Nebraska Statewide Groundwater-Level Monitoring Report

2018

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

Conservation and Survey Division
School of Natural Resources

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Nebraska Water Survey Paper Number 86

Institute of Agriculture and Natural Resources
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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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R.M. Joeckel, Nebraska State Geologist and Associate Director for the Conservation and Survey Division in the School of Natural Resources, UNL

Nebraska's Groundwater: A Resource Worthy of Respect

The term "groundwater" has come to be all but synonymous with Nebraska. Nearly three-quarters of the total volume of the High Plains Aquifer lies beneath the State. Groundwater maintains our streams, our ecosystems, our people, and our vitally important agricultural economy. Nebraska's total groundwater resource is vast, yet it is also vulnerable to natural and anthropogenic changes, necessitating a long-term commitment to wise management through informed decision making. Monitoring, studying, and reporting form 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 clean, abundant and accessible water to sustain our economy and way of life. Therefore, we must all partner in management as informed citizens.

Developments in water in Nebraska in 2018

Water issues make headlines in Nebraska every year. In late May 2018 the Groundwater Foundation (Lincoln) and the National Groundwater Association announced their merger in order to "raise the national profile of the groundwater industry" (Groundwater Foundation, 2018). Offices of the Groundwater Foundation will remain in Lincoln.

A Special Permit for a proposed poultry farm in Lancaster County, to be one of many suppliers to a Costco poultry plant opening in Fremont in 2019, was approved by the Lancaster County Board of Commissioners by a 3-2 vote in September 2018 (Lancaster County Commissioners, 2018). Some local residents continue to express concerns about potential water pollution and other matters, and three opponents of the proposed farm filed a notice of appeal with the Lancaster County Clerk in October (Olberding, 2018a, b). The U. S. Army Corps of Engineers reported in November that the remediation of groundwater contamination at the former Nebraska Ordnance Plant (Mead) was progressing but also that completion of the work will require many more years (Brichacek, 2018). Antelope Creek in Lancaster County was removed from the U. S. Environmental Protection Agency's (EPA) Impaired Waters list in October 2018 after 14 years of improvements (Hicks, 2018). Shell creek was removed from the EPA's Impaired Waters list earlier in the year (Hicks, 2018). EPA Region 7 awarded $1.2 million to Nebraska for environmental cleanups that include water issues (EPA, undated-a). Furthermore, Region 7 reached a settlement in August with two animal feeding operations near West Point for violations of the Clean Water Act (EPA, undated-b). The U.S. Atomic Safety and Licensing Board held hearings in Crawford during the fall of 2018 regarding a proposed expansion of Cameco's Crow Butte uranium mining operation near Marsland (Rempp, 2018).

The Lower Platte River Basin Consortium, which is scheduled to expire in 2019, continued to promote its draft drought contingency plan with two public open houses. The Central Platte Natural Resources District (CPNRD) Board of Directors approved changes in the Rules and Regulations for the Groundwater Management Plan that went into effect on November 1, 2018. The Papio-Missouri River Natural Resources District (P-MRNRD) adopted a new Groundwater Management Plan in February and its revised Groundwater Rules and Regulations went into effect on March 1, addressing new high capacity wells.

The Lincoln Water System installed a pipeline under the Platte River near Ashland to deliver water from well fields north of the Platte River to Lincoln for the first time (Salter, 2018).

The Central Nebraska Public Power and Irrigation District (CNPPID) approved bids in September on the construction of four pipelines intended to transfer high Platte River flows to U.S. Fish and Wildlife Service waterfowl production areas (Potter, 2018a). In November, CNPPID also approved additional diversions of surface water into Elmwood Reservoir for groundwater recharge. CNPPID and the Tri-Basin and Lower Republican Natural Resources Districts approved a 2017 proposal for a surface-water transfer project between the Platte and Republican basins to help meet the conditions of the Republican River Compact. The proposed project would transfer high Platte River flows from CNPPID's E65 Canal through a pipeline to the east branch of Turkey Creek, a tributary of the Republican River in Gosper County. The NRDs purchased land in Turkey Creek Canyon early in 2018 and the CNPPID and Platte Republican Diversion Interlocal Agreement Partners submitted an application to the Nebraska Department of Natural Resources (DNR) in April 2018 (Potter, 2018b). Opposition to the proposed water transfer, however, continued to emerge. In early August, Kansas Governor Jeff Colyer notified the Nebraska DNR of his opposition to the proposed project on the basis of a potential range extension of invasive fish species (Kansas Department of Agriculture, undated), and the Kansas Chapter of the Sierra Club sent a similar letter (Sierra Club Kansas Chapter, 2018) thereafter. A September 1 newspaper opinion written by the Director of the Nebraska Game and Parks Commission described the proposed project as "short-sighted, ill-conceived and potentially damaging" (Douglas, 2018). Audubon Nebraska has also registered opposition to the proposal (Audubon Nebraska, undated). Public hearings regarding an integrated water management plan were held in November.

In February 2018, the governors and attorneys general of Nebraska and Colorado reached a settlement of old claims regarding Colorado's use of surface water according to the Republican River Compact (Office of Governor Pete Ricketts, undated), and the Denver Post reported that Colorado would be required to make a $4 million payment to Nebraska by December 31 in order to validate the agreement (Schulte, 2018).

In June 2018, the Nebraska Supreme Court held in Upper Republican NRD v. Dundy County Board of Equalization that groundwater resources are linked to land ownership, thereby rejecting arguments for decoupling the two in the case of the Rock Creek Augmentation Project in Dundy County (Nebraska Supreme Court, 2018). A Nebraska District Court (Valley County) ruled in at least one case with a reference to groundwater during 2018 (Prokop v. Lower Loup Natural Resources District). LB 758 was introduced in the Nebraska Legislature in January (Nebraska Legislature, undated). Among other provisions, this bill allows Natural Resources Districts to make voluntary payments in lieu of taxes on private lands acquired for water augmentation projects. The bill was approved by Governor Pete Ricketts at the end of February. Three recent federal bills are relevant to water and groundwater nationwide. The Water and Energy Sustainability through Technology Act was introduced in 2017 and passed through multiple committees and subcommittees before being referred to the Subcommittee on Energy in May 2018. Agriculture Improvement Act of 2018 was introduced in April 2018 and passed the Senate amended in June. America's Water Infrastructure Act of 2018 was introduced in the Senate during May 2018.

Conservation and Survey Division Activities in 2018

CSD has studied Nebraska's groundwater, geology, and soils for 126 years. It made many contributions to the University and its stakeholders in 2018. CSD personnel were involved in more than $11.4 million in active external funding and they produced 41 publications, including 18 peer-reviewed scientific journal articles and 5 geologic maps. CSD personnel also taught 10 courses at the University, provided more than 3,300 continuing education credits (CEUs) for professionals, and made nearly 60 presentations to diverse audiences. Continuing a seven-decade tradition of detailed subsurface geological investigations, CSD drilled or logged more than 10,500 ft of geologic test holes in 2018.

SELECT RECENT GROUNDWATER PUBLICATIONS AND RESOURCES

The Groundwater Atlas of Red Willow County, Nebraska
Divine, D.P. and Eversoll, D.A., 2018. Conservation and Survey Division, University of Nebraska, Resource Atlas 11, 35 p.

Recognition of Regional Water Table Patterns for Estimating Recharge Rates in Shallow Aquifers
Gilmore, T. E., Zlotnik, V., & Johnson, M.* 2018. Groundwater, 0(0) (online view). https://doi.org/10.1111/gwat.12808

Combining hydraulic head analysis with airborne electromagnetics to detect and map impermeable aquifer boundaries
Korus, J.T., 2018, Water, v. 10, no. 8, p. 975. doi: 10.3390/w10080975

Nebraska GeoCloud brings high-tech hydrogeologic data down to earth
Korus, J.T., 2018, Water Well Journal 72 (1): 10-11.

Assessing decadal trends of a nitrate-contaminated shallow aquifer in western Nebraska using groundwater isotopes, age-dating, and monitoring
Wells, M., Gilmore, T., Mittelstet, A., Snow, D., Sibray, S., Wells, M. J., et al., 2018. Water, 10(8), 1047. https://doi.org/10.3390/w10081047

Online Resources

go.unl.edu/groundwater

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

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

Other Online Resources

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

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

INTRODUCTION

Groundwater-level information is valuable to citizens and stakeholders.
It quantifies the availability of groundwater and informs management decisions.

This report is a 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 1950s. 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 the central role in the statewide groundwater-level monitoring program, other agencies have assumed the responsibilities of building and maintaining observation networks and measuring groundwater-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 Natural Resource Districts (NRDs) (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 groundwater-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 identifying 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 essential information only escalates as water-use pressure steadily increases. 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.

Purpose and Methods

The vast majority of groundwater used in Nebraska is pumped from the High Plains Aquifer (HPA), although there are multiple aquifers in the State (Fig. 2, 3). The HPA underlies parts of eight states, including South Dakota, Wyoming, Nebraska, Colorado, Kansas, Oklahoma, Texas and New Mexico. In total, Nebraska overlies approximately 64,600 m^2 of the HPA, or 36% of the total aquifer by area. By volume as of 2009, Nebraska has approximately 2.040 billion acre-feet of saturated sediments, or 69% of the total volume of the HPA (McGuire et. al., 2012). The greatest area of saturated thickness in the HPA, nearly 1,000 feet, is located under the western portion of the Nebraska Sand Hills (c.f. Korus et. al. 2013, pp. 44).

Although Nebraska is fortunate to have such vast supplies of groundwater, any groundwater supply is vulnerable to depletion through overpumping. According to the 2012 US Census of Agriculture, Nebraska leads the nation in irrigated acres with more than 8.3 million acres. Without proper oversight, irrigation pumping on this scale can rapidly deplete aquifers and lead to large-scale economic hardship. Recent news stories from Colorado (e.g., Finley, 2017) and parts of Kansas, Oklahoma, Texas and New Mexico (e.g., James and Reilly, 2015) highlight the need for groundwater conservation efforts. The present report illustrates the changes in groundwater levels in Nebraska at different time scales, resulting from both natural and human influenced changes. This information is important to both state and local lawmakers in assessing the

Figure 1. Nebraska Natural Resources Districts

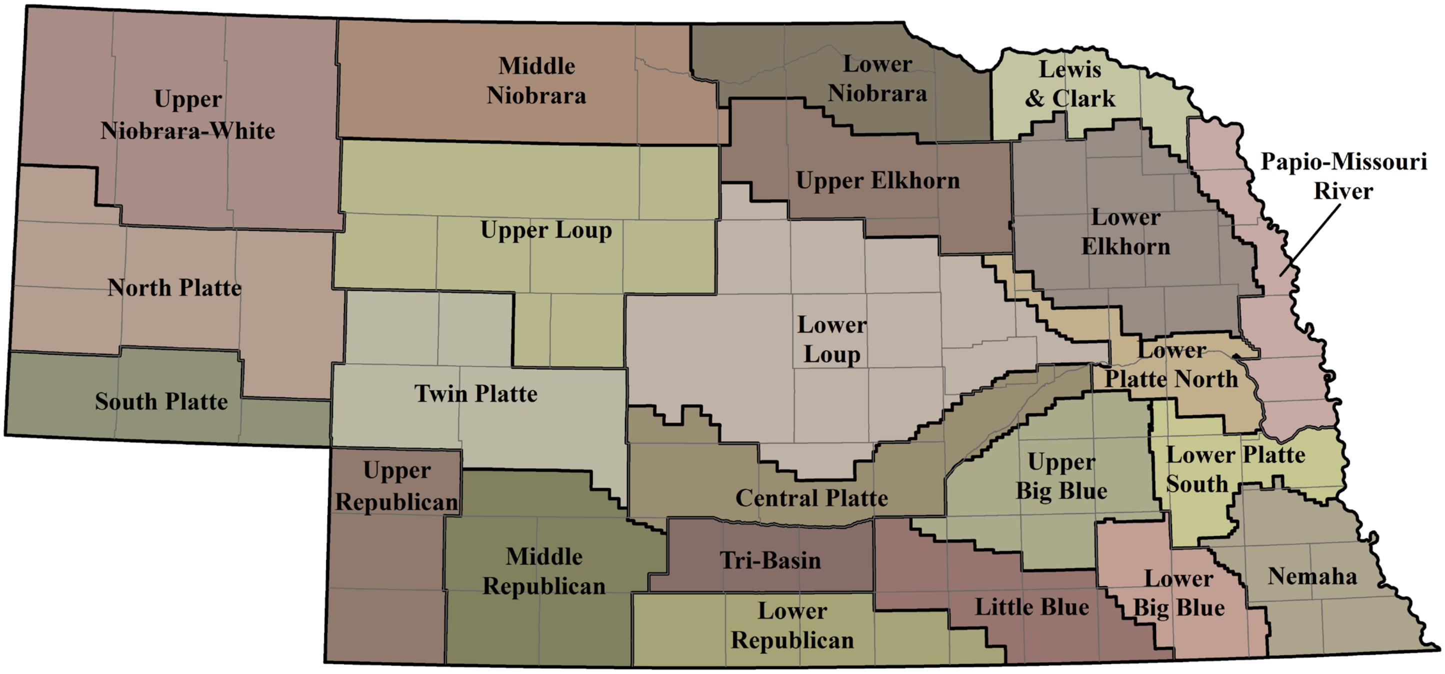
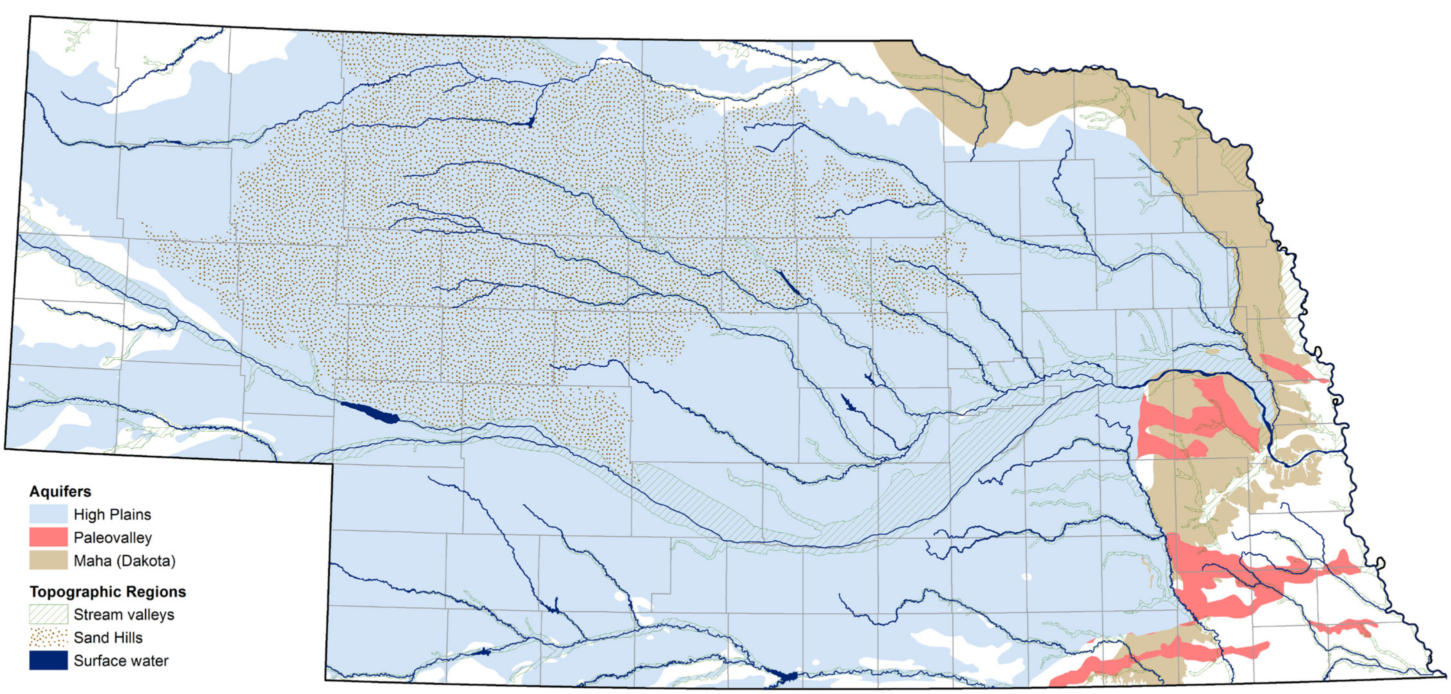


Figure 2. Important Aquifers and Topographic Regions of Nebraska



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

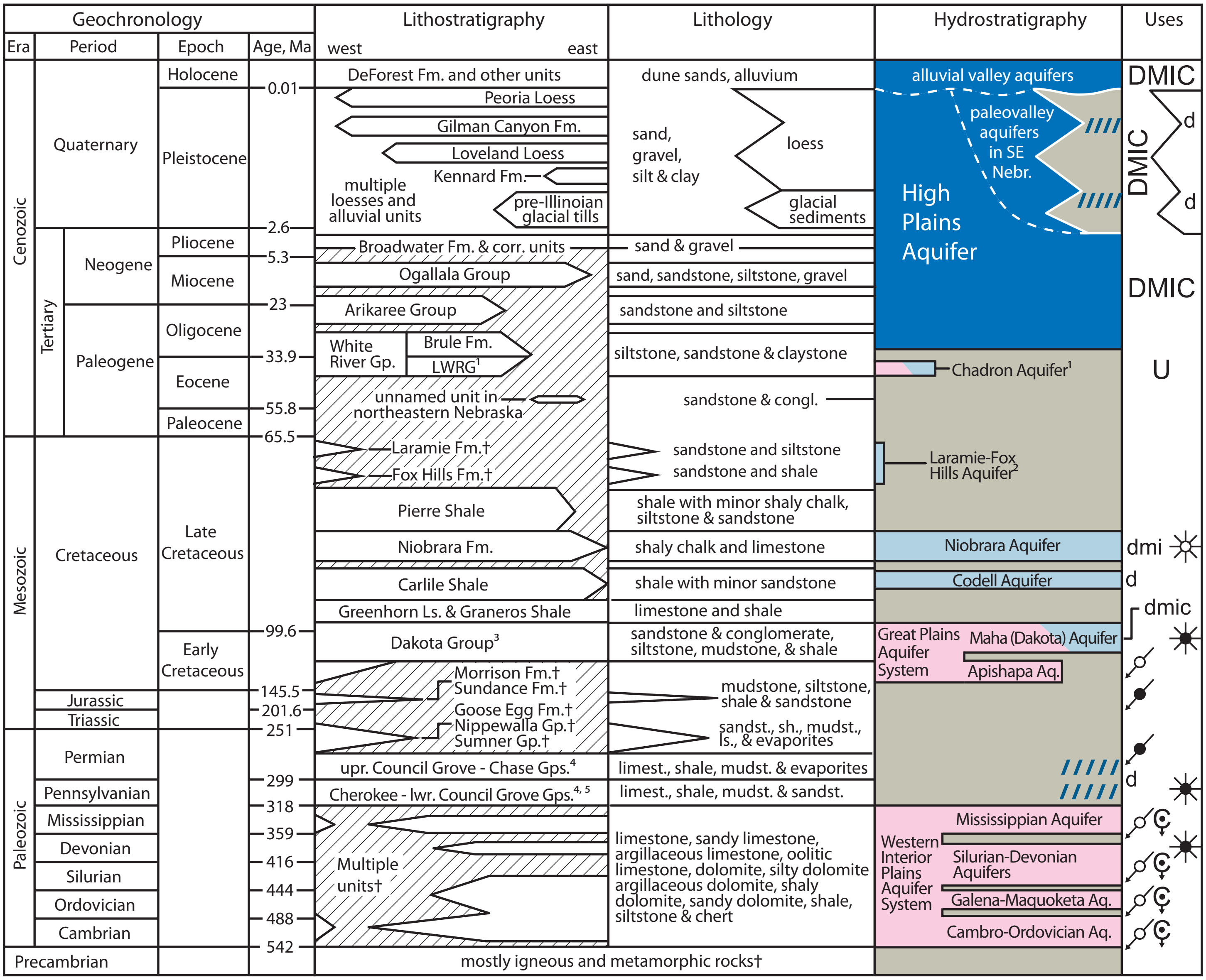


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

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

current state of Nebraska's groundwater resources, and to local producers in making land management decisions.

This report summarizes changes in Nebraska's groundwater levels over periods of one , five, and ten years prior to 2018, as well as from 1981 to 2018, predevelopment to 1981 and predevelopment to 2018. 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. We stress that the maps presented in this report provide overviews of the general locations, magnitudes, and extents of rises and declines. Local conditions, which may vary considerably, are not depicted in these maps and, indeed, cannot be represented with accuracy. The reader is referred to Figures 1 thru 4 for the locations of NRDs, rivers, aquifers, and counties mentioned in the text.

The one-, five-, and ten-year changes are presented in the spring 2017 to spring 2018, spring 2013 to spring 2018, and spring 2008 to spring 2018 maps, respectively. Groundwater levels measured from thousands of wells throughout the State during the spring of 2018 (Fig. 5) were compared to levels measured in the same wells in the spring of the preceding year. A spreadsheet of wells used for mapping are available for download at http://snr.unl.edu/data/water/groundwater/gwlevelchangemaps.aspx. For the one-, five-, and ten-year change maps, contours were generated using computer interpolation. These contours were incorporated into the final maps in areas where the principal aquifer is geographically continuous and in relatively good hydraulic connection, and where data density is comparatively high. In areas not meeting these criteria, 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 HPA is separated by deeply entrenched parts of the Niobrara, Republican, and Platte River valleys. For the spring 1981 to spring 2018 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 2018 and predevelopment to spring 1981 maps, water levels from wells measured in 2018 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 are generally presumed to be those that predated intensive groundwater irrigation. Such intensive use of groundwater began during the approximate period 1930 to 1960, although not synchronously across the State. Predevelopment map 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 (e.g. Fig. 7). A computer point density interpolation was used to determine the number of observation points within a 6-mile (approximately 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 (www.ncdc.noaa.gov). The 30-year normal currently in use is calculated on the basis of average annual precipitation during 1981-2010. A precipitation surface is generated using the inverse distance weighted interpolation method in ArcGIS with a 1,640 foot (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.

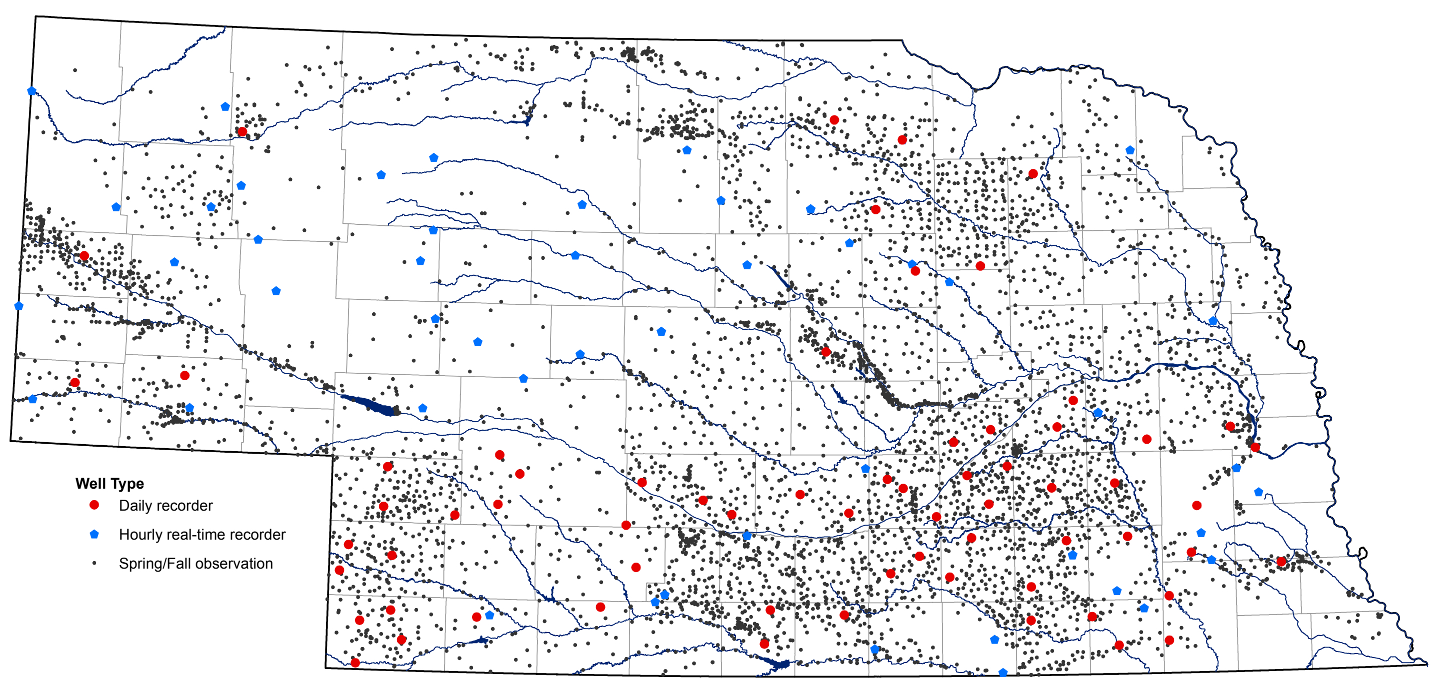
Factors Causing Groundwater-Level Changes

Long-term groundwater-level changes result from 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.

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 concept is a gross

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

Figure 5. Location of Observation Wells by Type

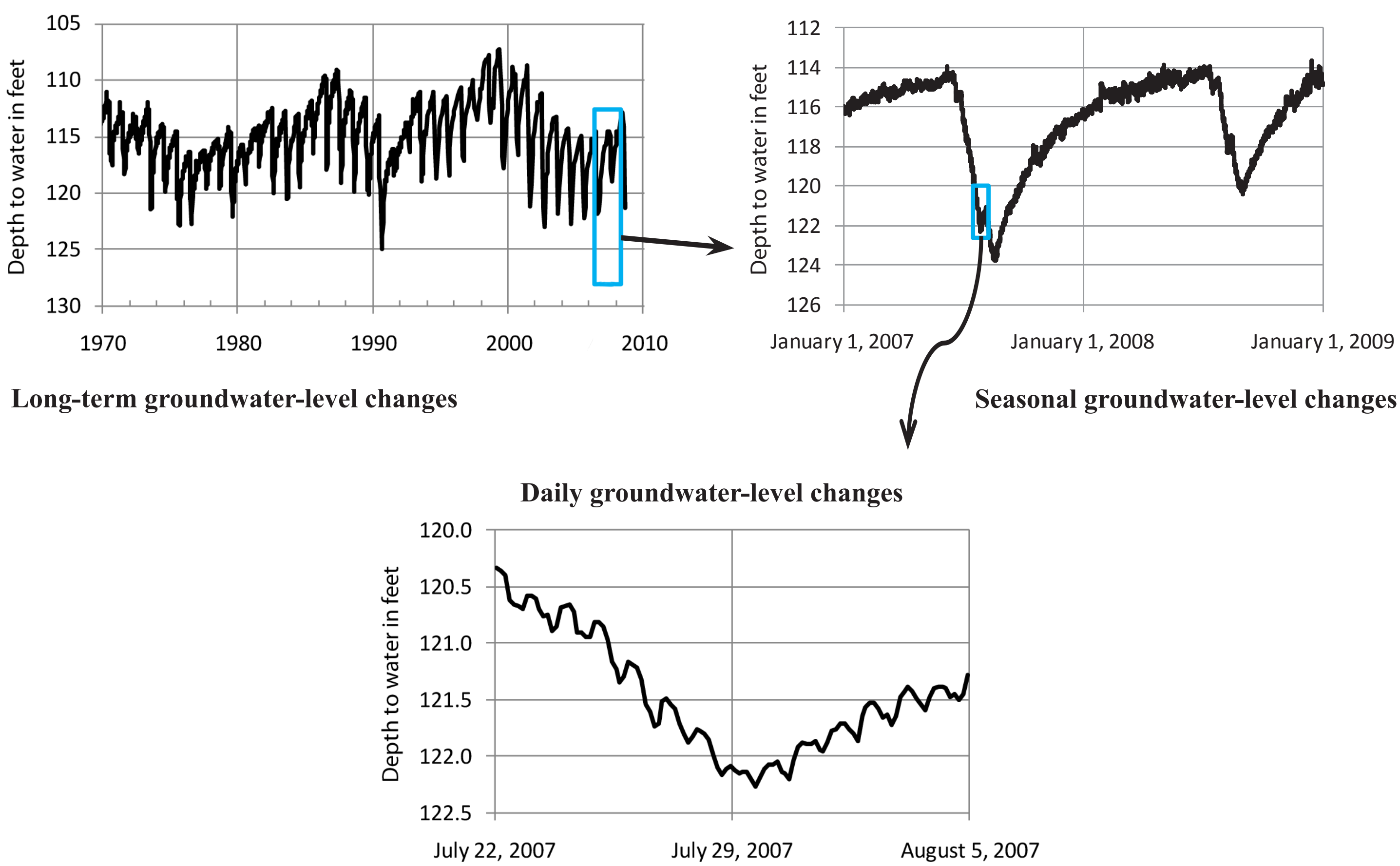


Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln oversimplification of hydrogeologic processes. 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, 1998, 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 solely 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 2017 TO SPRING 2018

With precipitation values above the long-term average for most of Nebraska, on average water levels experienced modest rises from 2017-2018.

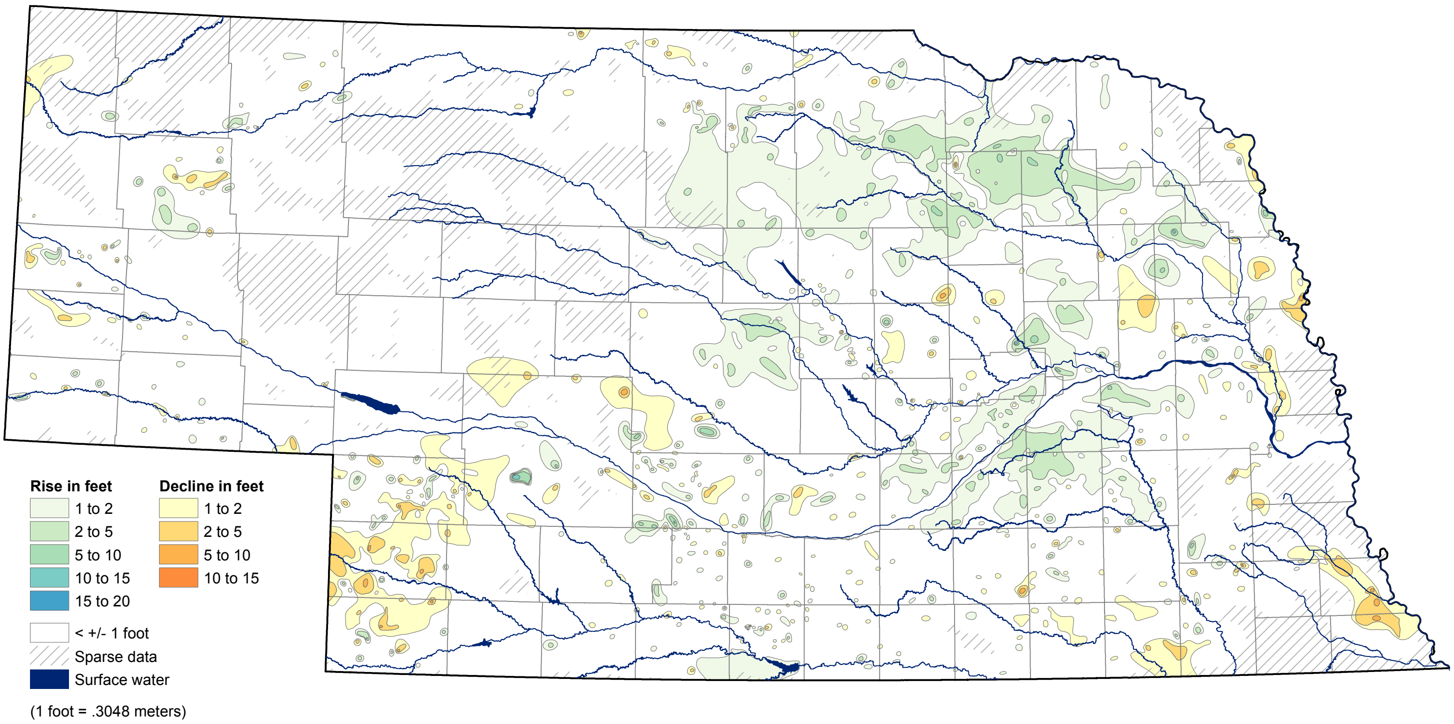
Groundwater levels in Nebraska generally experienced modest rises from the spring of 2017 to the spring of 2018. In total, 5,364 wells were measured consecutively in 2017 and 2018. Of those wells, 41% recorded groundwater-level declines compared to the spring of 2017, with 11% experiencing a decline of greater than one foot (Fig. 7). Groundwater-level rises were recorded in 58% of wells measured, with 23% of wells recording a rise greater than one foot. Approximately 1% of wells had neither rises nor declines from the spring of 2017 to the spring of 2018. The average water-level change for all wells in Nebraska was a rise of 0.27 feet. From January 2017 to January 2018, precipitation values for Nebraska were generally above normal, and values ranged from 70 to 150% of the 30-year average (Fig. 8).

In general, groundwater-level rises were recorded in central and eastern Nebraska, where precipitation values ranged from near average to much-above-average. Large areas of rises greater than two feet are mapped in portions of Antelope, Butler, Custer, Platte, Polk and York Counties. More localized areas of groundwater-level rises were recorded in the northern half of the Panhandle, particularly in and around Box Butte County, parts of which received 140% of the 30-year precipitation average (Fig 8). A rise of greater than 16 feet was recorded in central Lincoln County in the vicinity of the Nebraska Cooperative Republican Plate Enhancement (NCORPE) project well field. NCORPE is a joint project of four Natural Resources Districts (NRDs) that was created to help the State of Nebraska and those NRDs meet river-flow obligations in the Republican and Platte Rivers in accordance with the Republican River Compact. A portion of the NCORPE wells were pumped continuously for four months between November 2016 and March 2017, producing drawdowns in the vicinity of that well field. The rise depicted in Figure 8 is associated with the recovery of water levels adjacent to the NCORPE well field following 13 months of non-pumping from March 2017 until spring readings were taken in April 2018. Results of groundwater modeling performed by NCORPE indicate that "NCORPE may have no greater impact than pre-existing irrigation over the long term" (NCORPE 2018). For more information on the NCORPE project and associated water-level impacts, see Young et. al. (2017 p. 14).

Groundwater-level declines were limited to southeastern and southwestern Nebraska, both of which received near-average to slightly below-average precipitation. The most extensive areas with declines greater than two feet were mapped in portions of Burt, Chase, Colfax, Dundy, Jefferson, Nemaha, Perkins, and Richardson Counties (Fig. 7). Additionally, despite significantly above-average precipitation, portions of Box Butte County had groundwater declines of as much as 2 to 5 feet in heavily pumped areas.

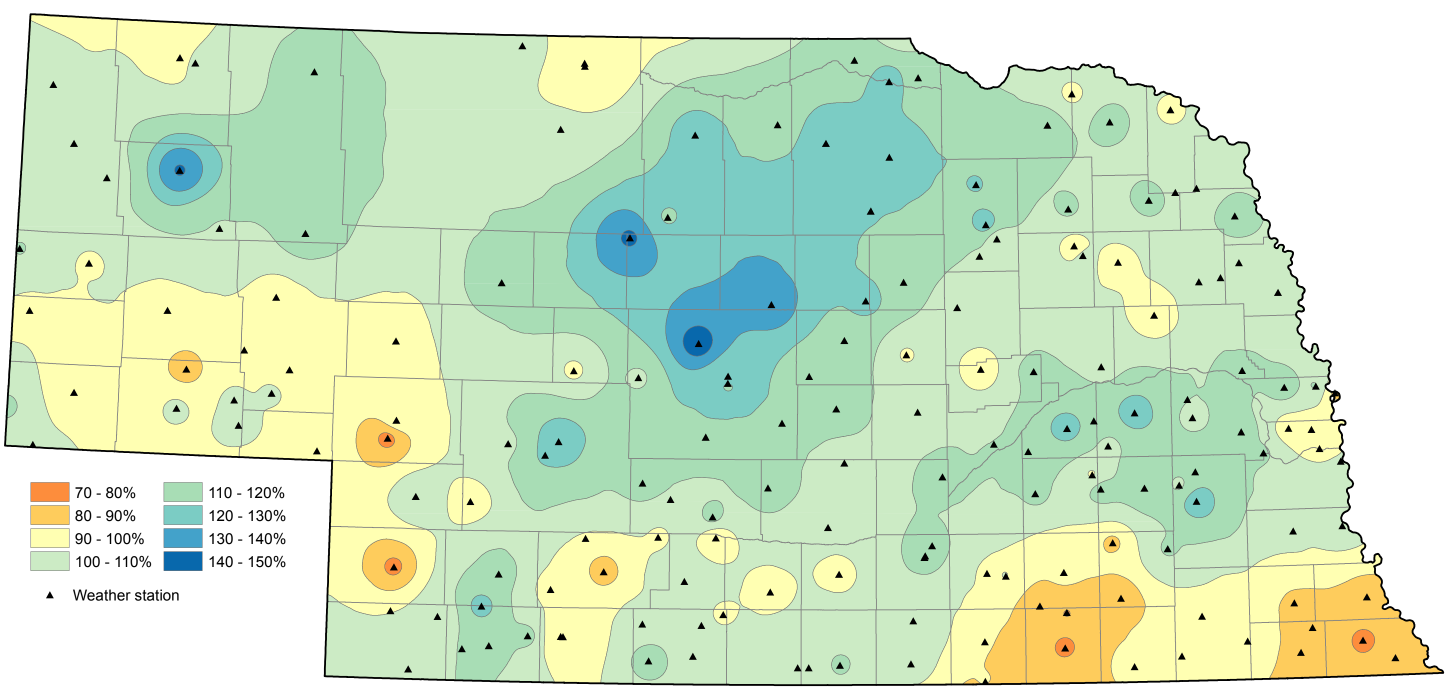
From spring 2017 to spring 2018, localized rises or declines of one to two feet occur throughout Nebraska. These changes are generally restricted to the vicinity of a single well site. Possible causes for such minor fluctuations include: (1) varying pumping schedules due to local precipitation patterns, (2) changes in land use and crop rotation from well to well, or (3) pumping of nearby wells around the time of measurement.

Figure 7. Groundwater-Level Changes in Nebraska - Spring 2017 to Spring 2018



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 2017 to January 2018



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

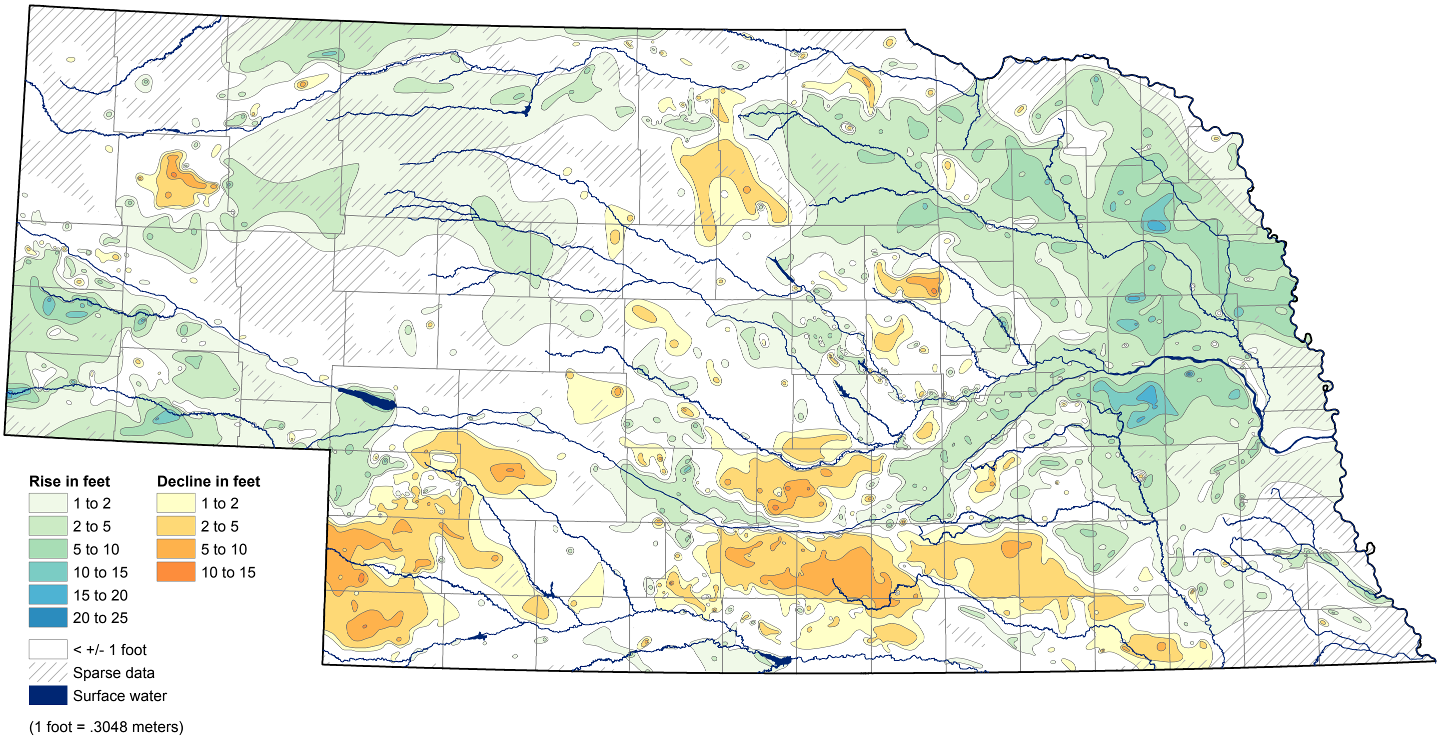
CHANGES IN GROUNDWATER LEVELS, SPRING 2013 TO SPRING 2018

Groundwater-level changes from 2013-2018 generally illustrate recovery following the drought of 2012.

The five-year groundwater-level change map was developed based on 4,567 wells which were measured consecutively in spring 2013 and spring 2018. Of these wells, 61% recorded groundwater-level rises, with 44% of wells recording rises greater than one foot. Approximately 1% of wells recorded no change from spring 2013 to spring 2018. Over the past five years, average water levels have risen by 0.83 foot statewide. The rises depicted in Figure 9 are the result of recovering water-levels following the record-setting drought of 2012. With the exception of declines recorded in Brown and Rock Counties, water levels in the northern two thirds of Nebraska have generally risen, and such rises have exceeded 15 feet in some places. Precipitation values in this region have varied over the same time period from near-average to as much as 140% of the 30-year average (Fig 10).

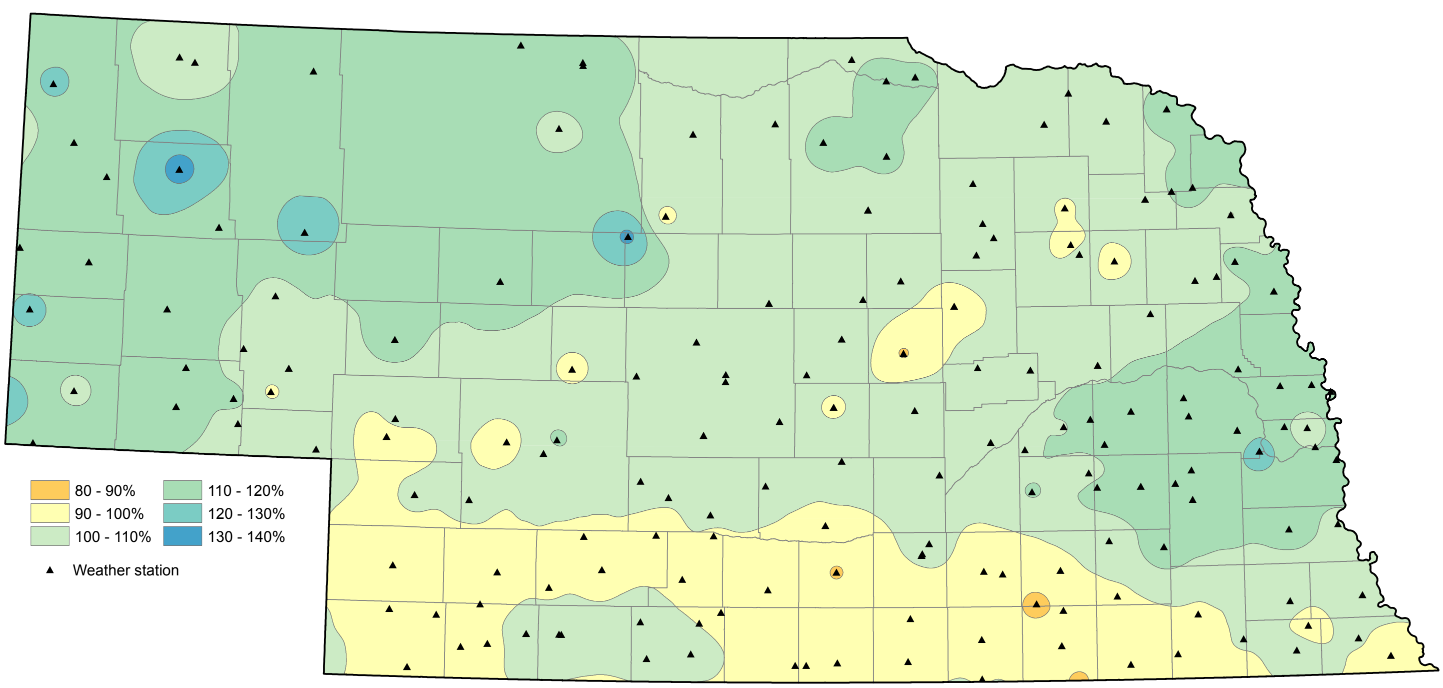
Of the 4,567 wells measured, 38% of wells recorded declines, with 26% of wells recording declines of greater than one foot. Most declines were located in the southern one-third of Nebraska. Most declines appear to be due to the lingering effects of heavy irrigation pumping and extreme drought conditions during the 2012 and early 2013 growing seasons. Over the past five years, precipitation in this region has ranged from near-average to slightly below-average. Other notable areas of decline were recorded in portions of Brown, Greeley, Wheeler and Rock Counties. Declines in these counties may be the result of: (1) localized below average precipitation, (2) delayed aquifer response to heavy pumping experienced during the drought of 2012, or (3) a combination of both factors. Declines recorded in central Box Butte County follow the general trend of approximately one-foot-per-year decline despite near-average precipitation values.

Figure 9. Groundwater-Level Changes in Nebraska - Spring 2013 to Spring 2018



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 10. Percent of Normal Precipitation - January 2013 to January 2018



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2008 TO SPRING 2018

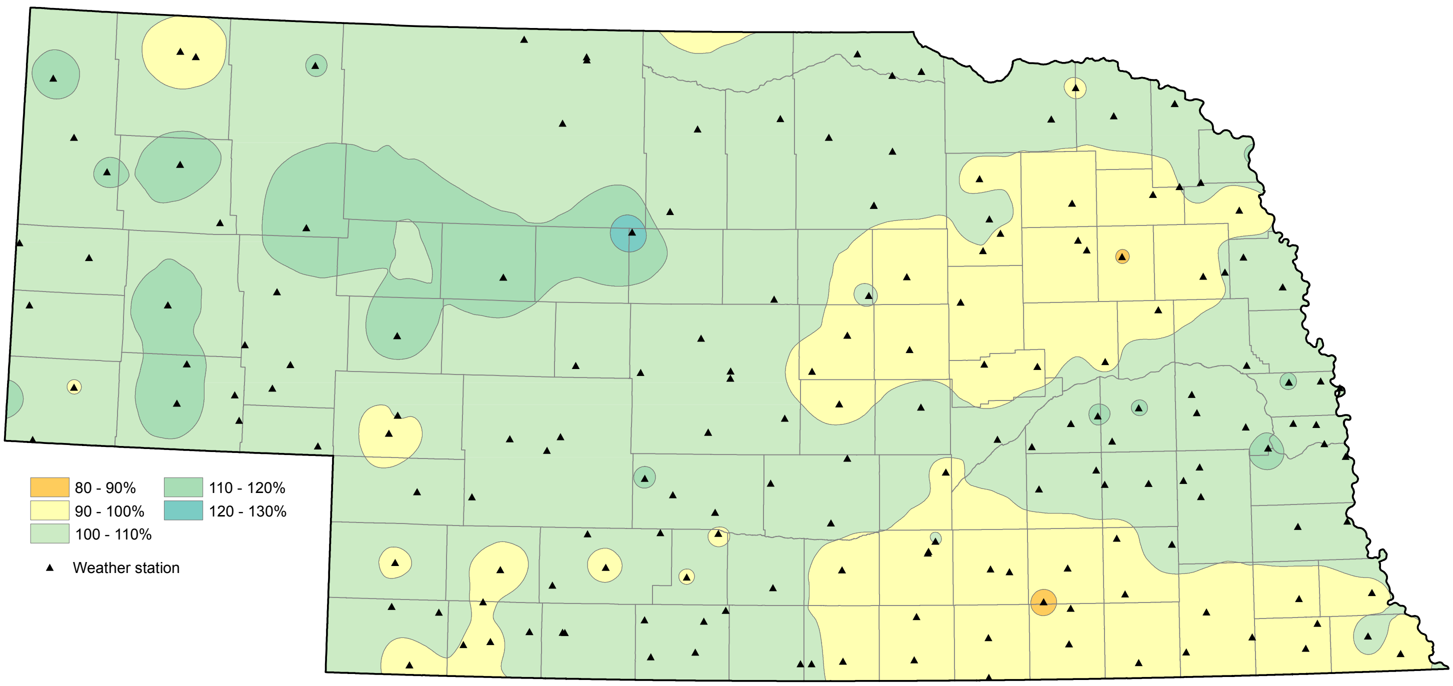
Despite major shifts in climate conditions and record setting drought, modest groundwater-level rises were recorded throughout much of Nebraska over the last 10 years.

Climate conditions from the spring of 2008 to the spring of 2018 ranged 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 (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. From the spring of 2012 through the spring of 2013, however, Nebraska experienced the driest single year on record, 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. Despite the major year-to-year fluctuations in precipitation extremes, precipitation values have remained near the 30 year average for Nebraska over the last 10 years (Fig. 11).

From the spring of 2008 to the spring of 2018, groundwater levels have remained fairly close to levels recorded in 2008, with most levels fluctuating 1 to 5 feet statewide (Fig 12). Of 4,319 wells measured in both spring of 2008 and spring of 2018, 55% recorded groundwater-level rises, with 39% rising more than one foot. Groundwater-level declines were recorded in 45% of wells measured in Nebraska from the spring of 2008 to spring 2018 (Fig. 12), with 31% experiencing declines of greater than one foot. Groundwater levels in wells have risen by an average of 0.37 feet statewide over the last 10 years.

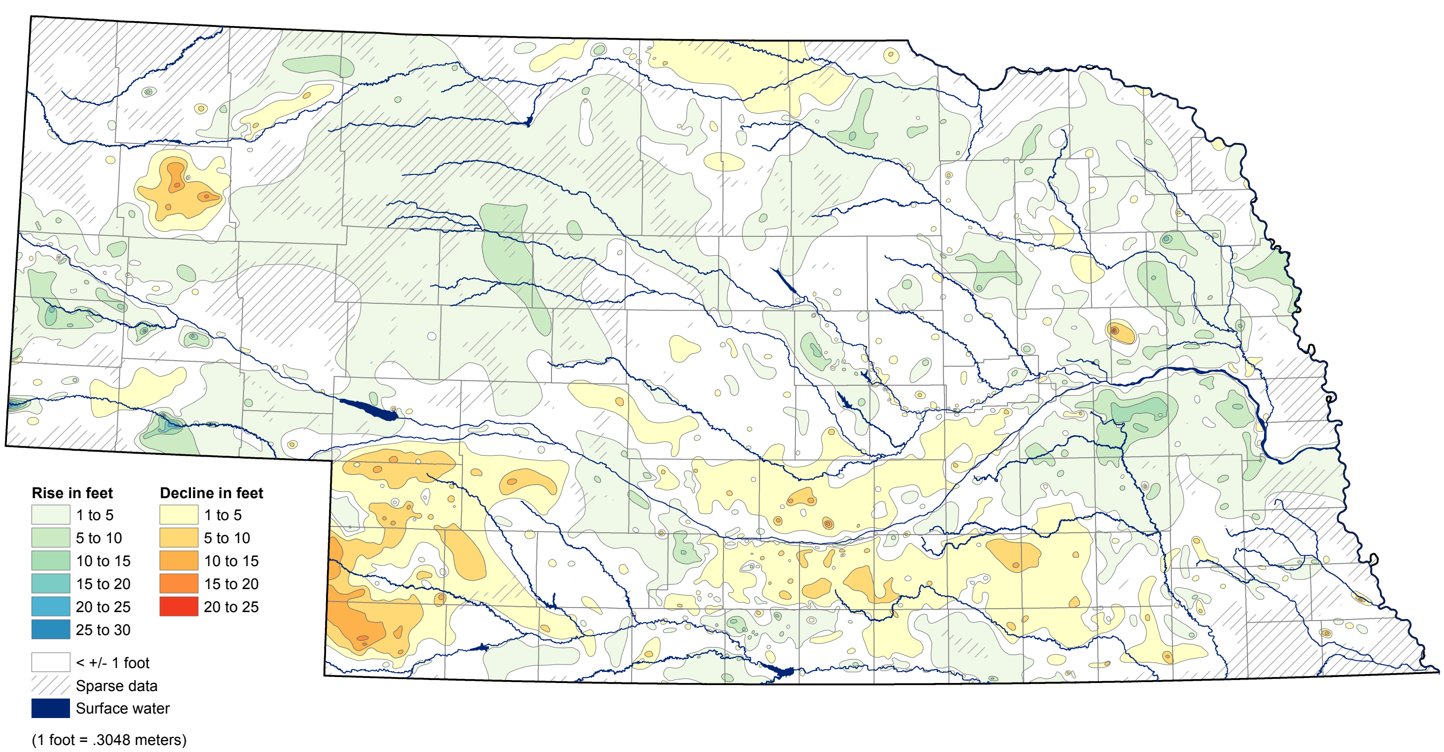
From the spring of 2008 to the spring of 2018, groundwater levels have fluctuated regionally, despite near average precipitation statewide. The regional patterns of water-level changes are possibly the result of (1) extreme regional variability in year to year precipitation and associated irrigation pumping rates, (2) delayed reaction time of aquifers to climate trends, (3) and increased runoff during brief, high-intensity rainfall events. Although some long-term trends can be observed at this scale, such as steadily increasing levels in the central Sand Hills and steadily decreasing levels in known problem areas, over the past 10 years water levels have fluctuated from year to year due to extreme variations in yearly rainfall, recharge, and evapotranspiration. As a result, water-level changes mapped in Figure 12 may not be the result of long term trends, but rather the effects of short term extremes.

Figure 11. Percent of Normal Precipitation - January 2008 to January 2018



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

Figure 12. Groundwater-Level Changes in Nebraska - Spring 2008 to Spring 2018



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 2018

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 2018 groundwater levels continue to indicate long-term declines and rises in certain areas of Nebraska (Fig. 13). Almost all areas of significant groundwater-level declines spatially correspond to areas of high irrigation-well densities in aquifers that are deep and have little or no connection to surface water (Fig. 14). The greatest measured decline from predevelopment to 2018 was approximately 122 feet, in Box Butte County just north of the city of Alliance. Regions of notable groundwater-level declines from predevelopment to spring 2018 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 smaller 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, where there are extensive canals and surface-water-irrigation systems.

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 around 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 feet to more than 120 feet from predevelopment levels (Fig. 13). Records from wells in both the southwestern counties and Box Butte County indicate that rates of decline have been essentially steady, despite changes in groundwater management practices, water use allocations, and fluctuations in the amount of annual precipitation (Korus and Burbach, 2009b).

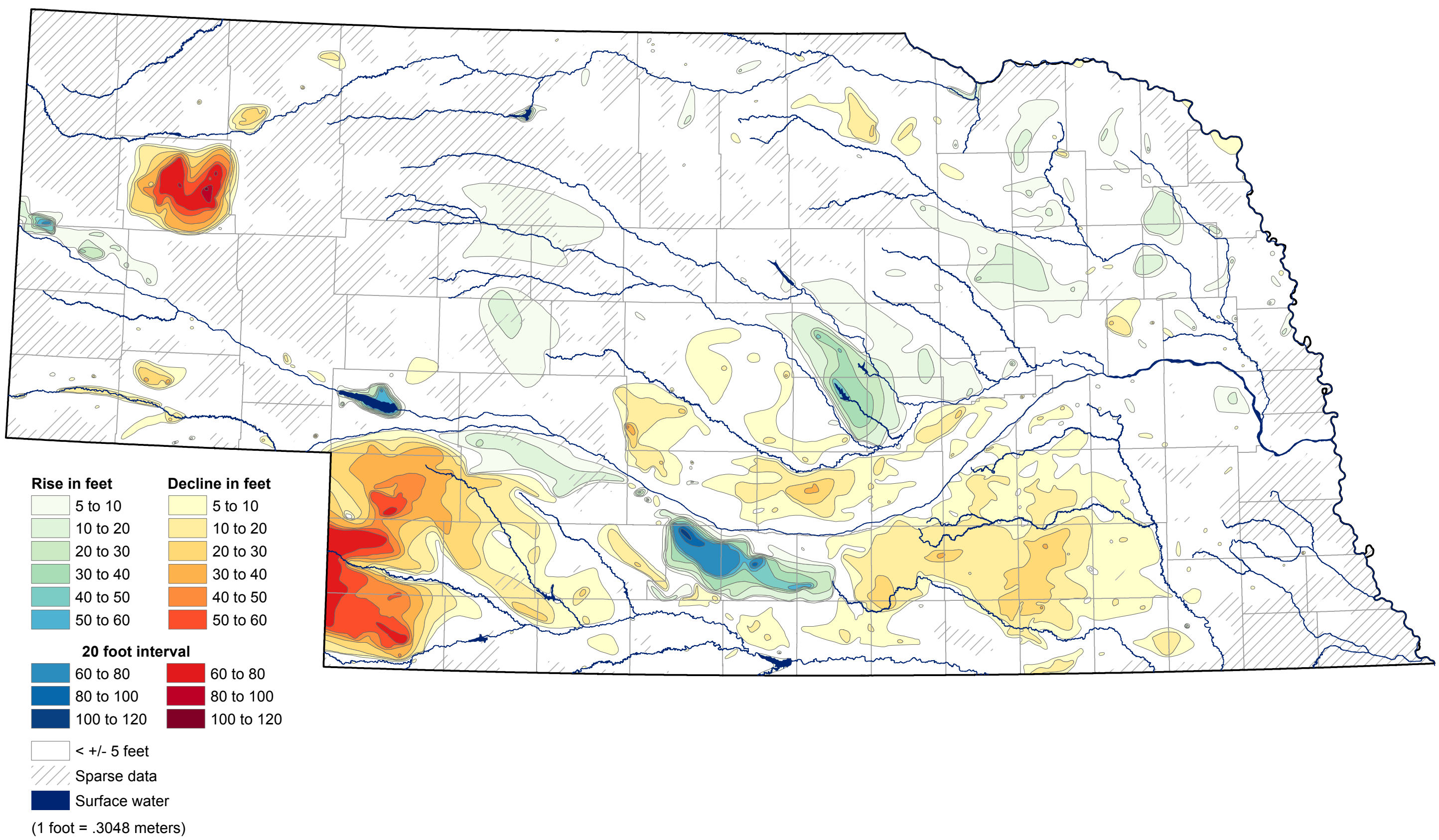
A large portion of southeast to south central Nebraska has experienced long-term groundwater-level declines since predevelopment (Fig. 13). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this region have declined more than 10 feet, and in some areas by more than 30 feet, since predevelopment times.

Groundwater-level declines also occurred in large areas between the Platte and Loup or South Loup rivers and in the Republican River Valley, Panhandle, and parts of Holt and Colfax counties. Irrigation well density is high in some, but not all, of the aforementioned areas. In addition to high well densities, where present, aquifer characteristics, rates of recharge, and irrigation scheduling may have contributed to these declines.

Groundwater-level rises from predevelopment generally occurred in areas of surface-water-irrigation systems. Storage of water in Lake McConaughy began in 1941, and seepage losses caused groundwater-level rises of as much as 60 feet in nearby observation wells (Ellis and Dreeszen, 1987). Groundwater levels around the lake 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. 13). 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.

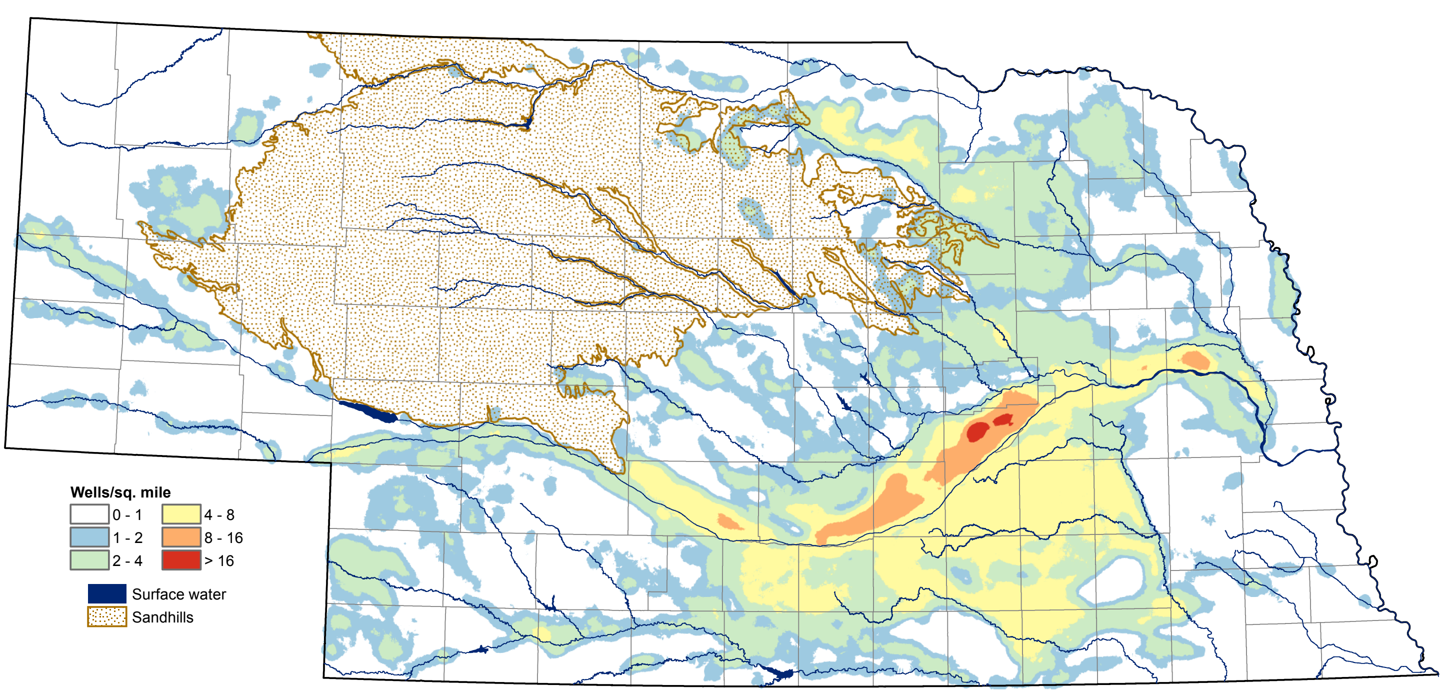
Groundwater-level rises of 10 to more than 50 feet occurred in portions of central Nebraska (Fig. 13). The highest groundwater-level rises occurred in Valley, Sherman, and Howard counties as the result of seepage from irrigation canals, Sherman and Davis Creek reservoirs, and deep percolation of irrigation water applied to crops.

Figure 13. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2018



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 14. Density of Active Registered Irrigation Wells - December 2018



Source: Nebraska Department of Natural Resources

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 1981 AND SPRING 1981 TO SPRING 2018

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.

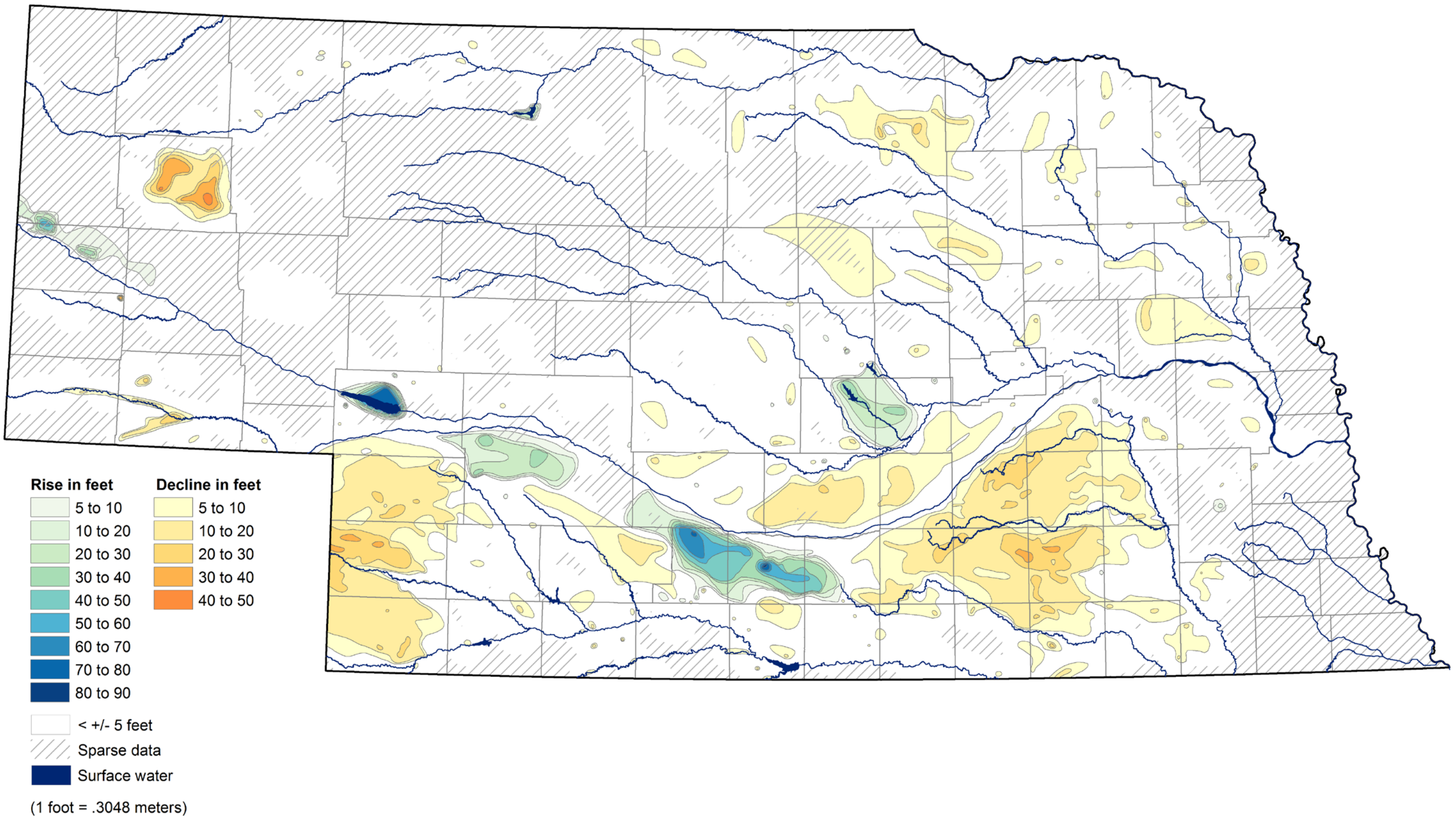
Groundwater-level changes from predevelopment to spring 1981 reflect the responses of aquifers to the spread of groundwater and surface-water-irrigation systems in Nebraska. Areas of significant groundwater-level declines generally corresponded to areas of dense irrigation well development (cf. Johnson and Pederson, 1981). Declines were generally equal in magnitude in both the eastern and western areas (Fig. 15). 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 and 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, 30 feet in Chase County in the southwest, and as much as 10 feet in Clay and Fillmore counties in the south central. Declines occurred in smaller areas of the Republican River drainage as well as the northeast. Almost all groundwater-irrigated areas in Nebraska experienced declines associated with groundwater withdrawals. Such declines are the unavoidable responses of aquifers to development, according to laws of hydrologic mass balance (Korus and Burbach, 2009a).

Groundwater-level rises from predevelopment to spring 1981 were associated with irrigation canal systems and reservoirs (Fig. 15). 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 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. 16). In central and eastern Nebraska, areas in which declines had occurred from predevelopment to 1981 experienced rises of 5 feet to more than 20 feet from 1981 to 2018. 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-1930s. Although water levels in Polk, Hamilton and York Counties continue to rise from 1981 levels, rising levels have slowed or begun to decline in other counties in south central/southeast Nebraska following the drought of 2012. 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 groundwater-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.

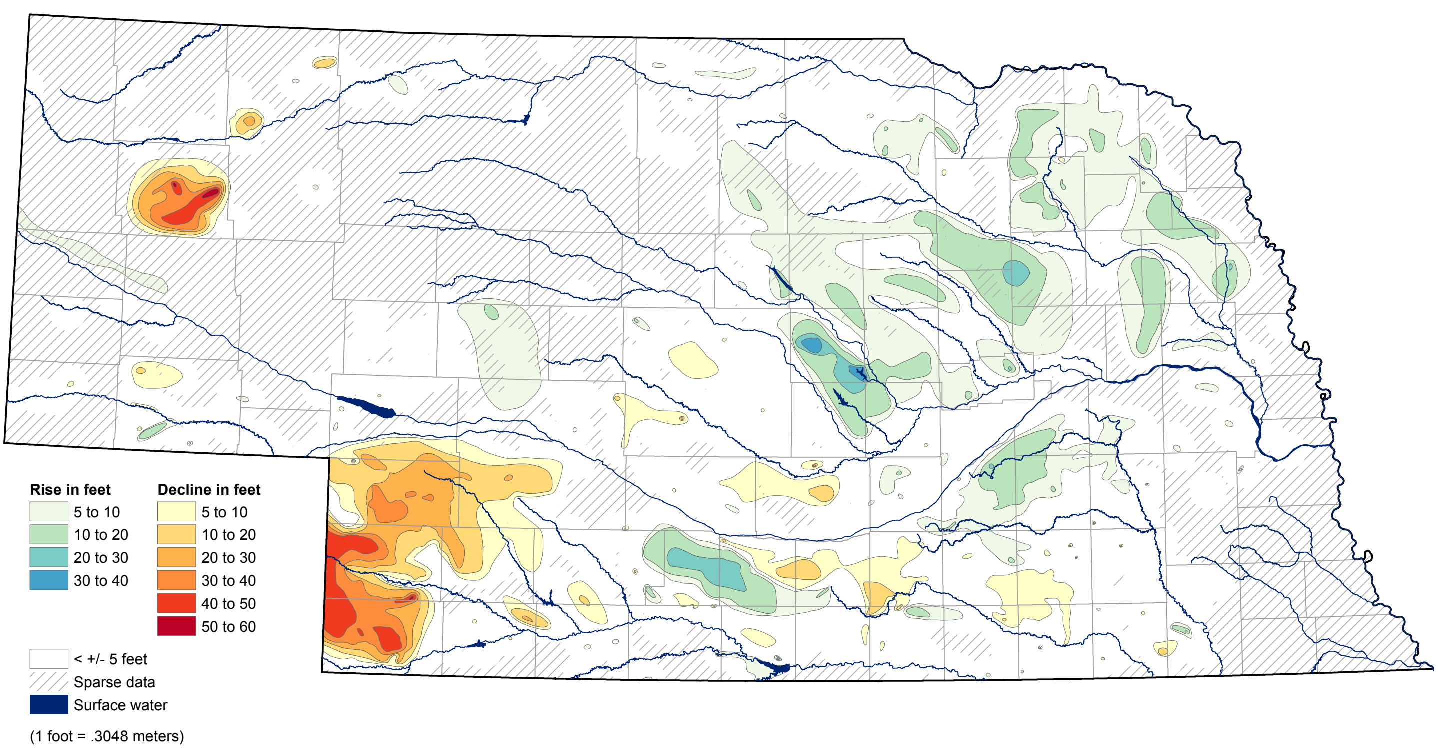
Declines in south central/southeast Nebraska reached a maximum in 1981 and had recovered such that declines in some areas are now less than 5to 10 feet compared to predevelopment levels (Figs 13, 15, 16). Groundwater levels in most of this area, however, remain below predevelopment levels. The post-1981 recovery of groundwater levels in central and eastern Nebraska probably resulted from a combination: (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 (Korus and Burbach, 2009a). These rises may also 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. The hydrograph for the Exeter Recorder Well, which is screened in the shallow aquifer, exemplifies this phenomenon (Fig. 17). The steady

Figure 15. 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

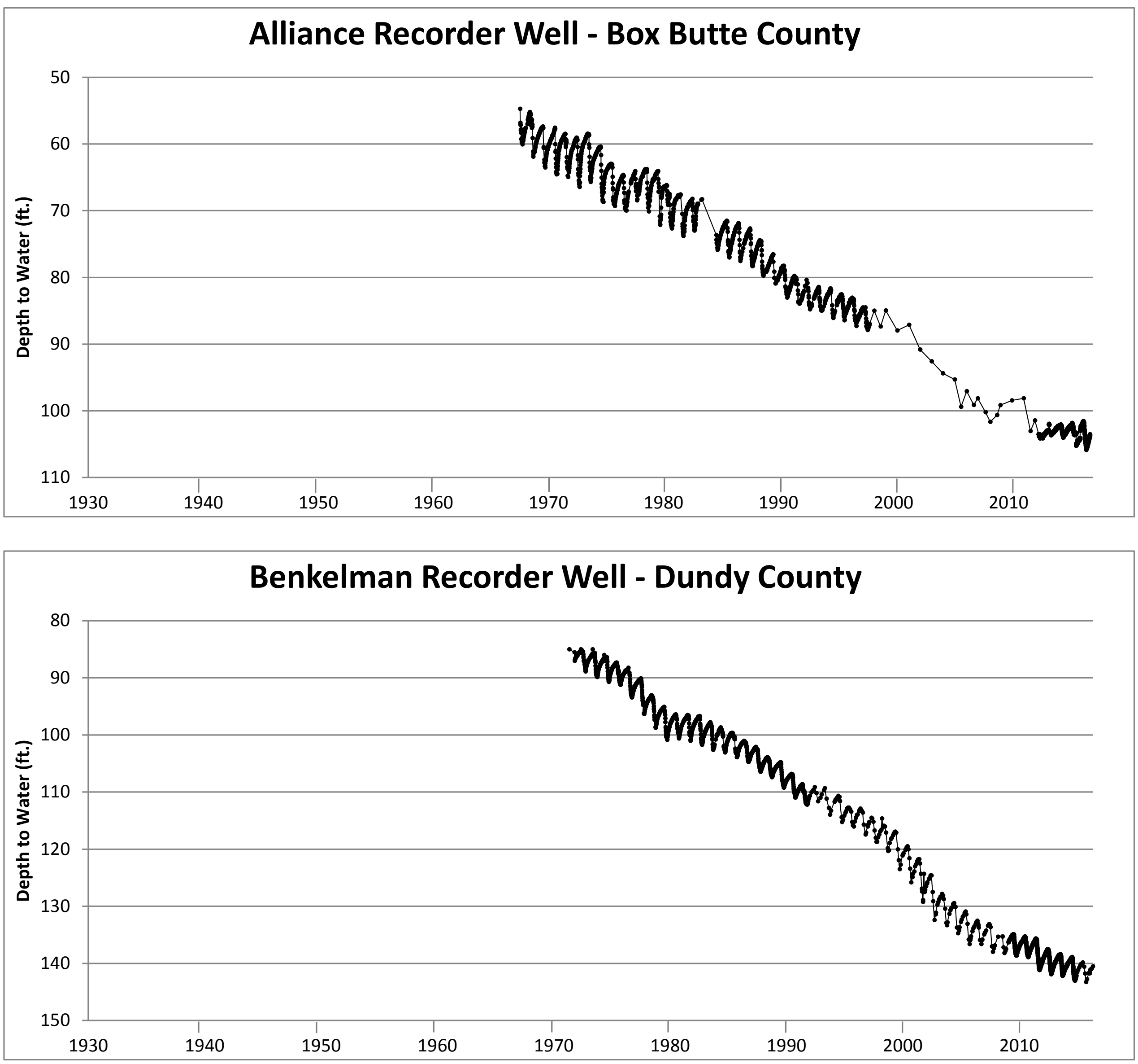
Figure 16. Groundwater-Level Changes in Nebraska - Spring 1981 to Spring 2018

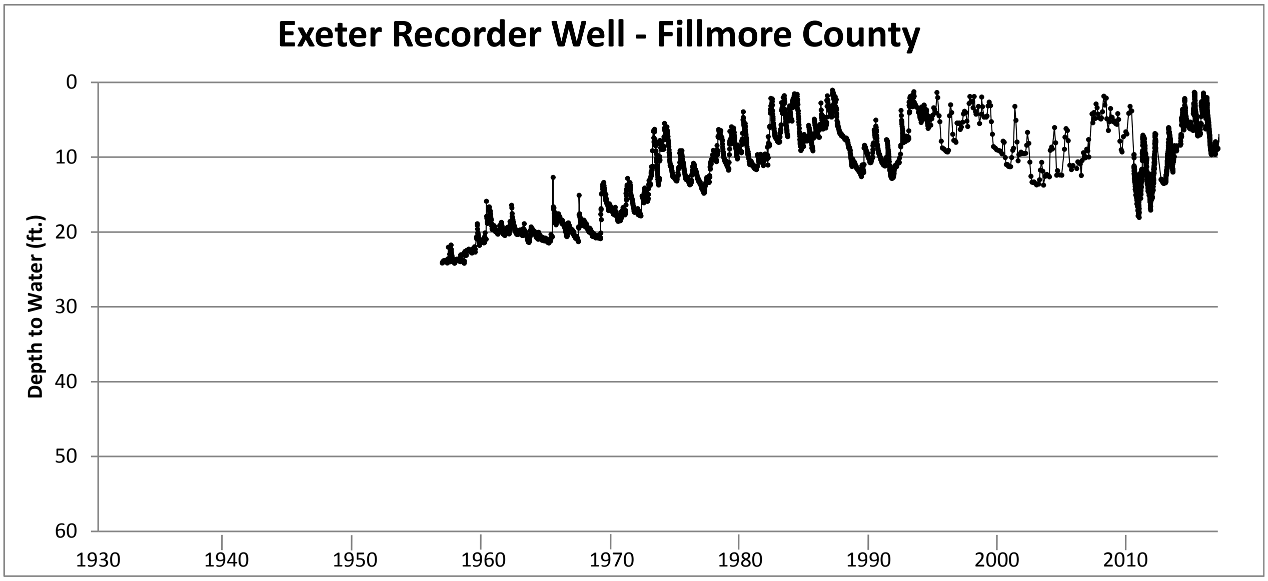


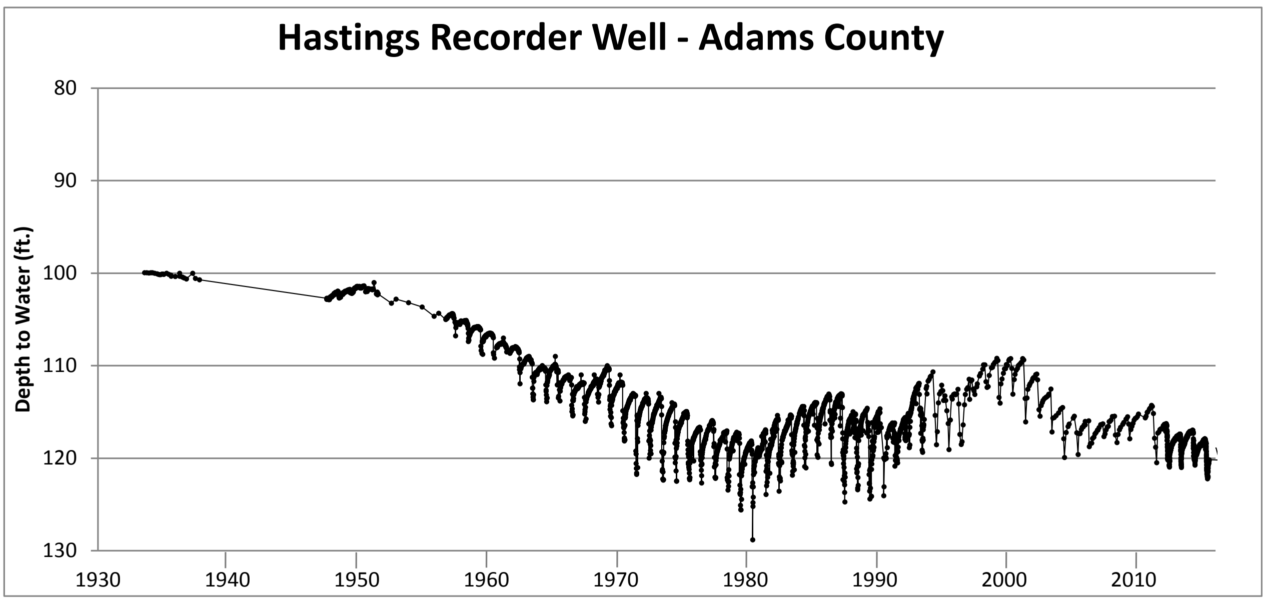
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District groundwater-level rise in this well between 1956 and 1981 temporally corresponds to the steady decline observed in nearby wells that are screened in the deep aquifer. Thus, excess irrigation water pumped from the deep aquifer probably recharged the primary aquifer in areas where the confining layer is discontinuous, or semi permeable which allows some movement of water over a long period of time.

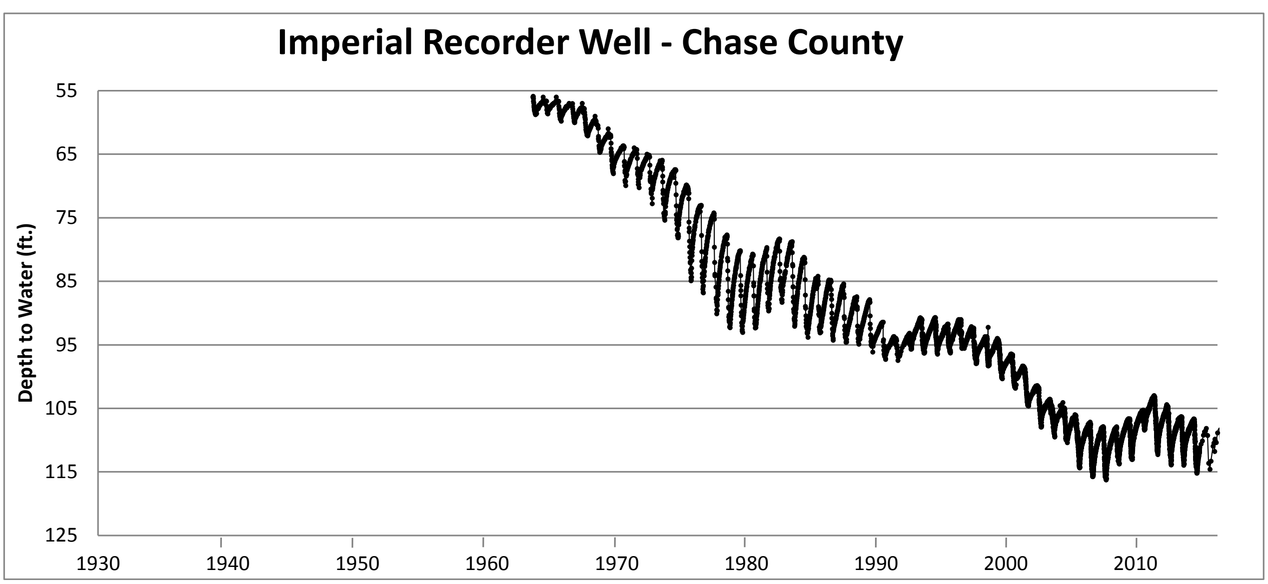
In contrast to the groundwater-level rises in the east, levels continued to decline in parts of western Nebraska from 1981 to 2018 (Fig. 16). The Alliance, Benkelman, and Imperial Recorder wells show declines of 50 to 60 feet in just 50 years, an average decline of about 1 foot per year (Fig. 17). Brief 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 (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 and its sources and rates of recharge.

Figure 17. Groundwater-Level Hydrographs Typical of Southeast and Southwest Nebraska




Exeter Recorder Well - Fillmore County
Depth to Water (ft.)
0
10
20
30
40
50
60
1930
1940
1950
1960
1970
1980
1990
2000
2010


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
125
1930
1940
1950
1960
1970
1980
1990
2000
2010

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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
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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
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1983	Nebraska Water Survey Paper 57	Johnson, M.S.; Pederson, D.T., 1984
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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
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2012	Nebraska Water Survey Paper 80	Young, A.R.; Burbach, M.E.; Korus, J.T.; Howard, L.M.; 2012
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2017	Nebraska Water Survey Paper 85	Young, A.R.; Burbach, M.E.; Howard, L.M.; Waszgis M.M.; Lackey, S.O., Joeckel R.M., 2017
2018	Nebraska Water Survey Paper 86	Young, A.R.; Burbach, M.E.; Howard, L.M.; Waszgis M.M.; Lackey, S.O., Joeckel R.M., 2018

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