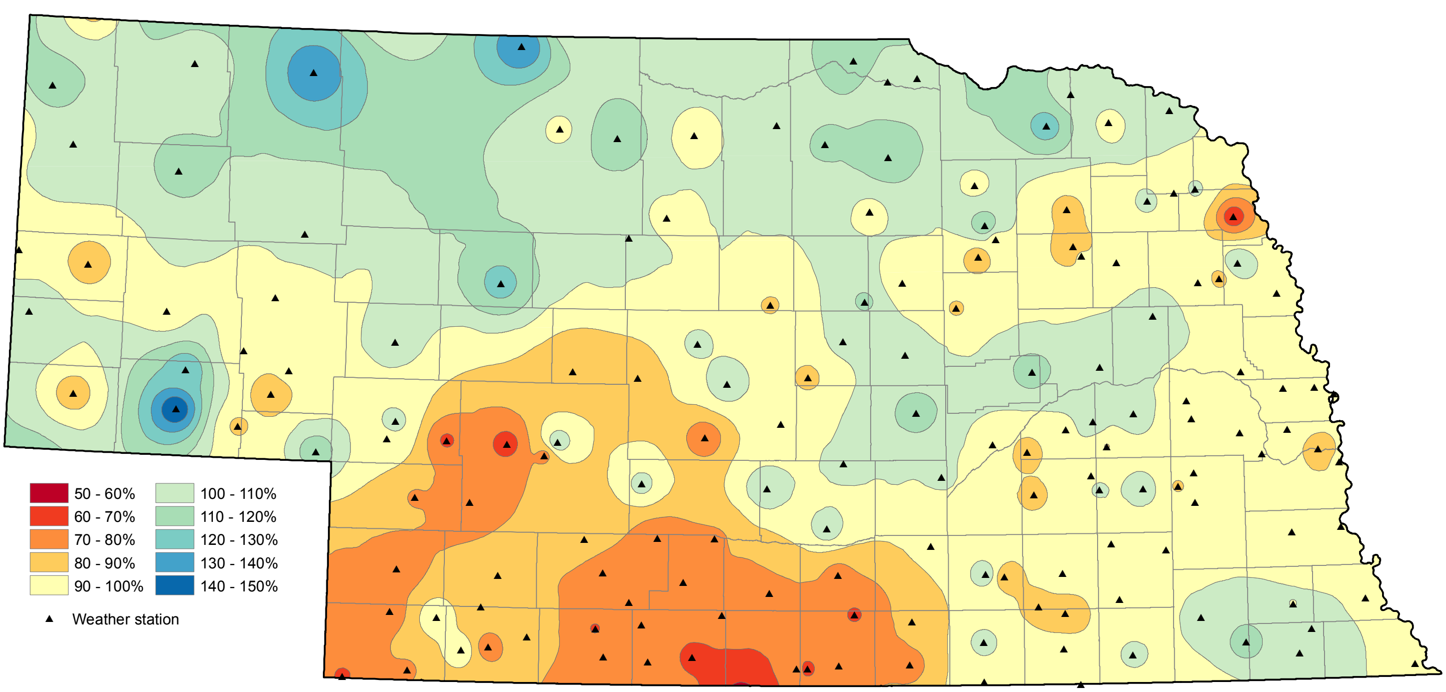
Localized groundwater-level rises were recorded for areas throughout the State, with most rises the result of changes observed in single wells. These changes may have resulted from crop rotation, or changes in pumping practices on a well to well basis. Northern Colfax County recorded a rise of 1 to 7 feet. This area had declines of more than 20 feet from the spring of 2012 to the spring of 2013. Slightly above-average precipitation and new water management practices for this area caused groundwater levels to rebound from the 2012 low. Other areas of groundwater-level increases were recorded in parts of Holt, Hooker, Thomas, Kimball, Cheyenne, Deuel, and Perkins Counties, mostly due to much above average precipitation values resulting in reduced irrigation pumping, higher recharge rates, and increased stream flows.

Figure 10. Groundwater-Level Changes in Nebraska - Spring 2013 to Spring 2014



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 11. Percent of Normal Precipitation - January 2013 to January 2014



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2009 TO SPRING 2014

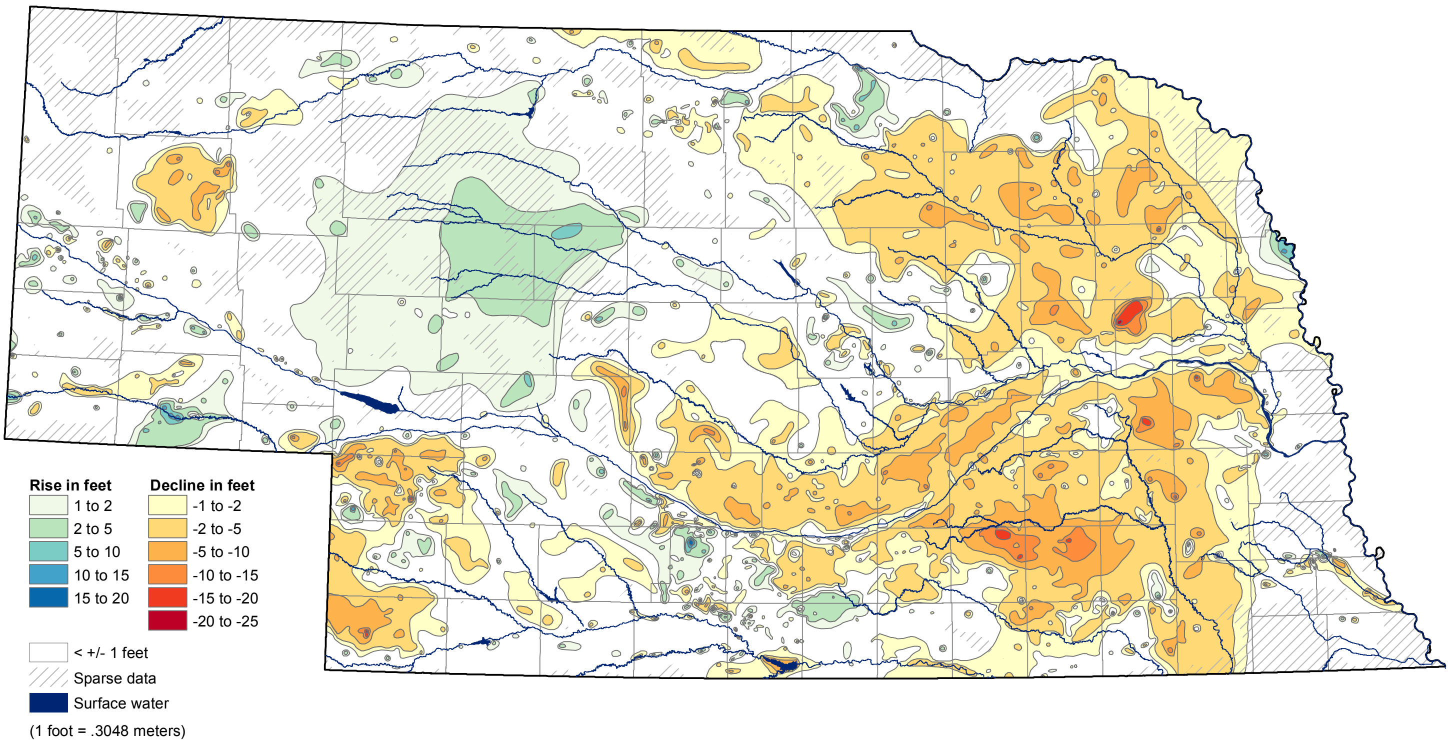
Extreme swings in precipitation from 2009-2014 resulted in near average precipitation values for Nebraska, however drawdowns resulting from the 2012 Drought caused an average statewide water level decline of 1.56 feet.

The five-year period between spring 2009 and spring 2014 was dominated by extreme swings in precipitation. Total average precipitation for the five-year period was near to slightly below the 30-year average (Fig. 13). Much above-average precipitation from 2009-2011 increased recharge to aquifers, and reduced demand for irrigation water causing rises in groundwater levels for many parts of the state (cf. Young et. al. 2012, pg. 10). Following the extremely wet years from 2009-2011, 2012 was the driest year on record for the state of Nebraska. The 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 recent years, resulting in significant net groundwater-level declines, particularly for parts of eastern Nebraska during the five-year period (Fig. 12).

The five-year groundwater-level change map was developed based on 4,683 wells which were measured in 2009 and 2014. Of these wells, 71% recorded declines, 54% of all wells recorded declines greater than one foot. One-tenth percent of wells recorded no change from spring 2009 to spring 2014. Vast areas of groundwater-level declines occurred over numerous parts of Nebraska. The greatest area of decline occurred in northern Colfax County, which recorded groundwater-level declines of up to 25 feet. Much of the eastern half of Nebraska recorded groundwater-level declines from 2-10 feet. Generally, areas of decline in eastern Nebraska had total precipitation from 80-100% for the five-year period 2009-2014. Most groundwater-level declines were the result of extreme drought conditions during the 2012 and early 2013 growing season.

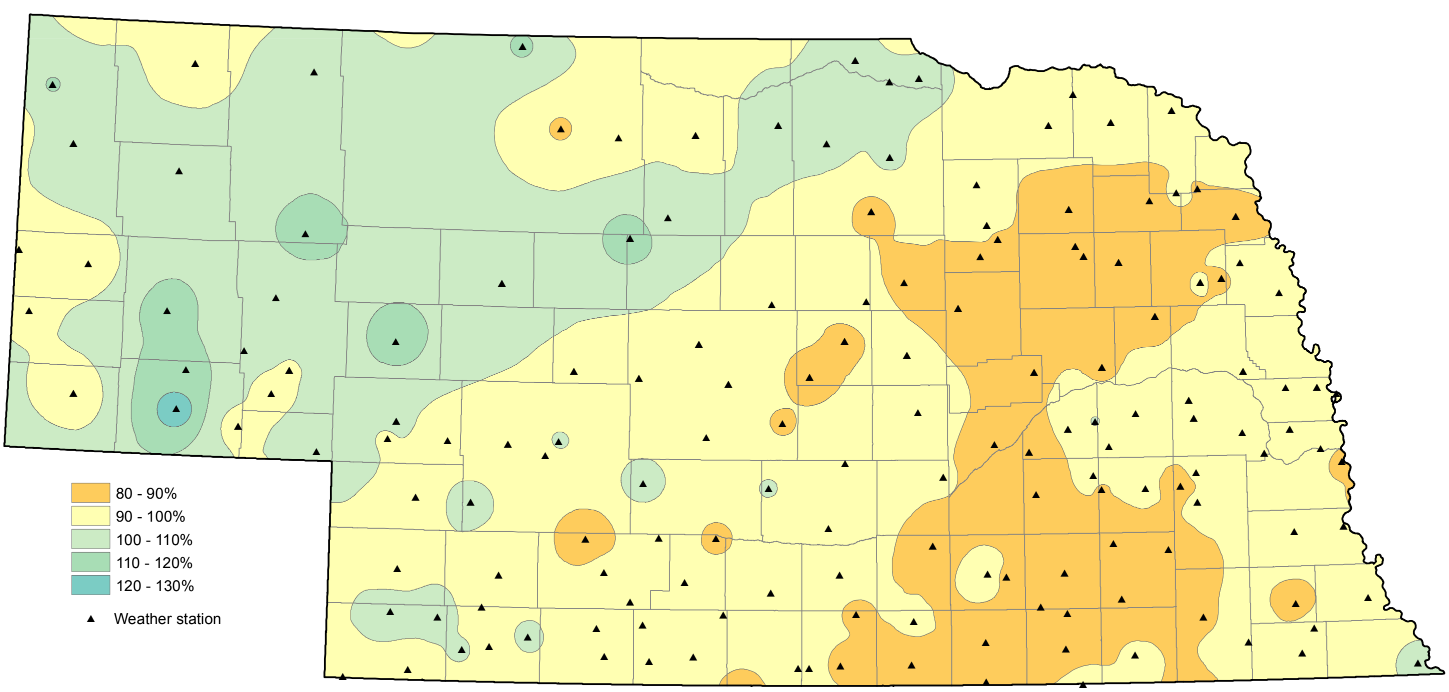
Other parts of Nebraska experienced average-to above-average precipitation when compared to the 30-year average. These areas generally corresponded to areas of groundwater-level rises. Of the 4,683 wells measured, 29% of wells recorded water level rises, while 13% of all wells recorded rises greater than one foot from spring 2009 to spring 2014. Most of the Nebraska Sand Hills received slightly more than average precipitation, and recorded groundwater-level rises from 1-10 feet. Similarly, Cheyenne County had precipitation values of 120-130% of the 30-year average, and had groundwater-level rises of more than 10 feet in some locations.

Figure 12. Groundwater-Level Changes in Nebraska - Spring 2009 to Spring 2014



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 13. Percent of Normal Precipitation - January 2009 to January 2014



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2004 TO SPRING 2014

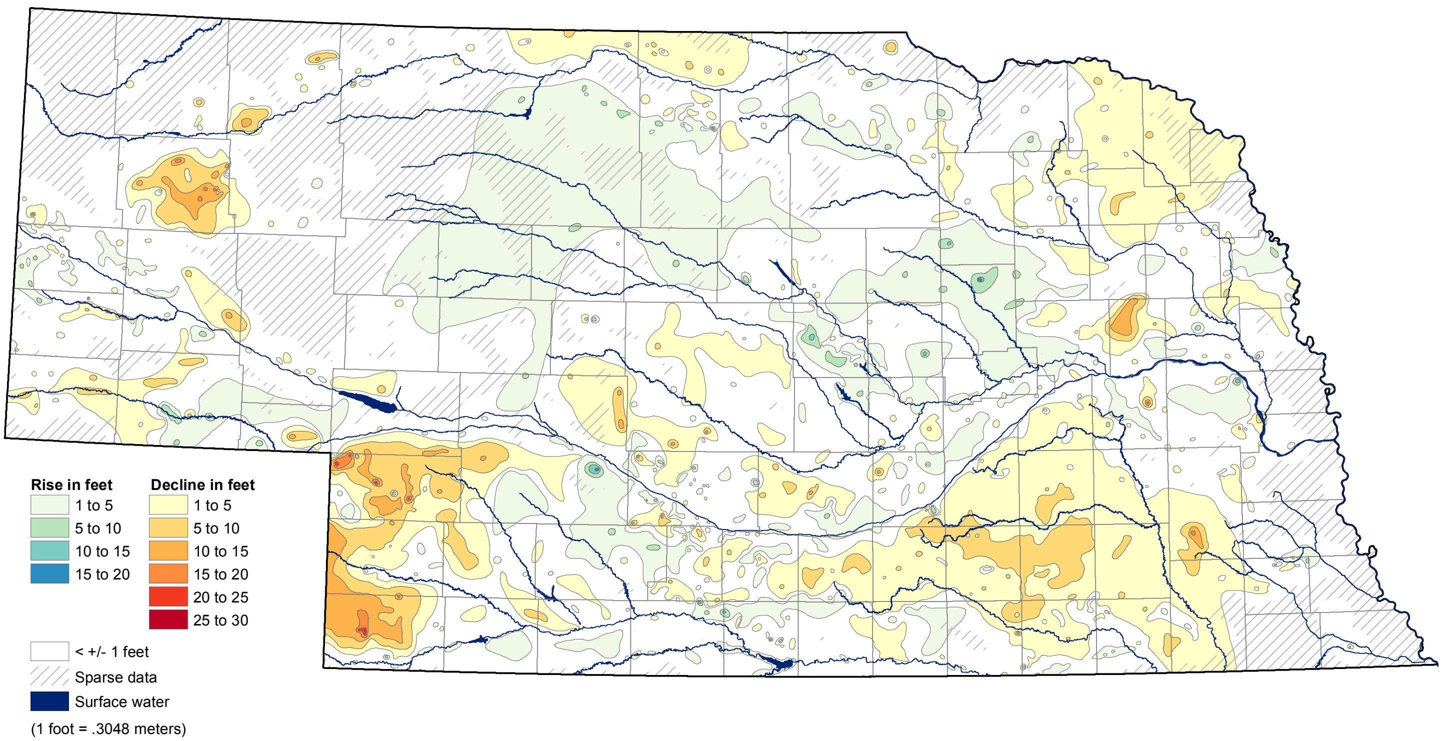
Contrasting patterns of groundwater-level changes over the past ten years reflect variations in the timing and locations of precipitation and irrigation withdrawals.

Groundwater-level changes from 2004 to 2014 were dominated by multiple contrasting periods of change. 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 were the driest years 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. Overall, the average precipitation for the 10-year period from 2004 to 2014 was near the 30-year normal for most of the state despite persistent drought conditions in 2012 and early 2013 (Fig. 15).

The largest continuous area of groundwater-level rise was recorded across the central Sand Hills which had a rise of 1-5 feet (Fig. 14). Parts of Boone, Antelope, Madison, Wheeler, and Platte Counties also saw rises ranging from 1-10 feet. Many of these areas are slow to react to extreme events such as the drought of 2012, thus rises in these areas may still represent groundwater-level rises associated with the extremely wet years from 2009 to 2011. As a result, many of these areas may decline in coming years. 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.

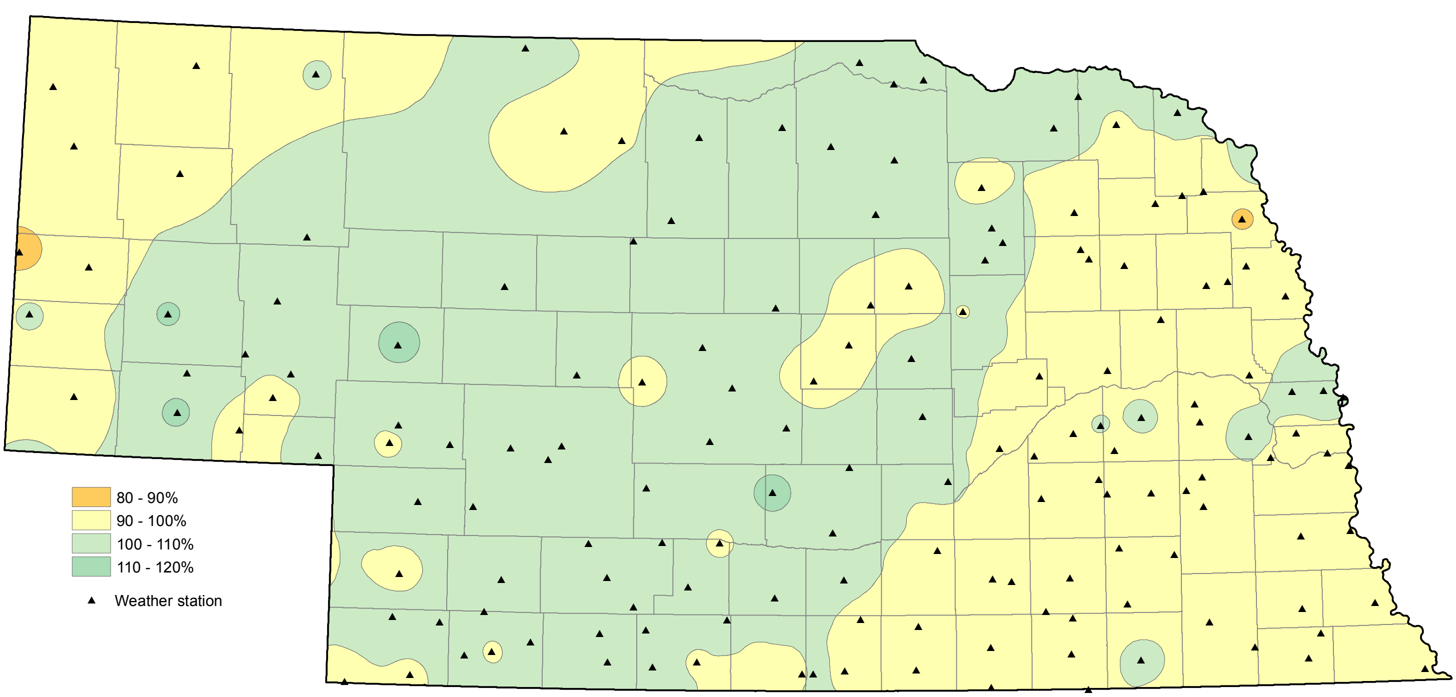
Many areas of the State recorded groundwater-level declines, largely the result of the increased demand for irrigation water and decreased recharge due to recent drought conditions. However, despite near-average precipitation for the State between 2004 and 2014, groundwater levels in some parts of the State continued 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 25 feet occurring in parts of Box Butte, Perkins, Chase and Dundy 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 1-20 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 14. Groundwater-Level Changes in Nebraska - Spring 2004 to Spring 2014



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. Percent of Normal Precipitation - January 2004 to January 2014



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

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 2014

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 2014 groundwater levels continue to indicate long-term declines and rises in certain areas of Nebraska (Fig. 16). 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. 17). The largest groundwater-level declines from predevelopment to spring 2014 occurred in the southwestern part of the state near Chase, Perkins, and Dundy Counties, and in the panhandle in Box Butte County. 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 1946. Intensive groundwater development for irrigation since 1950 has caused water levels to decline 5 to more than 90 feet from predevelopment levels (Fig. 16). 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).

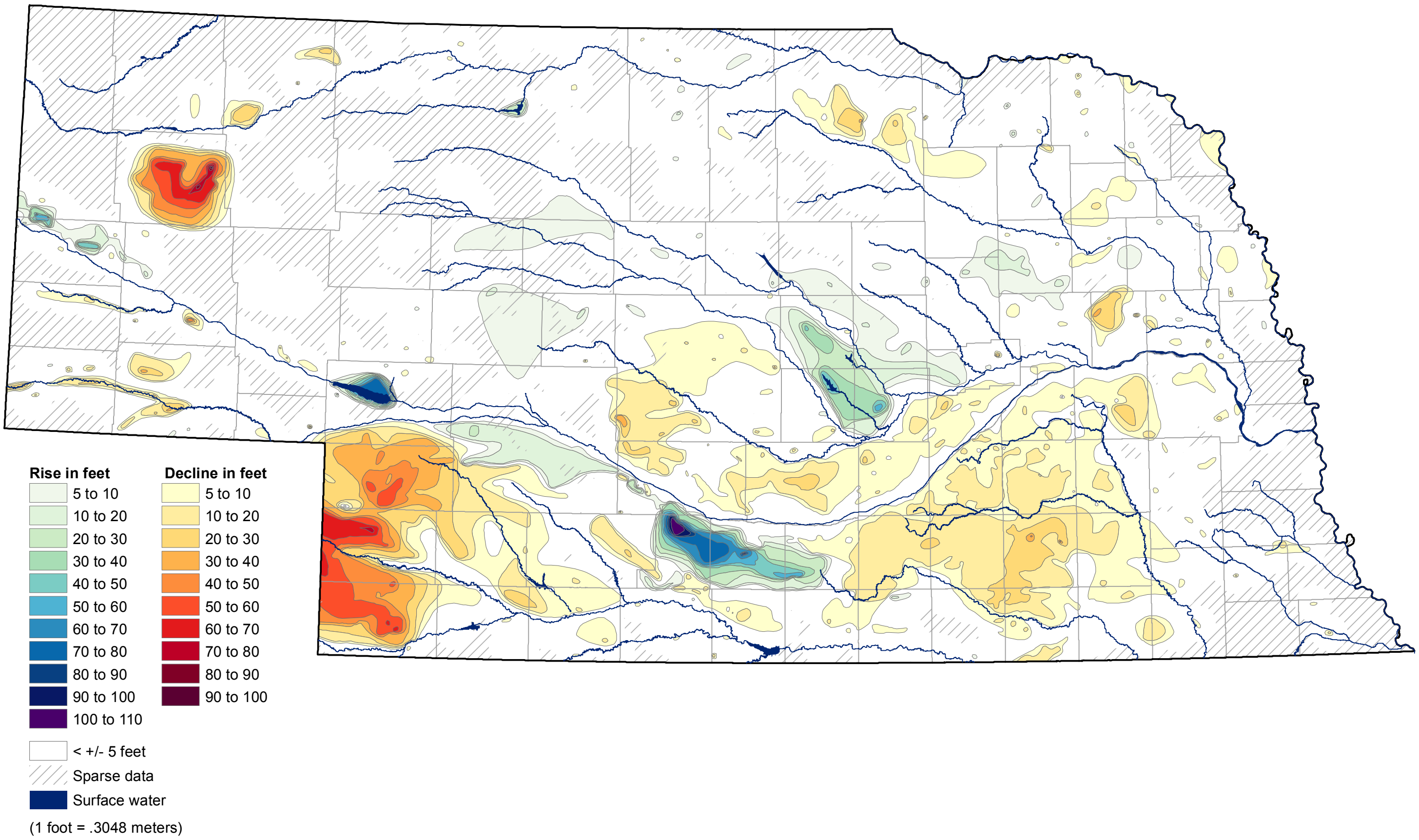
A large portion of southeast to south-central Nebraska has experienced long-term groundwater-level declines since predevelopment (Fig. 16). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this region have declined more than 10 feet, and in some areas more than 20 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 (Fig. 16). 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. 16). 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.

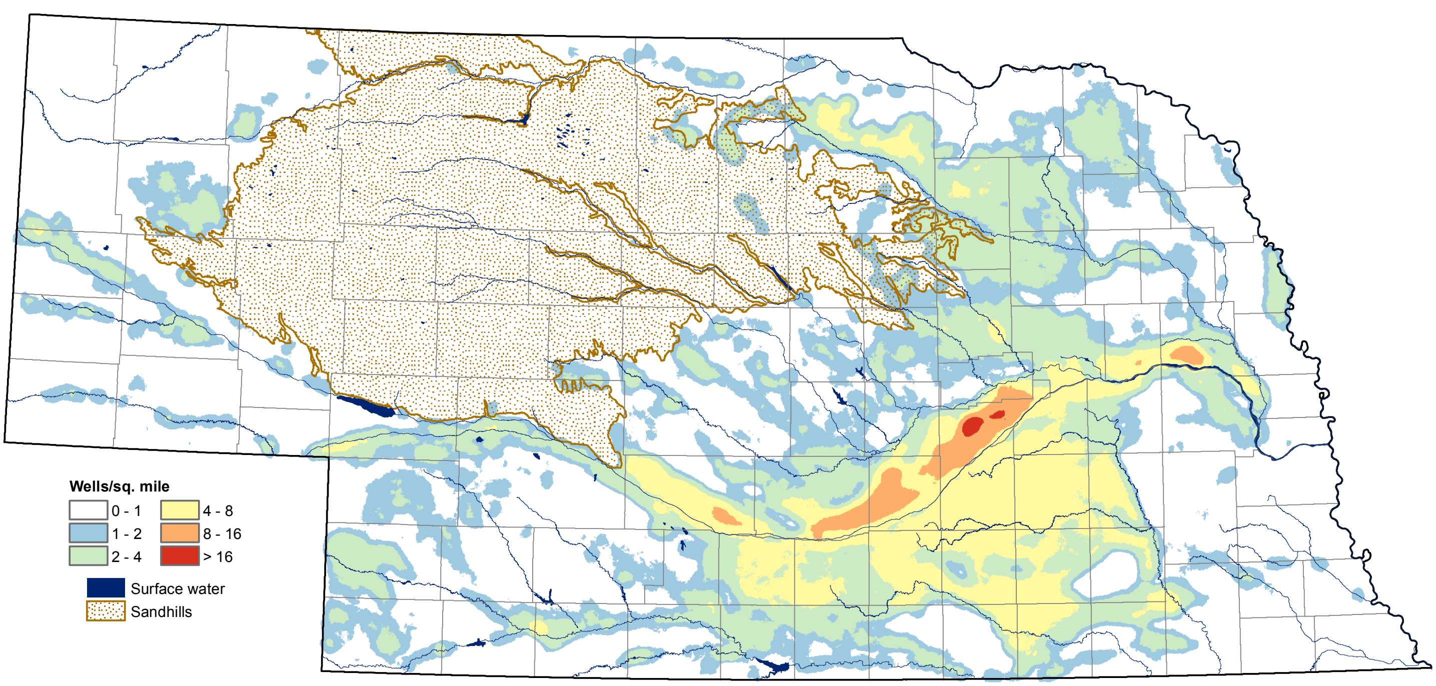
Groundwater-level rises of 10 to more than 60 feet occurred in portions of central Nebraska (Fig. 16). The highest water-level rises occurred in Valley, Sherman, and Howard Counties as the result of seepage from irrigation canals, Sherman and Davis Creek Reservoirs, and deep percolation of irrigation water applied to crops. Eastward of that area, rises occurred in aquifers that are relatively deep, have little connection to surface water, and have high densities of irrigation wells.

Figure 16. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2014



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. Density of Active Registered Irrigation Wells - January 2014



Source: Nebraska Department of Natural Resources

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 1981 AND SPRING 1981 TO SPRING 2014

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.

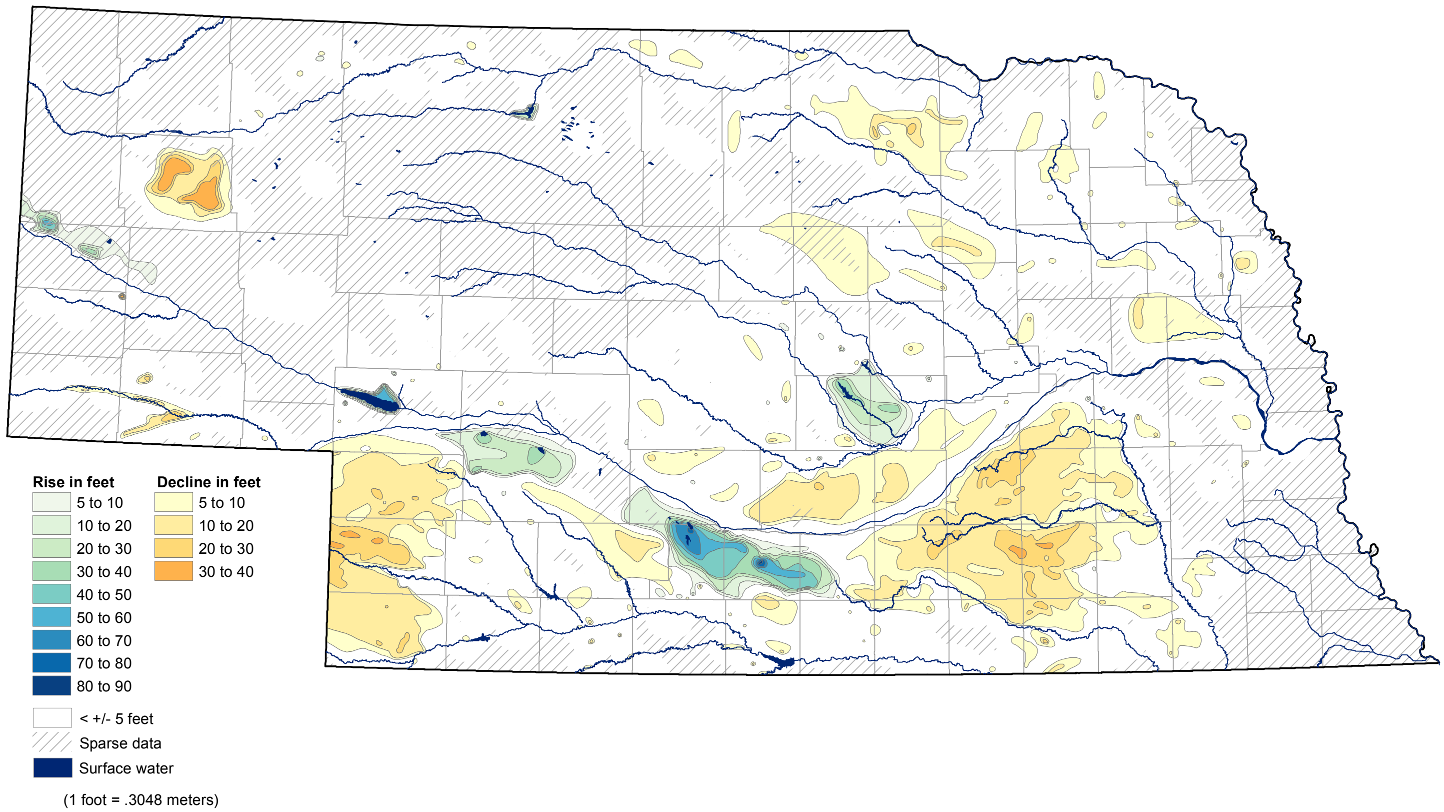
Groundwater-level changes from predevelopment to Spring 1981 reflect the responses of aquifers to the development of groundwater and surface water irrigation systems in Nebraska. Areas of significant groundwater-level declines generally corresponded to areas of dense irrigation well development (cf. Johnson and Pederson, 1981). Declines were generally equal in magnitude in eastern and western areas (Fig. 18). 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 30 feet in Box Butte County in the Panhandle, Chase County in the southwest, and Clay and Fillmore Counties in the south-central/southeast portion of the State. Declines occurred in smaller areas of the Republican River drainage as well as the northeast region. 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. 18). 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 60 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. 19). 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 2014. 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. 20). Many areas in central and eastern Nebraska have returned to 1981 levels, or have had a net rise in groundwater levels. However, the extent and magnitude of net gains in groundwater levels has decreased in these regions since the spring of 2011 due to extreme drought conditions of 2012 (cf. Young et. al. 2012, pg. 17). With few exceptions in localized areas in central and eastern Nebraska, water levels are still within 5 feet of 1981 levels.

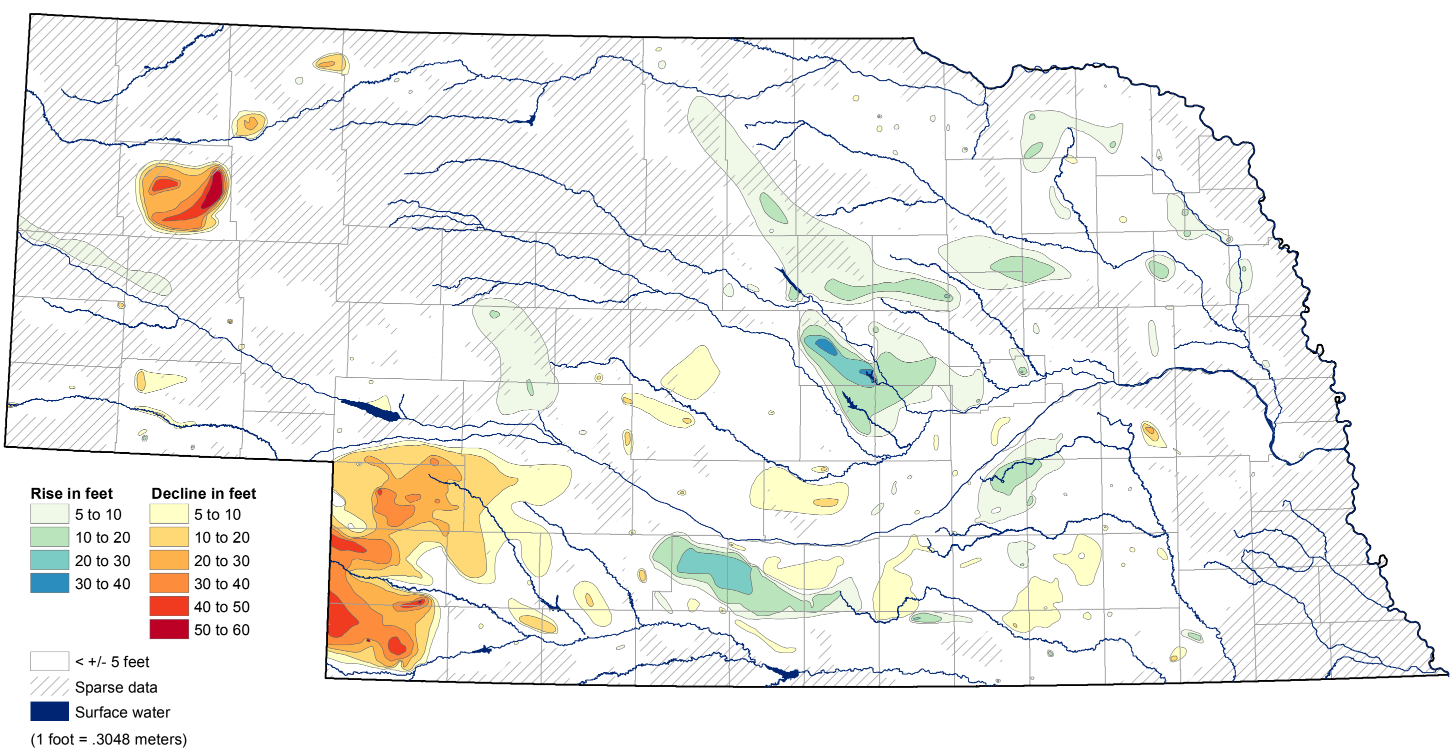
Declines in the south-central/southeast region of Nebraska reached a maximum in 1981 and have since recovered such that changes in some areas are now less than 5-10 feet compared to predevelopment levels (Figs 16, 18, 19). Groundwater levels in most of this area, however, remain below predevelopment 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 overapplication and deep percolation, which thereby recharged the shallow aquifer. Evidence for this phenomenon is shown in the hydrograph for the Exeter Recorder Well, which is screened in the shallow aquifer (Fig. 20). The steady rise from 1956 to 1981 in this well corresponds to the steady decline observed in nearby wells

Figure 18. 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

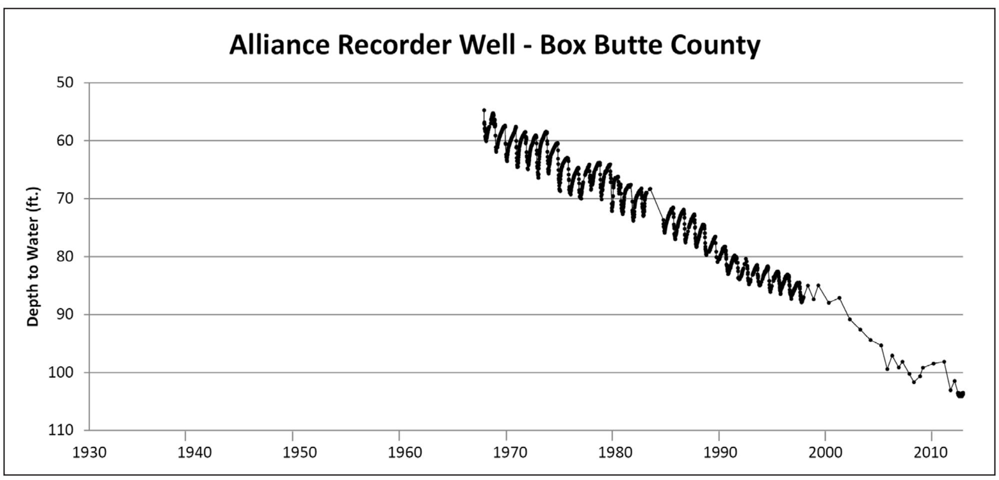
Figure 19. Groundwater-Level Changes in Nebraska - Spring 1981 to Spring 2014

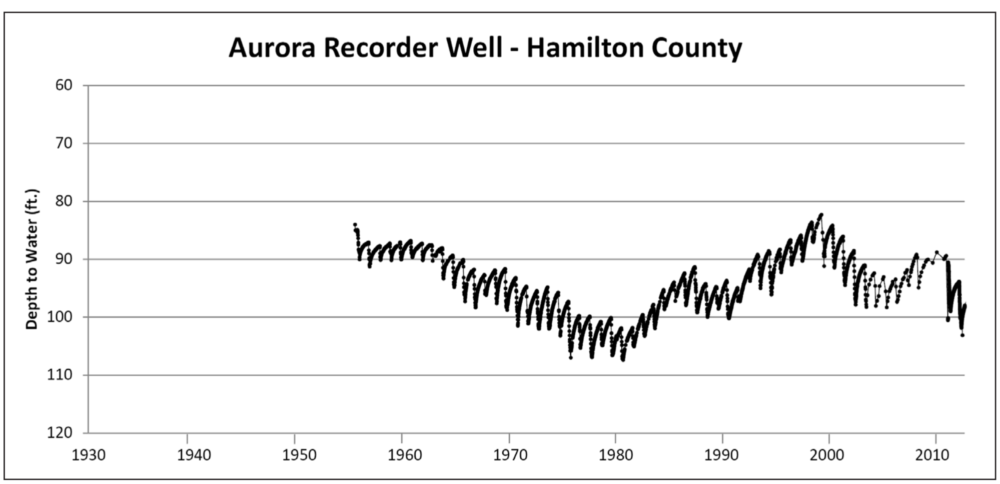


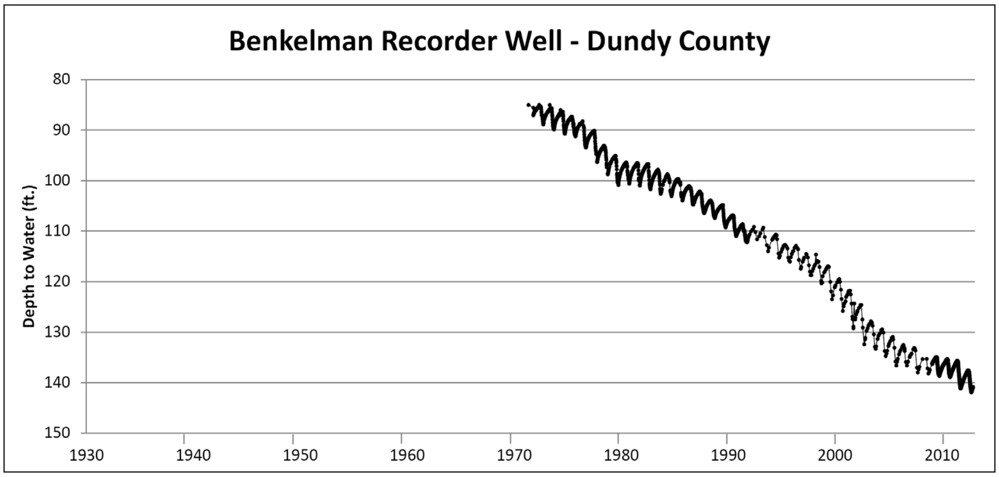
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District that are screened in the deep aquifer. This excess water may have served as a source of new recharge to the primary aquifer in areas where the confining layer is sufficiently permeable.

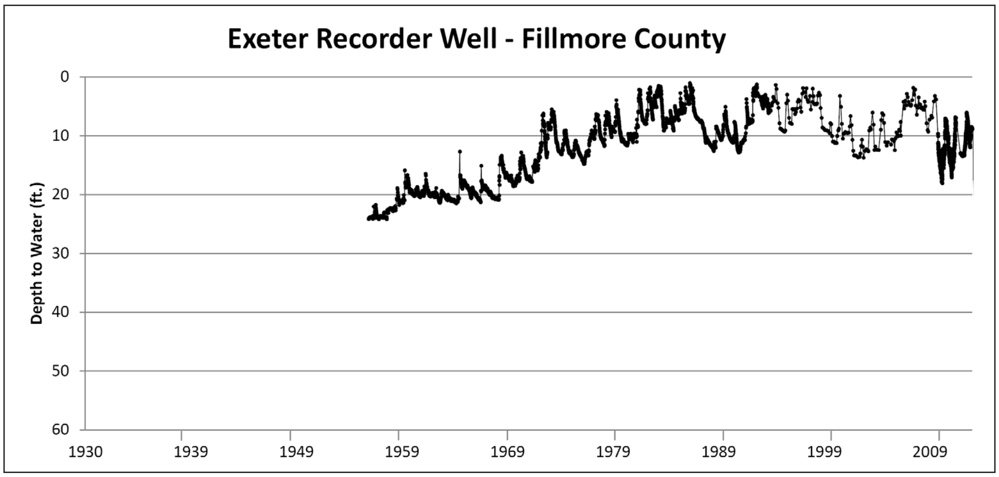
In contrast to the groundwater-level rises in the east, levels continued to decline in parts of western Nebraska from 1981 to 2014 (Fig. 19). The Alliance, Benkelman, and Imperial Recorder wells show declines of 50-60 feet in just 50 years, an average of about 1 foot per year (Fig. 20). Brief periods 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.

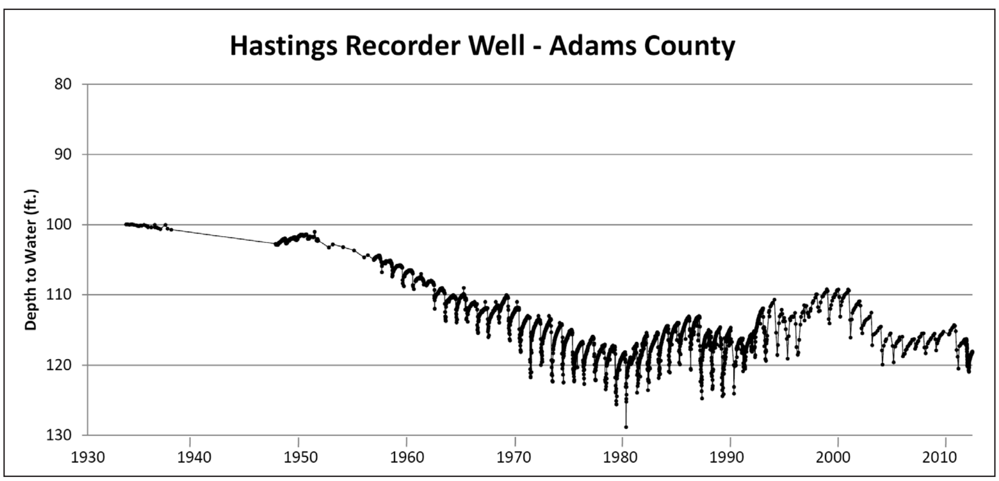
Figure 20. Groundwater-Level Hydrographs Typical of Southeast and Southwest Nebraska

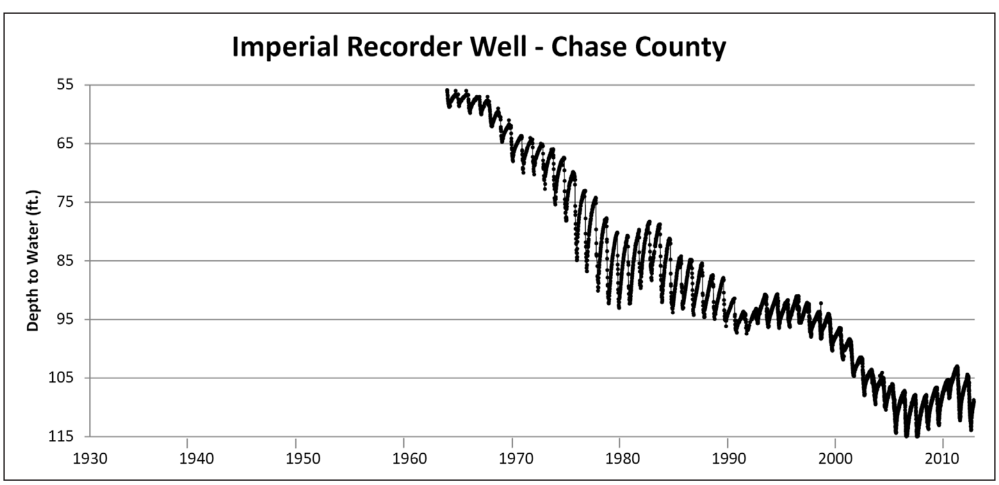





Benkelman Recorder Well - Dundy County
Depth to Water (ft.)
80
90
100
110
120
130
140
150
1930
1940
1950
1960
1970
1980
1990
2000
2010


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

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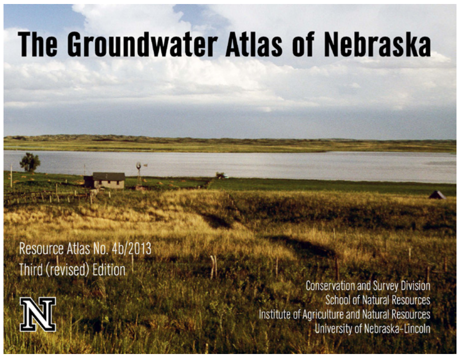
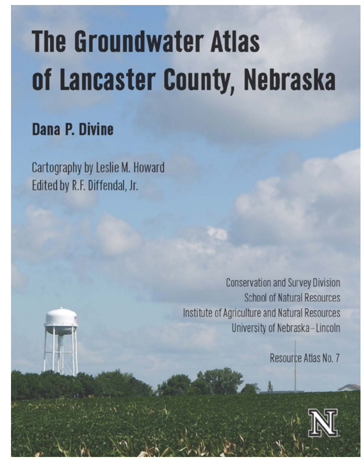


The Groundwater Atlas of Nebraska
The Groundwater Atlas of Nebraska is an award-winning publication describing all aspects of groundwater in Nebraska. This atlas contains more than forty maps, covering topics ranging from the history of water use in Nebraska, basic geology, historic water level changes, water quality, and more.



The Groundwater Atlas of Lancaster County, Nebraska
The Groundwater Atlas of Lancaster County, Nebraska describes the geologic setting of the county as it pertains to groundwater. The atlas contains maps, cross sections, photographs and related discussion regarding the location and amount of groundwater. Some water quality information is also included. All of the data used to create the maps are available as ArcGIS files.

Online Resources

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

The Nebraska Real-Time Groundwater-Level Network
The network consists of 57 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 Resource Districts
http://nrdnet.org/find-your-nrd.php

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

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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
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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
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1976	Nebraska Water Survey Paper 44	Ellis, M.J.; Pederson, D.T. 1977
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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
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1985	Nebraska Water Survey Paper 61	Ellis, M.J.; Pederson, D.T., 1986
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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
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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
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