Nebraska Statewide Groundwater-Level Monitoring Report

2017

**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 85

Institute of Agriculture and Natural Resources
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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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CONTENTS

FIGURES

FOREWORD

Nebraska water issues of interest, 2016-2017

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 volume of the High Plains Aquifer lies beneath the State, and groundwater maintains our streams, our ecosystems, our people, and our vitally important agricultural economy. Although Nebraska's total groundwater resource is vast, it is also quite vulnerable to changes induced by natural processes and by humankind, necessitating a long-term commitment to wise management through informed decision making. Monitoring, studying, and reporting 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 2017

TransCanada's Keystone XL pipeline extension in Nebraska re-emerged as a prominent issue at the beginning of 2017. President Trump issued a Presidential Memorandum on the pipeline on January 24 and the U.S. Department of State issued a permit to TransCanada in late March. In Nebraska, public meetings were held in York, O'Neill, Norfolk, and Ralston during May-July and a public hearing was held in Lincoln in early August.

The Nebraska Public Service Commission voted 3-2 in favor of pipeline construction and issued a Final Order on November 20. Oral arguments were subsequently heard on December 12. Thereafter, Motions for Reconsideration were denied in a subsequent Order issued on December 19 (Nebraska Public Service Commission, undated).
The Nebraska Department of Environmental Quality (NDEQ) sampled lakes and streams in the North Platte, South Platte, and White-Hat drainage basins during 2017 as part of their Basin Rotation Monitoring Program (Nebraska Department of Environmental Quality, 2017). The NDEQ also developed the South Loup River Special Study in 2017 and received funding for participation in the National Lake Assessment. The Drinking Water Division of Nebraska Health and Human Services moved to the NDEQ offices in Lincoln during 2017. CSD personnel participated in the review process for updated Groundwater Management Plans in the Papio-Missouri River Natural Resources District (NRD) and the Little Blue NRD. The Papio-Missouri River NRD hosted three public hearings regarding their revised plan toward the end of 2017. The Nebraska GeoCloud project, which involves the CSD as well as NRDs, was initiated in 2017. It will be the internet warehouse for the ~15,000 miles of airborne geophysics data (relevant to groundwater) collected in Nebraska over the past decade (Korus, 2018). Mammoth Trading, Inc. published a case study on groundwater trading in western Nebraska (Young, 2016) and groundwater markets were being operated in the Twin Platte and South Platte NRDs by the end of 2016 (Arens, 2016). The Central Platte NRD facilitates a groundwater exchange program that began in October 2016.

Ground was broken for a controversial Costco chicken processing plant in Fremont in June, despite water-pollution and other environmental concerns (Soderlin, 2017a) that were raised in 2016. The Nebraska Department of Environmental quality announced in September 2017 that it would issue a permit allowing for construction to proceed, and it is expected that operations at the completed plant will begin in the spring of 2019 (Soderlin, 2017b). Nevertheless, parallel environmental concerns are very likely to be raised over the permitting of scores of new chicken barns projected to be built in eastern Nebraska to supply the Fremont plant (Soderlin, 2017c).

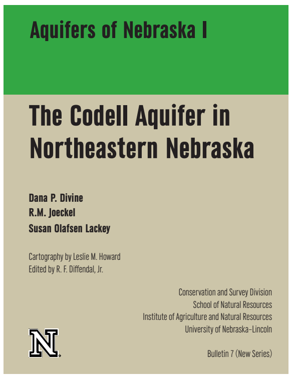
The Nebraska Supreme Court made a ruling in December 2017 (Cappel v. State) that certain claims, against the State regarding surface water unavailability for irrigation resulting from compliance with the Republican River Compact, are barred by sovereign immunity.

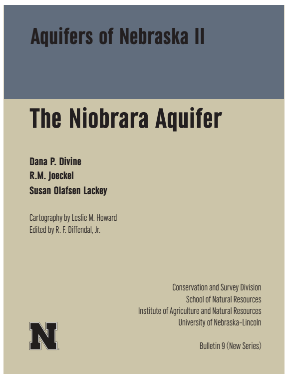
The Nebraska Water Sustainability Fund provided $10,682,546 to twelve projects dealing with surface water and groundwater, including Platte-Republican diversion, eastern Nebraska aquifer framework modeling, vadose zone nitrate transport, and a drought management plan. Nevertheless, some concerns have been raised about the impact of projected State budget shortfalls in 2018 on the Fund.

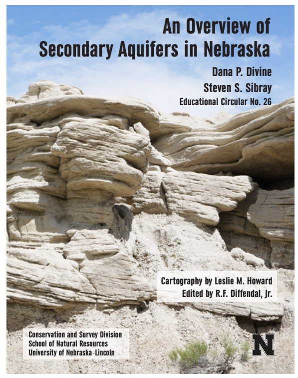
Conservation and Survey Division Activities in 2017

CSD studies Nebraska's groundwater, geology, and soils and serves Nebraskans. In 2018, it celebrates its quasquicentennial (125th year). During 2017, CSD personnel produced more 35 written works, including 19 peer-reviewed scientific publications and 4 geologic maps. CSD personnel had more than $2.6 million in active external funding, provided in excess of 1,500 continuing education credits (CEUs) for professionals, made nearly 60 presentations to various audiences, drilled or logged more than 11,000 ft of geologic test holes, and taught more than 300 student credit hours at the University of Nebraska-Lincoln.

RECENT GROUNDWATER PUBLICATIONS AND RESOURCES







Divine, D.P., Joeckel, R.M., Lackey, S.O. 2016. Aquifers of Nebraska I: The Codell Aquifer in Northeastern Nebraska, Conservation and Survey Division, University of Nebraska, Bulletin 7 (New Series), 21 p.

Divine, D.P., Joeckel, R.M., Susan, S.O. 2017. Aquifers of Nebraska II: The Niobrara Aquifer. Lincoln: Conservation and Survey Division, University of Nebraska, Bulletin 8 (New Series). pp. 32

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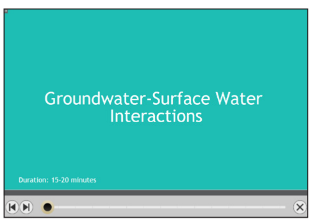

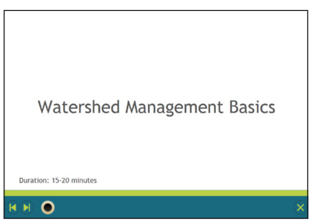

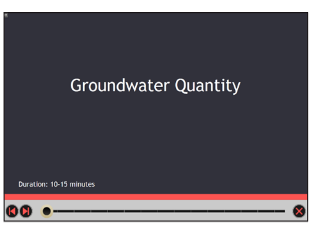

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Gilmore, T.E., Korus, J.T., Ingram, E., Young, A.R. 2017. Groundwater Quantity. Interactive Educational Module for Natural Resources District Board Members and Staff, University of Nebraska-Lincoln School of Natural Resources and Department of Biological Systems Engineering. Created October 2017. http://nebraskawatershedscience.org/module1/

Szilagyi, J., 2017. Anthropogenic Hydrological Cycle Disturbance at a Regional Scale: State-Wide Evapotranspiration Trends (1979-2015) Across Nebraska, USA, Journal of Hydrology, 557, 600-612, doi:10.1016/j.jhydrol.2017.12.062, in press.

Online Resources

go.unl.edu/groundwater

The Nebraska Real-Time Groundwater-Level Network

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

Historic Nebraska Statewide Groundwater-Level Monitoring Reports

Recent reports, including the current issue, are available as PDFs for download. Water-level change maps are available for download beginning with 1954 through the maps included in this report.

Other Online Resources

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 pressures 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 water, 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, leading 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

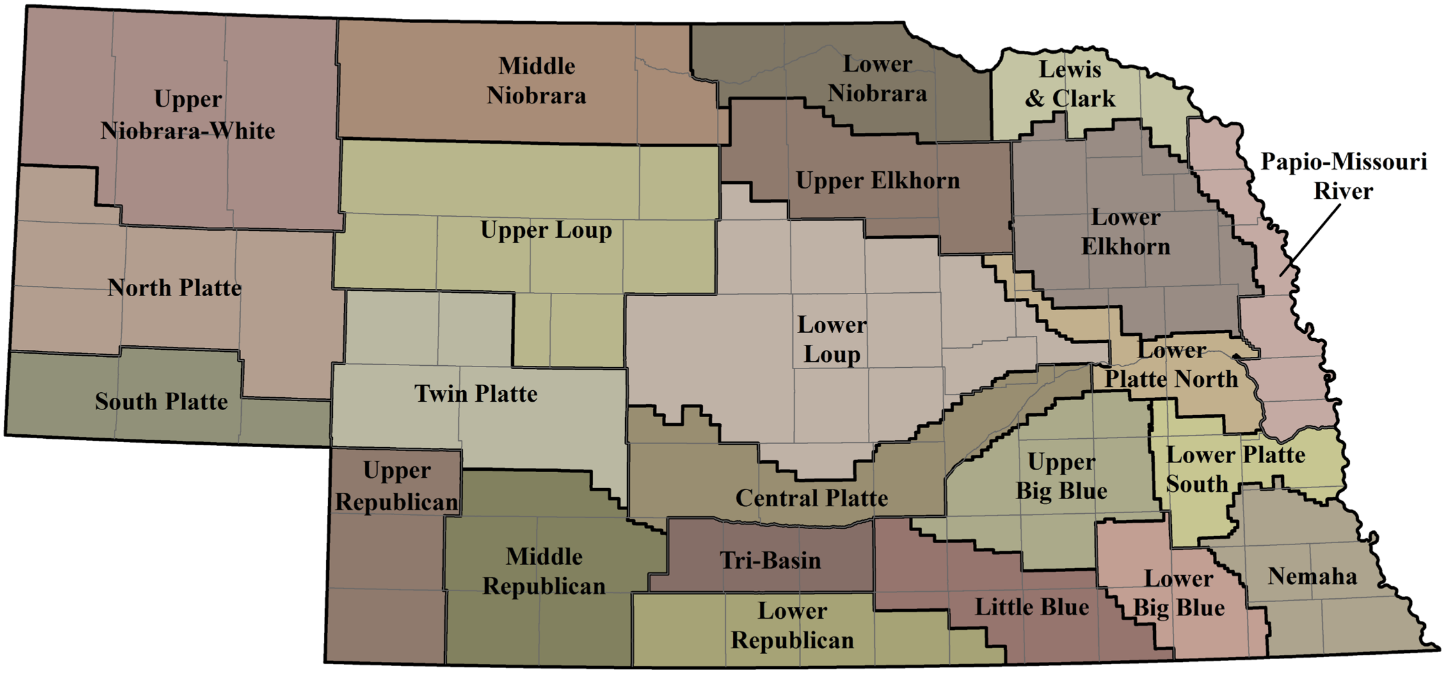
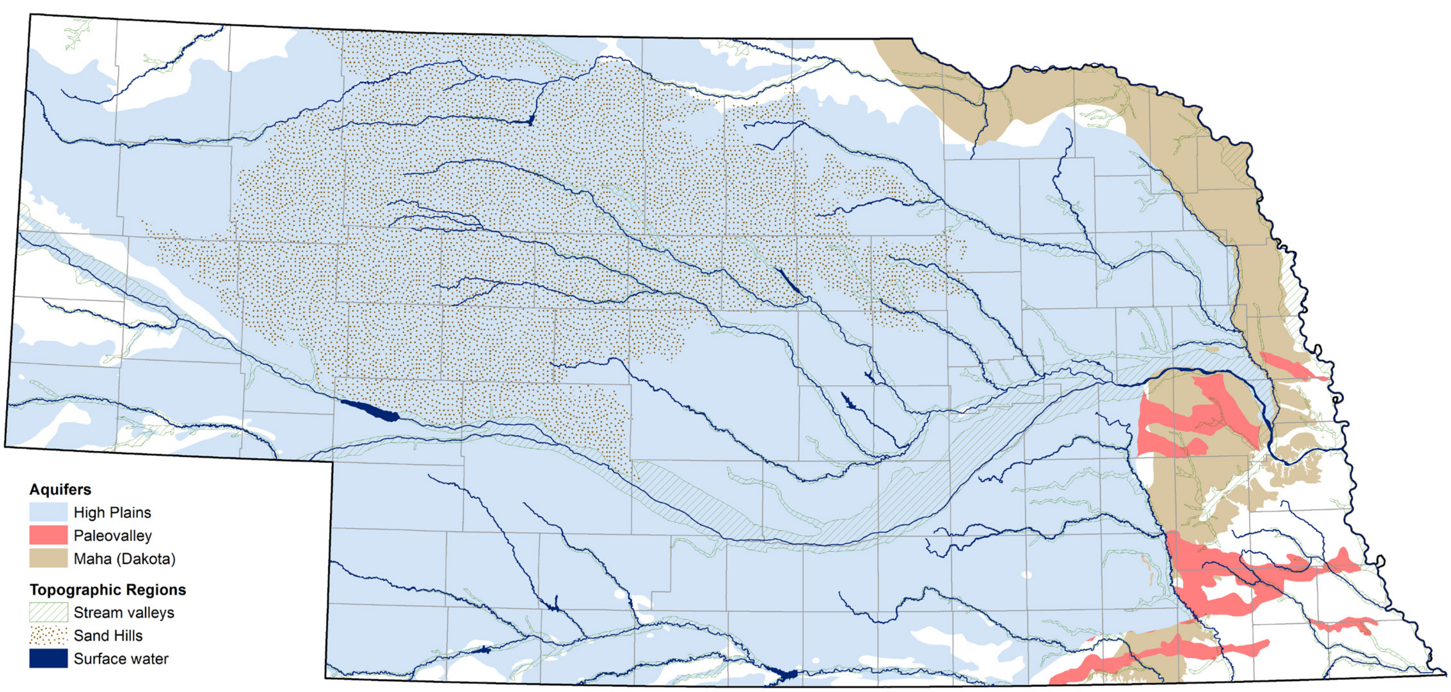


Figure 2. Important Aquifers and Topographic Regions of Nebraska



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

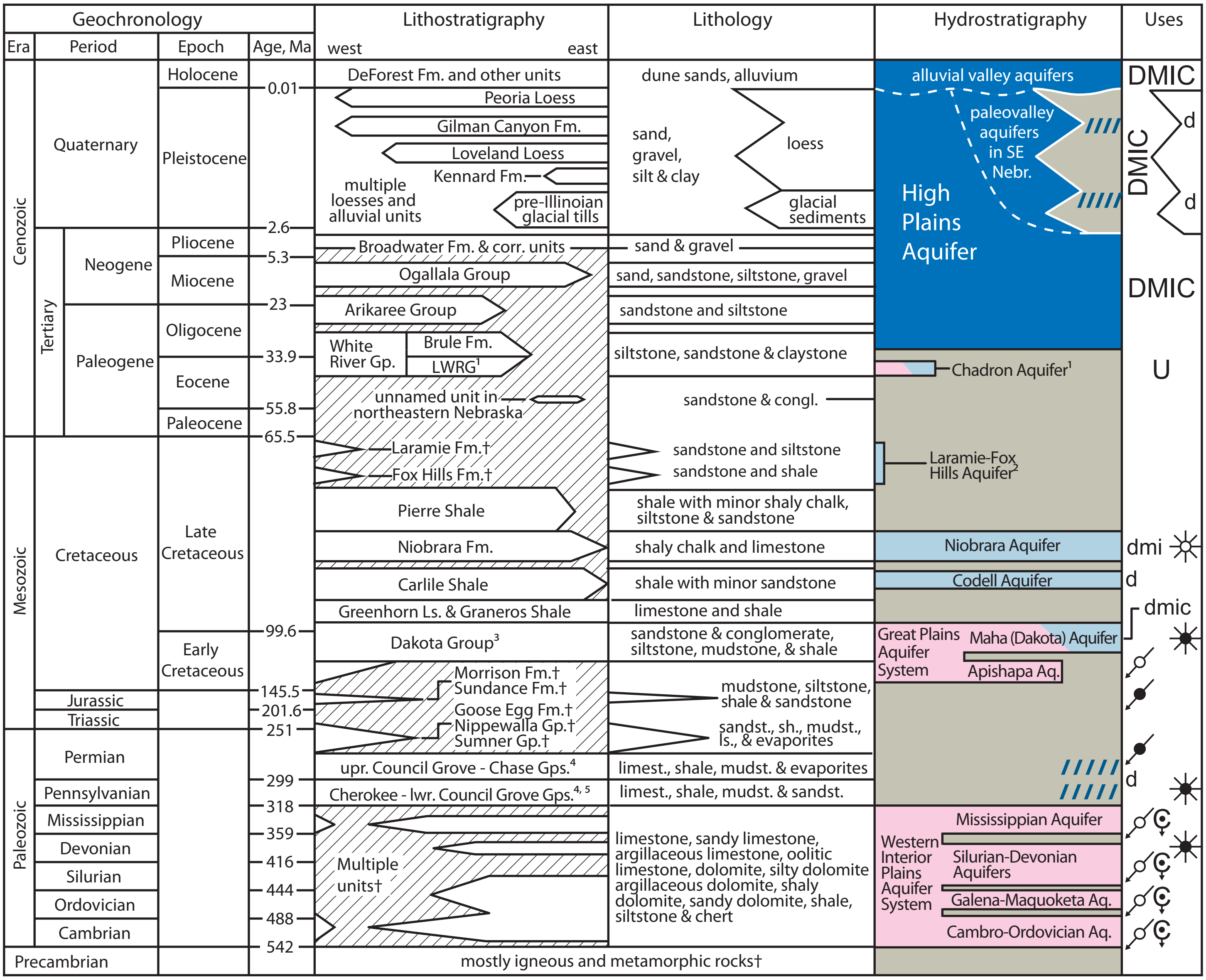


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

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
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

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 1, 5, and 10 years prior to 2017, as well as from 1981 to 2017, predevelopment to 1981 and predevelopment to 2017. 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 – 4 for the locations of NRDs, rivers, aquifers, and counties mentioned in the text.

The 1-, 5-, and 10-year changes are presented in the spring 2016 to spring 2017, spring 2012 to spring 2017, and spring 2007 to spring 2017 maps, respectively. Groundwater levels measured from thousands of wells throughout the State during the spring of 2017 (Fig. 5) were compared to levels measured in the same wells in the spring of the preceding 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 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 2017 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 2017 and predevelopment to spring 1981 maps, water levels from wells measured in 2017 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 (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 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.

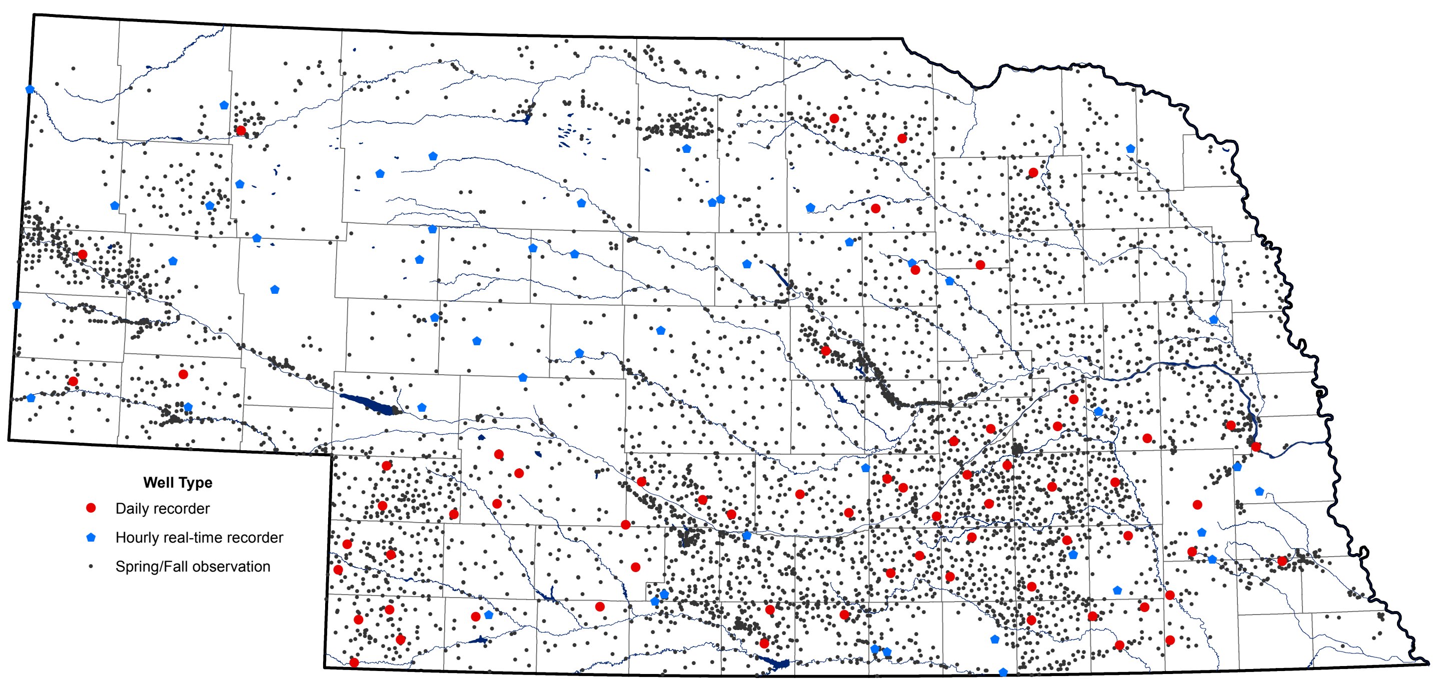
Factors Causing Groundwater-Level Changes

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 oversimplification of hydrogeologic processes. The aquifer

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

Figure 5. Location of Observation Wells by Type

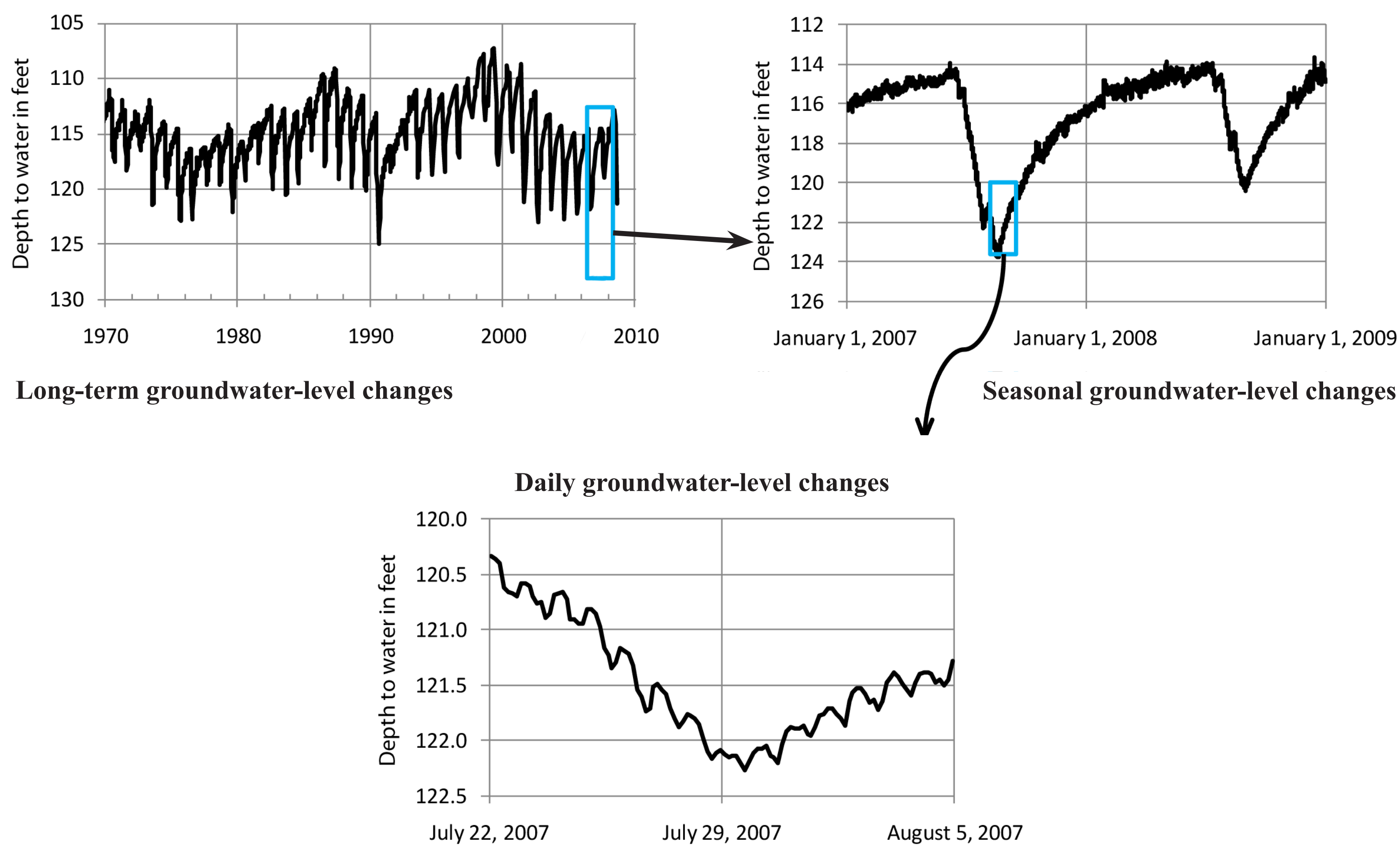


Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln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

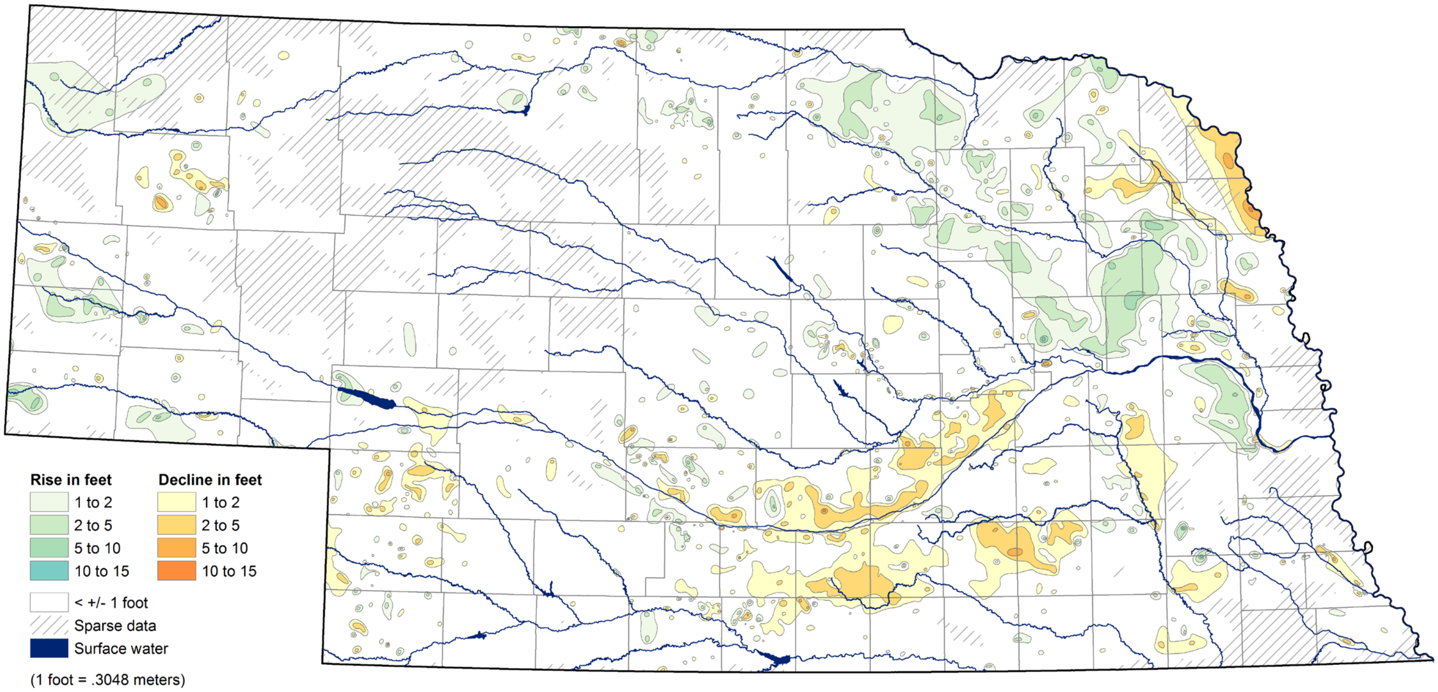
CHANGES IN GROUNDWATER LEVELS, SPRING 2016 TO SPRING 2017

With precipitation values near the long term average for most of Nebraska, on average groundwater levels experienced little change from 2016-2017.

In the spring of 2017, a total of 5288 monitoring wells were measured throughout the state of Nebraska (Fig. 5). Of those wells, 51% recorded groundwater-level declines compared to the spring of 2016, with 17% experiencing a decline of greater than one foot (Fig. 7). Groundwater-level rises were recorded in 48% of wells measured, with 17% of wells recording a rise greater than one foot. Approximately 1% of wells had neither rises nor declines from the spring of 2016 to the spring of 2017. The average water level change for all wells in Nebraska was 0.00 feet. Precipitation totals varied slightly throughout the state during 2016, with values ranging from as little as 70% to as much as 150% of the 30-year average (Fig. 8). With the exception of localized areas throughout the state, most of Nebraska received near average precipitation from January 2016 to January 2017.

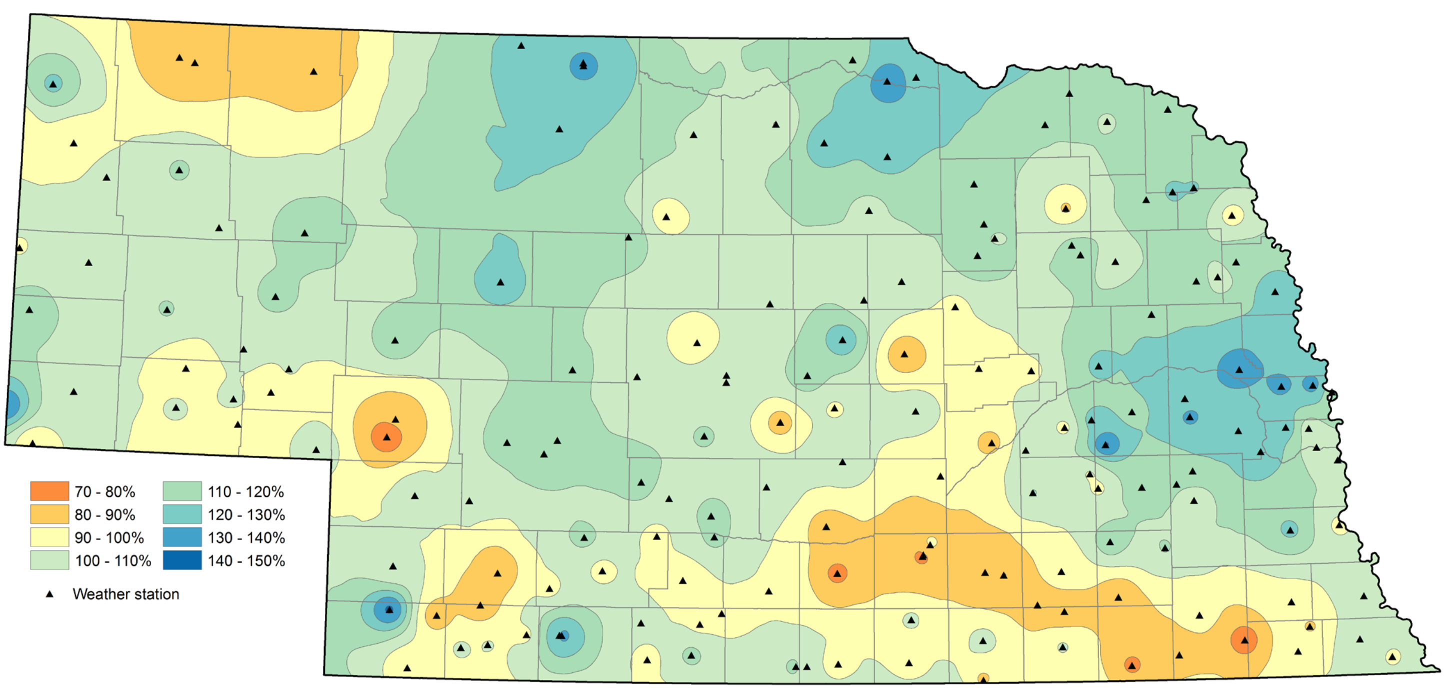
Groundwater levels fluctuated slightly from one well to another across Nebraska. These changes are represented in Figure 7 by local-scale groundwater-level changes of +/- 1-2 feet scattered throughout the State. Possible causes for such minor fluctuations include (1) varying pumping schedules due to local precipitation patterns, and (2) changes in land use and crop rotation from well to well. Two regions on the map (Fig. 7) stand out: (1) an area of 1-5 foot declines along and to the south of the Platte River in south central Nebraska, and (2) an area of groundwater rises of 1-10 feet in northeast Nebraska. Areas of decline in the south central part of Nebraska temporarily correlate to increased pumping due to slightly below normal precipitation values (Fig. 8). Modest groundwater-level rises in northeastern Nebraska generally correspond to areas of slightly above normal precipitation. We emphasize that some of the most severe declines following the drought of 2012 occurred within the same region. Many of the wells in this region are confined and are thus slow to recharge. Many of these wells have been steadily rising since the spring of 2014 due to generally above average precipitation and reduced demand for irrigation pumping.

Figure 7. Groundwater-Level Changes in Nebraska - Spring 2016 to Spring 2017



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 2016 to January 2017



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2012 TO SPRING 2017

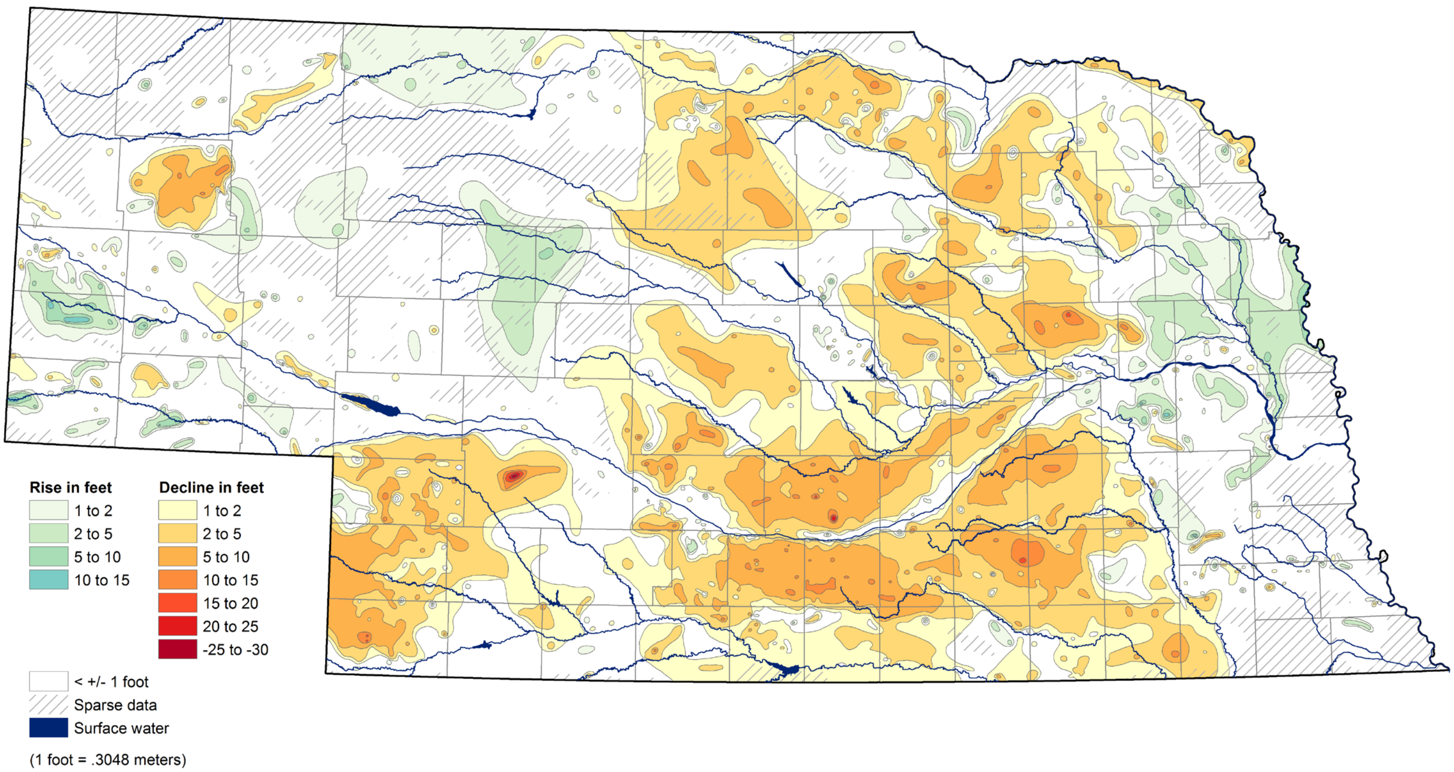
Groundwater-level changes from 2012-2017 generally illustrate persisting drawdowns following the drought of 2012.

The five-year groundwater-level change map was developed based on 4,605 wells which were measured in 2012 and 2017. Of these wells, 71% recorded declines, 55% of all wells recorded declines of greater than one foot. Approximately 0.8% of wells recorded no change from spring 2012 to spring 2017. Over this five-year period, significant groundwater-level declines occurred throughout most of Nebraska (Fig. 9). On average, groundwater levels declined 1.91 feet across Nebraska. Most of the eastern two thirds of Nebraska recorded groundwater-level declines from 1-10 feet, with declines greater than 15 feet locally. Generally, areas of decline in eastern Nebraska had total precipitation percentages from 80-100% of the 30-year average for the five-year period 2012-2017. Most groundwater-level declines were the result of heavy irrigation pumping and extreme drought conditions during the 2012 and early 2013 growing seasons, and locally, several additional seasons of below average precipitation.

Of the 4,605 wells measured, 28% of wells recorded groundwater-level rises, while 15% of all wells recorded rises of greater than one foot from spring 2012 to spring 2017. The Panhandle and northwestern portion of the Sand Hills received higher than average precipitation, particularly in 2015. Modest groundwater-level rises were recorded through much of these regions, with the exception of Box Butte County, where water levels continue to decline at a rate of approximately one foot per year.

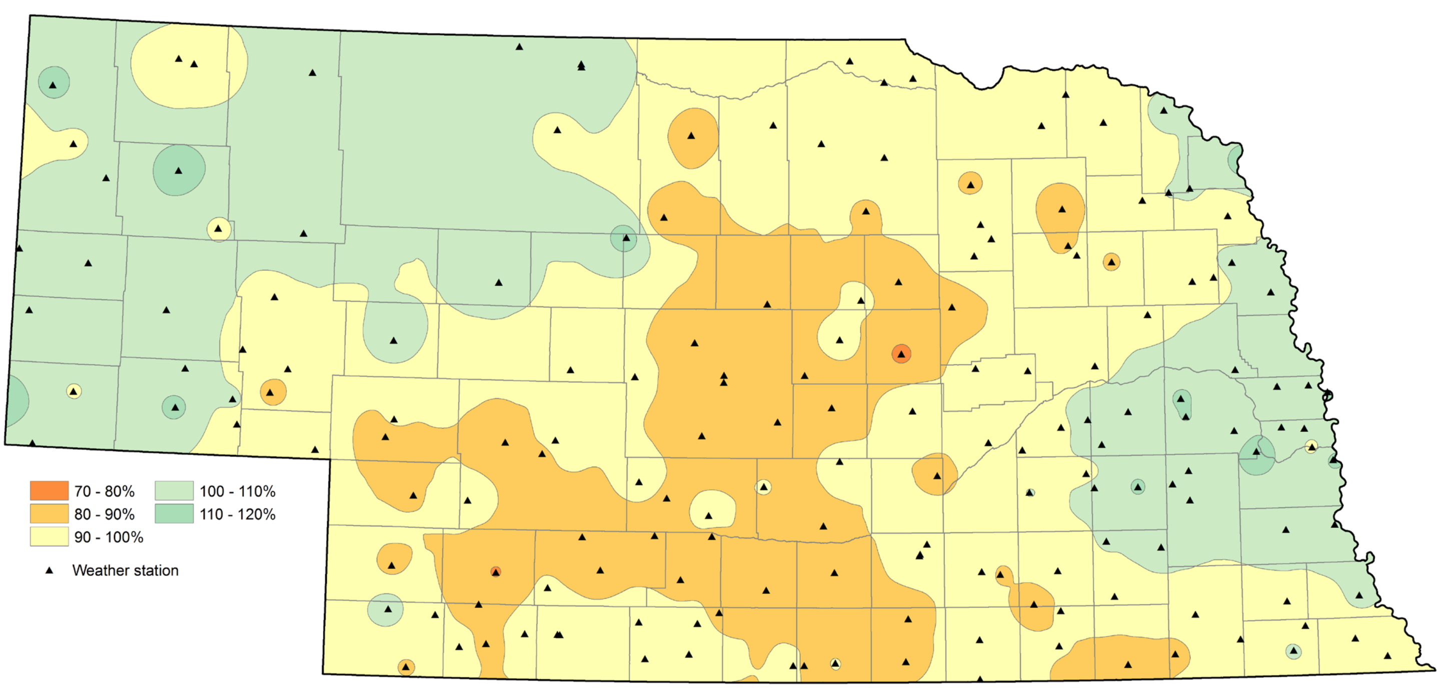
The five-year period between spring 2012 and spring 2017 included years with record low precipitation and others with above-average precipitation. Total average precipitation for the same five-year period, however, was near the 30-year average for much of Nebraska (Fig. 10). Groundwater-levels were relatively high through much of Nebraska following record wet years from 2009-2011 (cf. Korus et. al. 2012, pp. 10,-1). Following the record setting drought of 2012, reduced recharge to aquifers, combined with a much greater demand for irrigation water in 2012 and 2013, buffered many of the groundwater-level rises recorded in previous years. Although many of the declines resulting from 2012 still persist in central Nebraska, recent years with much above-average rainfall have allowed water levels to return to or exceed pre-drought levels in the southern half of the panhandle, and in eastern Nebraska. Declines in south central Lincoln County of 25-30 feet resulted from pumping associated with the Republican River augmentation project, also known as the N-CORPE Project. These declines are depicted in Figure 11 and discussed in detail on p. 14-15 of the present report.

Figure 9. Groundwater-Level Changes in Nebraska - Spring 2012 to Spring 2017



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 2012 to January 2017



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

GROUNDWATER LEVEL DECLINES IN LINCOLN COUNTY

Drawdowns in central Lincoln County are the result of groundwater pumping associated with the Nebraska Cooperative Republican Platte Enhancement project.

Groundwater-level declines of 30+ feet have been mapped in central Lincoln County from 2014 to present. Over the last three years, this area of decline has raised a great number of questions as to the timing and magnitude of the drawdown as mapped. The drawdown is the result of groundwater pumping associated with the Nebraska Cooperative Republican Platte Enhancement (NCORPE) project and timing of water level measurements. The purpose of NCORPE is to augment flow in the Republican River to meet interstate water flow requirements by pumping groundwater from wells in central Lincoln County. This water is piped to Medicine Creek where it subsequently flows to the Republican River.

Groundwater levels in the immediate vicinity of the pumped wells have been impacted by pumping. Certain wells in the well field, not necessarily all wells in the well field, were pumped between the following dates: April 1st, 2014-April 7th, 2015, October 27th, 2015-May 31st, 2016, and November 28th, 2016-March 30th, 2017. Representative hydrographs for the well field and the surrounding area are represented in Figure 11. Two sets of hydrographs are included, hydrographs on the left display data that were collected only since NCORPE Project wells began pumping in April of 2014. Blue vertical lines represent periods of pumping or well recovery. Horizontal red lines represent groundwater levels prior to the beginning of pumping in 2014. Wells in the left column represent groundwater-level changes over the long term for the area. Measurements for well 81 were discontinued in early 2013; however, this well provides a baseline for pre-project water levels and illustrates the long term history of groundwater-level fluctuations in the area. Seasonal drawdowns in well 29 likely result from irrigation pumping to the west. The general downward trend of this well is likely dominated by NCORPE Project pumping. Lincoln County has experienced fluctuating groundwater levels in response to a number of factors in post-development times, and NCORPE is but one, localized example. Groundwater levels in the area surrounding the NCORPE well field are generally 10-20 feet below predevelopment water levels (pre-1970s levels). These declines are primarily the result of irrigation pumping. Large declines occur during droughts, most notably the regional drought of 1999-2003. Following periods of drought, groundwater levels tend to rebound slightly during years of above-average precipitation. Precipitation has met or exceeded the 30-year average in the area over the past three years. Most wells in the area for which we have long term data have exhibited nearly constant water levels since pumping began in 2014. We estimated the saturated thickness in the area to be approximately 400 feet, but we are still engaged in assessing it.

Since 2014, groundwater levels immediately surrounding the NCORPE well field have fluctuated with pumping for the augmentation of flows in the Republican River. The slope of the water table, and thus the direction of groundwater flow in the well field, is from west to east. Groundwater declines follow a similar pattern, with the greatest declines in the eastern portion of the well field, and smaller declines in the western portion of the well field. Hydrographs indicate that groundwater levels recover between pumping cycles. However, the recovery is not to pre-project levels, with the most recent recovered groundwater-levels being 13 feet below pre-project levels in the western portion of the well field (Well 29) and approximately 40 feet below pre-project levels in the eastern portion of the well field (Well-27-2). Data from wells shown in Figure 11 are consistent with other observation wells in the area. Due to decreased pumping and above average precipitation in late 2017, as of January 2018 water levels have recovered by 5-20 feet since NCORPE wells were turned off on March 30th, 2017. At present, groundwater-level declines due to NCORPE project pumping are limited to within a few miles of the well field.

Groundwater-level declines for the NCORPE well field illustrated in Figure 9 depict a maximum decline between 25 and 30 feet, on the basis of a single welll (USGS Well ID 405557100564501). This well is located on the eastern end of the well field, approximately one mile to the north of the nearest pumping wells. As drawn, the map illustrates changes in groundwater-levels between March of 2007 and April 2017. Therefore, the declines depicted by this well represent a water level reading taken after wells were able to recover in the spring of 2007, compared to a reading taken while the NCORPE wells were pumping in the spring of 2017. Because this is a pumping level, this particular well is slightly overestimating the decline at that particular location. The map in figure 9 however does not include data from the wells in Figure 11, which for the same region have groundwater-level declines of 13-40 feet below pre-pumping levels, calculated after wells were allowed to recover. Therefore, due to the available data and mapping scale, Figure 9 may be slightly underestimating the declines in the vicinity of the NCORPE well field.

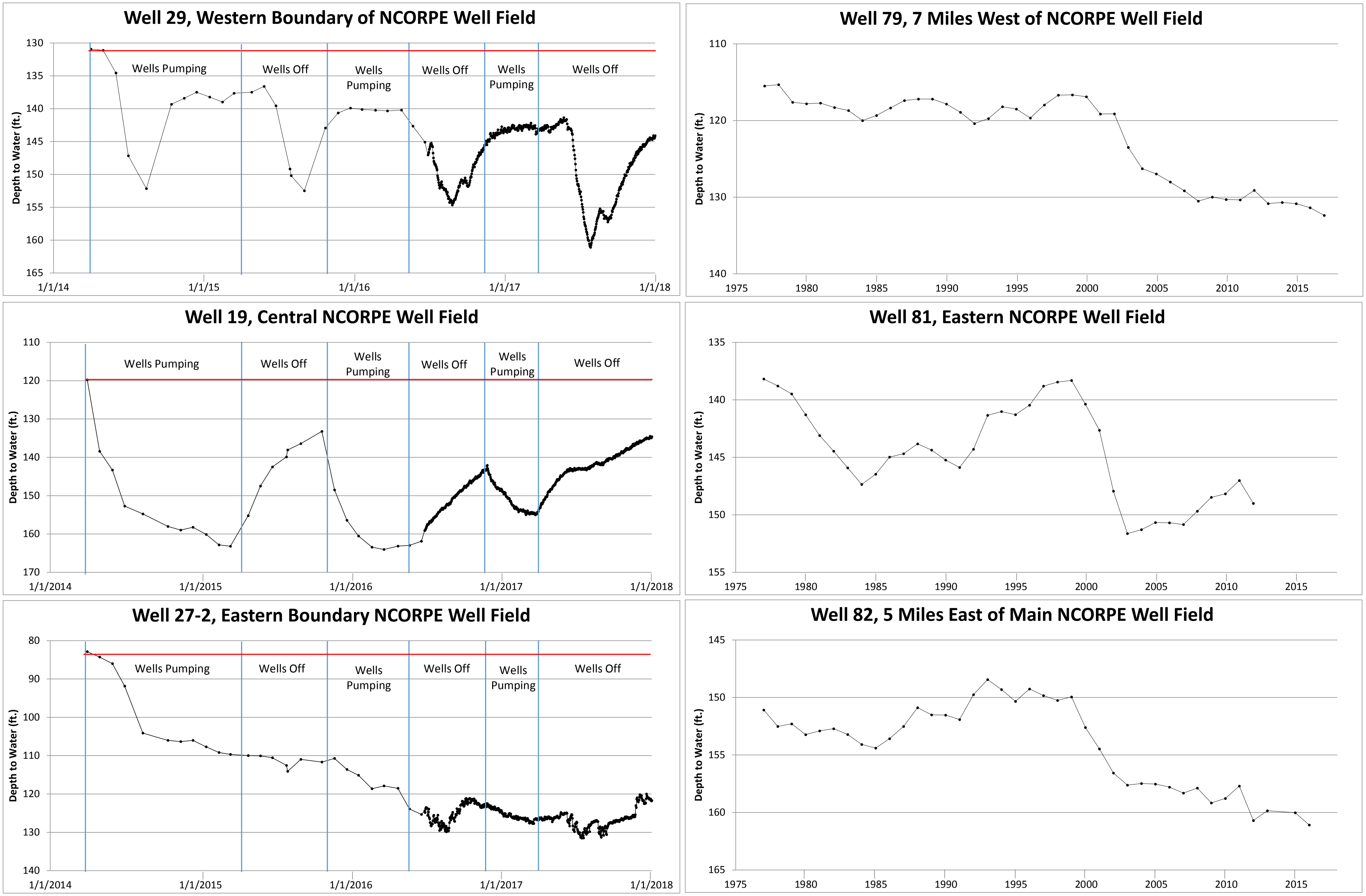


Figure 11. Central Lincoln County Hydrographs.
Hydrographs on right are from the NCORPE Project Well Field. Hydrographs on left show historic groundwater-Level readings immediately surrounding the NCORPE Well Field.
Source: Middle Republican NRD

CHANGES IN GROUNDWATER LEVELS, SPRING 2007 TO SPRING 2017

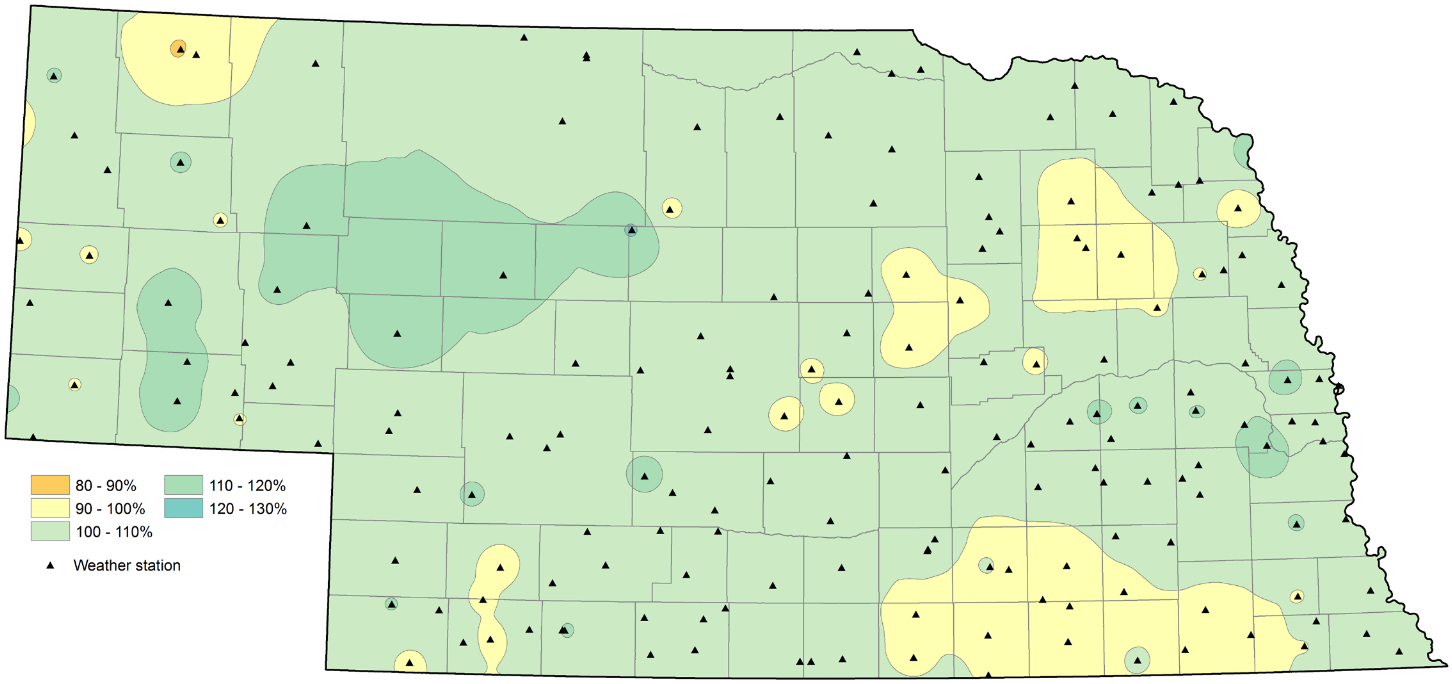
Despite major swings in climate conditions and record setting drought, modest groundwater-level rises were recorded throughout much of Nebraska.

Weather conditions from the spring of 2007 to the spring of 2017 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 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, beginning in the spring of 2012 through the spring of 2013 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. The Panhandle and eastern Nebraska experienced much-above-average precipitation from 2015-2017. The average precipitation for the 10-year period from 2005 to 2015 was near the 30-year normal for most of the state despite historic drought conditions in 2012 and early 2013 (Fig. 12).

Much of Nebraska recorded modest groundwater-level rises from the spring of 2007-spring 2017 (Fig.13). Of 4,380 wells measured in both spring of 2007 and spring of 2017, 60% recorded groundwater level rises, with 45% rising more than one foot. Despite the extreme drought conditions experienced during 2012, groundwater levels continue to rise from the relative low water levels experienced in the drought from 2000-2007. Water levels rose locally in parts of Nebraska because of multiple 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 groundwater-level rises of more than 10 feet in localized areas surrounding certain reservoirs. Near to above-average precipitation for most of the Nebraska between 2013 and 2017 reduced the need for irrigation pumping and increased recharge to aquifers, leading to groundwater-level rises for much of Nebraska.

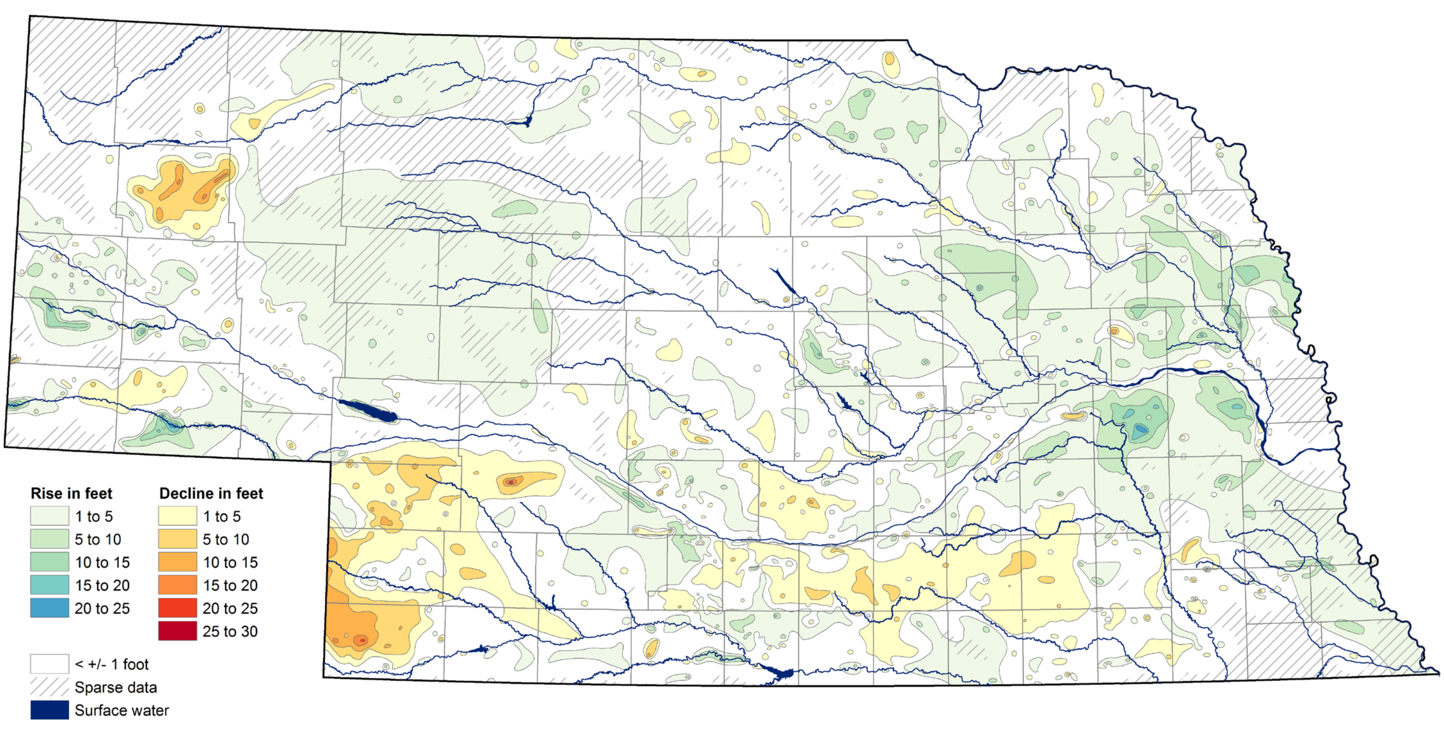
Groundwater-level declines were recorded in 40% of wells measured in Nebraska from the spring of 2007-spring 2017 (Fig. 13), with 27% experiencing declines of greater than one foot. Despite near-average precipitation for the state between 2007 and 2017, groundwater levels in some parts of the state continue to decline. Major areas of groundwater-level decline include the south central, Chase Dundy and Perkins counties, as well as Box Butte and Colfax counties. Declines of more than 5 feet occurred over much of these regions, with declines of more than 20 feet occurring in parts of Box Butte, Perkins, Dundy and Colfax counties. Groundwater-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 Nebraska, combined with a high density of irrigation wells per square mile have resulted in declines of 1-5 feet for much of the region. Other localized groundwater-level declines may have resulted from a combination of factors including increased irrigation water withdrawals or reduced recharge from near-normal to slightly below-normal precipitation on a regional scale.

Figure 12. Percent of Normal Precipitation - January 2007 to January 2017



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

Figure 13. Groundwater-Level Changes in Nebraska - Spring 2007 to Spring 2017



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 2017

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 2017 groundwater levels continue to indicate long-term declines and rises in certain areas of Nebraska (Fig. 14). 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. 15). The greatest measured decline from predevelopment to 2017 was 121.93 feet, in Box Butte County just north of the city of Alliance. Regions of notable groundwater-level declines from predevelopment to spring 2017 occurred in Box Butte County, the southwestern part of the State near Chase, Perkins, and Dundy counties, and in the panhandle. A large area of lesser declines occurred in the southeast corner of the High Plains Aquifer in southeast to south central Nebraska. The largest rises occurred in Gosper, Phelps, and Kearney counties, where there are extensive canals and surface-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 to more than 120 feet from predevelopment levels (Fig. 14). Records from wells in both the southwestern counties and Box Butte County 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 (Korus and Burbach, 2009b and forthcoming section).

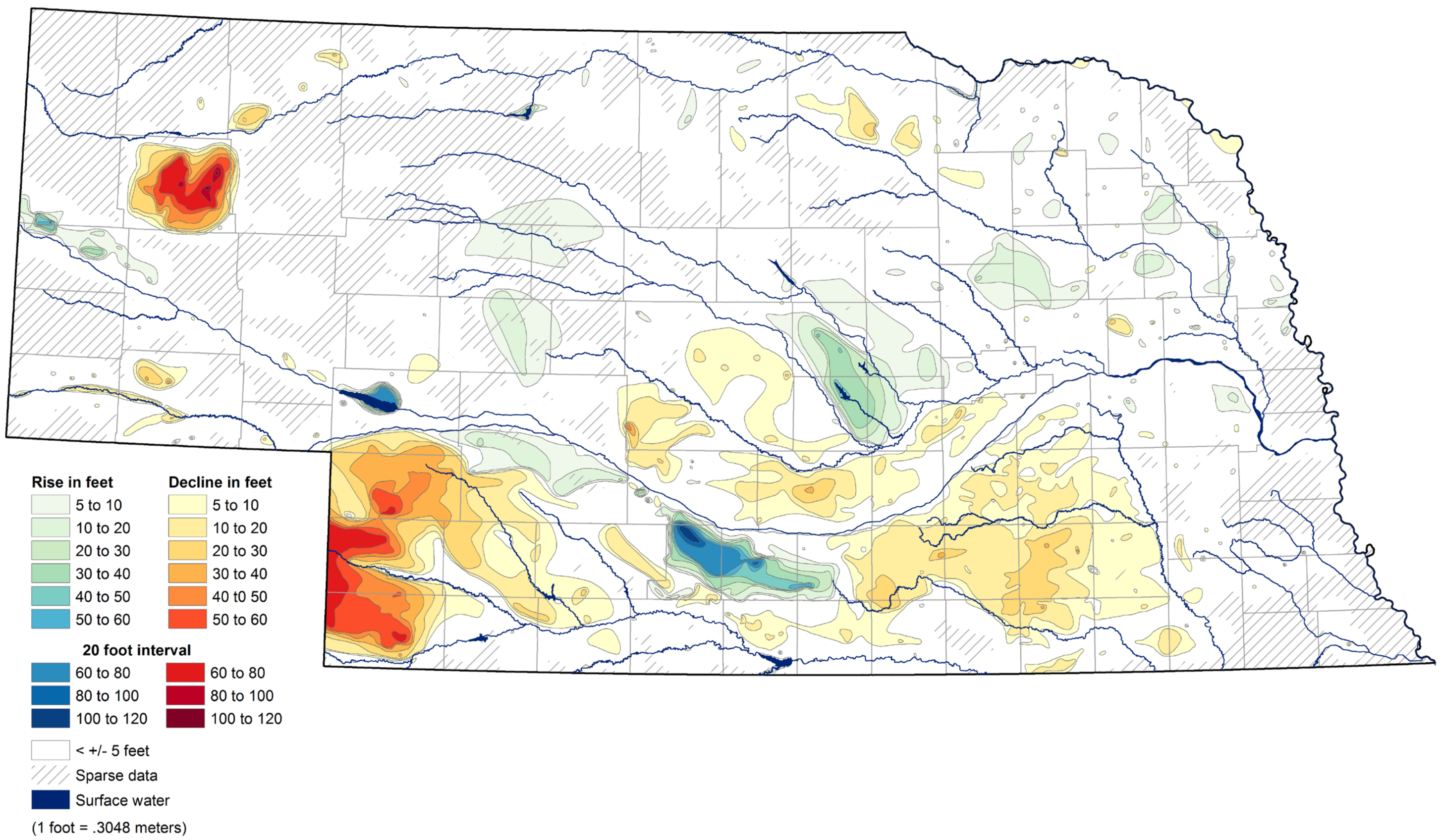
A large portion of southeast to south central Nebraska has experienced long-term groundwater-level declines since predevelopment (Fig. 14). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this region have declined more than 10 feet, and in some areas more than 30 feet, from predevelopment 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 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. 14). Groundwater levels have also risen in association with seepage from Sutherland Reservoir, Lake Maloney, and their associated canals in eastern Keith and central Lincoln counties. Rises of as much as 60 feet in southern Sioux, Scotts Bluff, and western Morrill counties are also associated with irrigation canal systems.

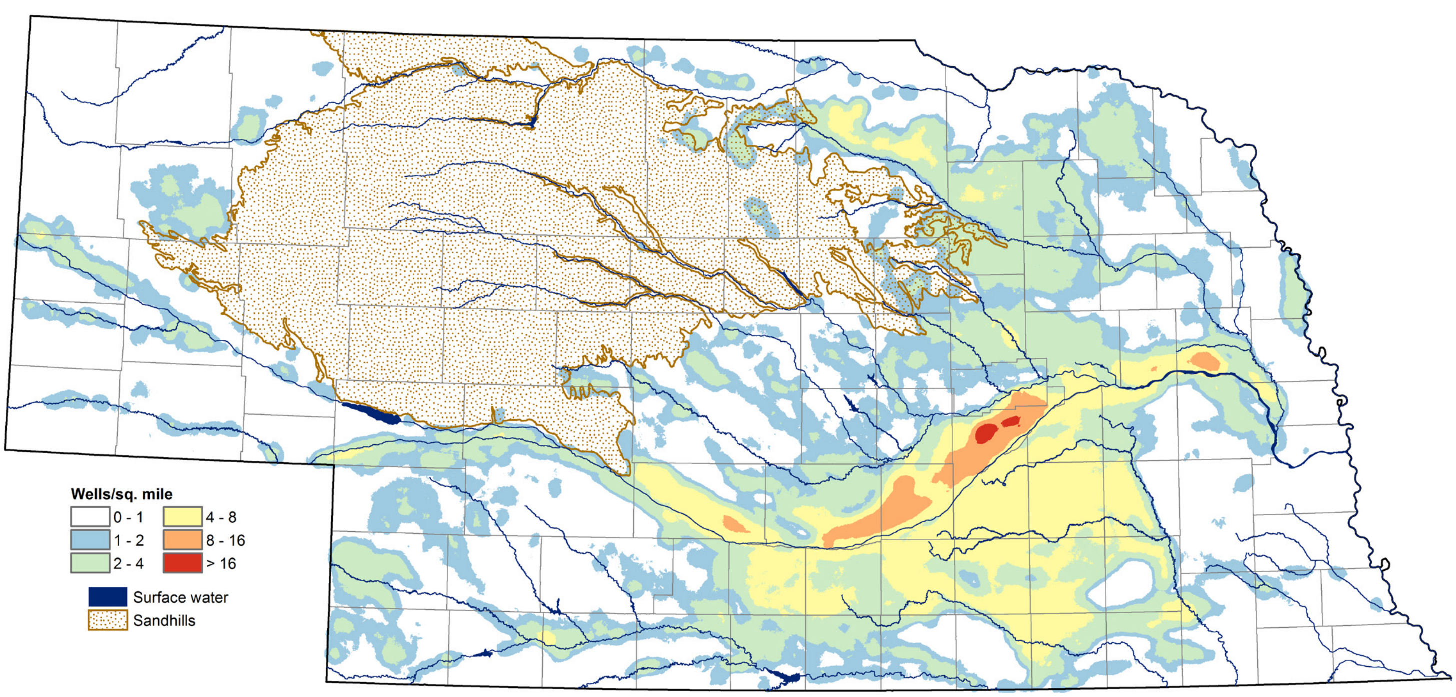
Groundwater-level rises of 10 to more than 50 feet occurred in portions of central Nebraska (Fig. 14). The highest groundwater-level rises occurred in Valley, Sherman, and Howard counties as the result of seepage from irrigation canals, Sherman and Davis Creek reservoirs, and deep percolation of irrigation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

Figure 14. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2017



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

Figure 15. Density of Active Registered Irrigation Wells - December 2017



Source: Nebraska Department of Natural Resources

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 1981 AND SPRING 1981 TO SPRING 2017

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

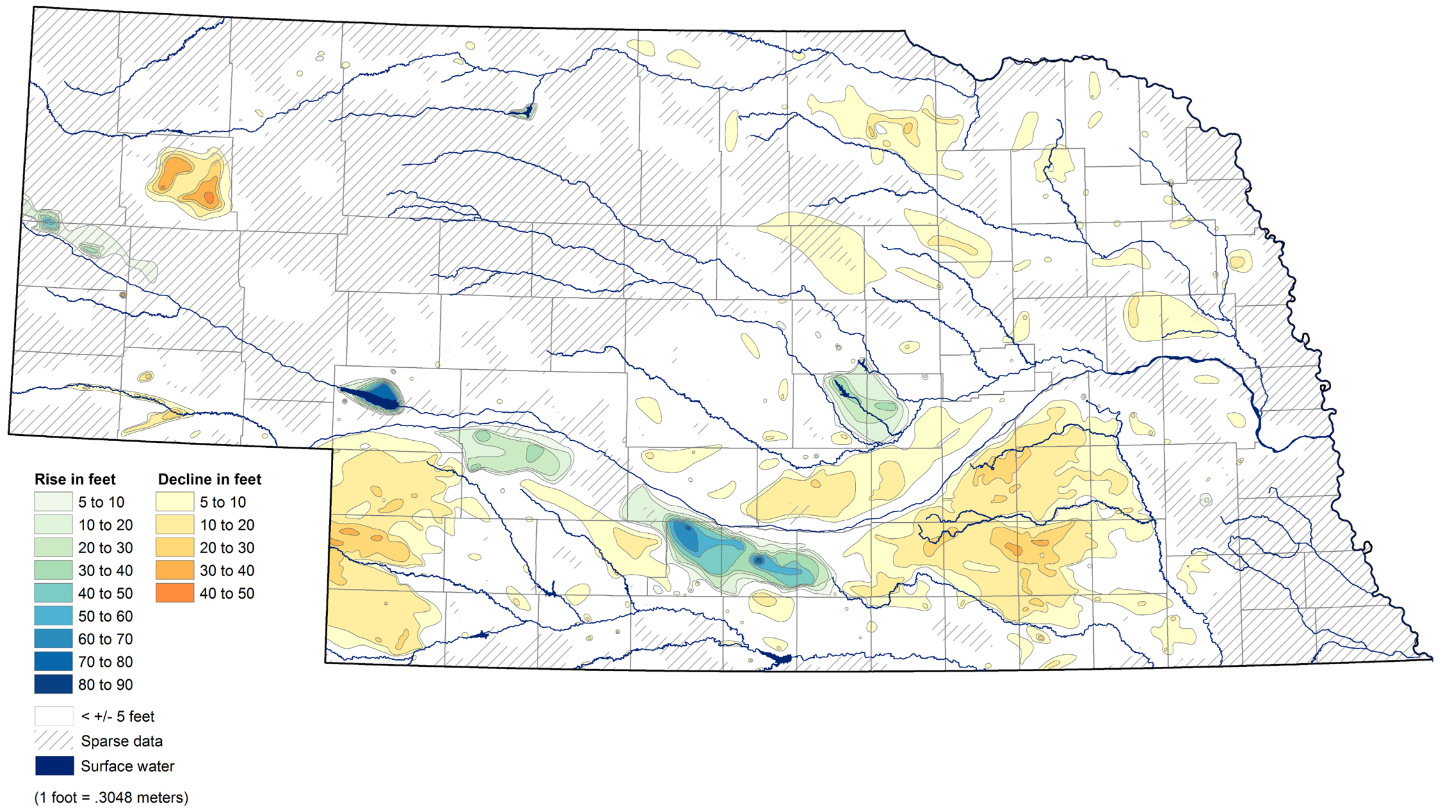
Groundwater-level changes from predevelopment to spring 1981 reflect the responses of aquifers to the development of groundwater and surface water irrigation systems in Nebraska. Areas of significant groundwater-level declines generally corresponded to areas of dense irrigation well development (cf. Johnson and Pederson, 1981). Declines were generally equal in magnitude in eastern and western areas (Fig. 16). The largest areas in which declines occurred were in Box Butte County in the Panhandle, Chase, Perkins, and Dundy counties in the southwest, south central/southeast Nebraska, Platte River Valley, central Nebraska, and northeast portion of the Sand Hills. Declines exceeded 40 feet in Box Butte County in the Panhandle, 30 feet in Chase County in the southwest, and up to 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. 16). The rise in southern Sioux and northern Scotts Bluff counties was associated with seepage from the Interstate Canal System, among numerous smaller systems, and excess water applied to crops beginning in the early 20th century. The rise in these counties exceeded 50 feet in some areas. The rise in Cherry County was associated with seepage from Merritt Reservoir beginning in the mid-1960s and exceeded 20 feet immediately adjacent to the reservoir. Seepage from Lake McConaughy beginning in 1941 caused groundwater levels to rise more than 100 feet by 1981. Reservoirs and canals south of the Platte River, which are used for hydroelectric power production and irrigation, provided seepage that caused groundwater levels to rise from eastern Keith County to western Kearney County (see discussion in previous section). Water levels began rising in this area after 1941 and had nearly reached their maximum by 1981. In Howard and Sherman counties, groundwater levels began rising in 1963 due to seepage from Sherman Reservoir, its irrigation-distribution system, and deep percolation of irrigation water applied to crops. Rises of 10 to more than 30 feet occurred in this area by 1981.

Compared to the changes discussed above, a much different pattern of groundwater-level changes has emerged in Nebraska since 1981 (Fig. 17). In central and eastern Nebraska, areas in which declines had occurred from predevelopment to 1981 experienced rises of 5 to more than 20 feet from 1981 to 2017. 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 some areas in south central/southeast Nebraska still have a net rise in groundwater levels compared to spring 1981, post-spring 1981 water level recovery in this region reached a maximum in the spring of 2012. Since the spring of 2012, water levels in many areas have been trending back toward, or in some areas have declined below 1981 levels. Since 2012, water levels in this region fluctuated 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.

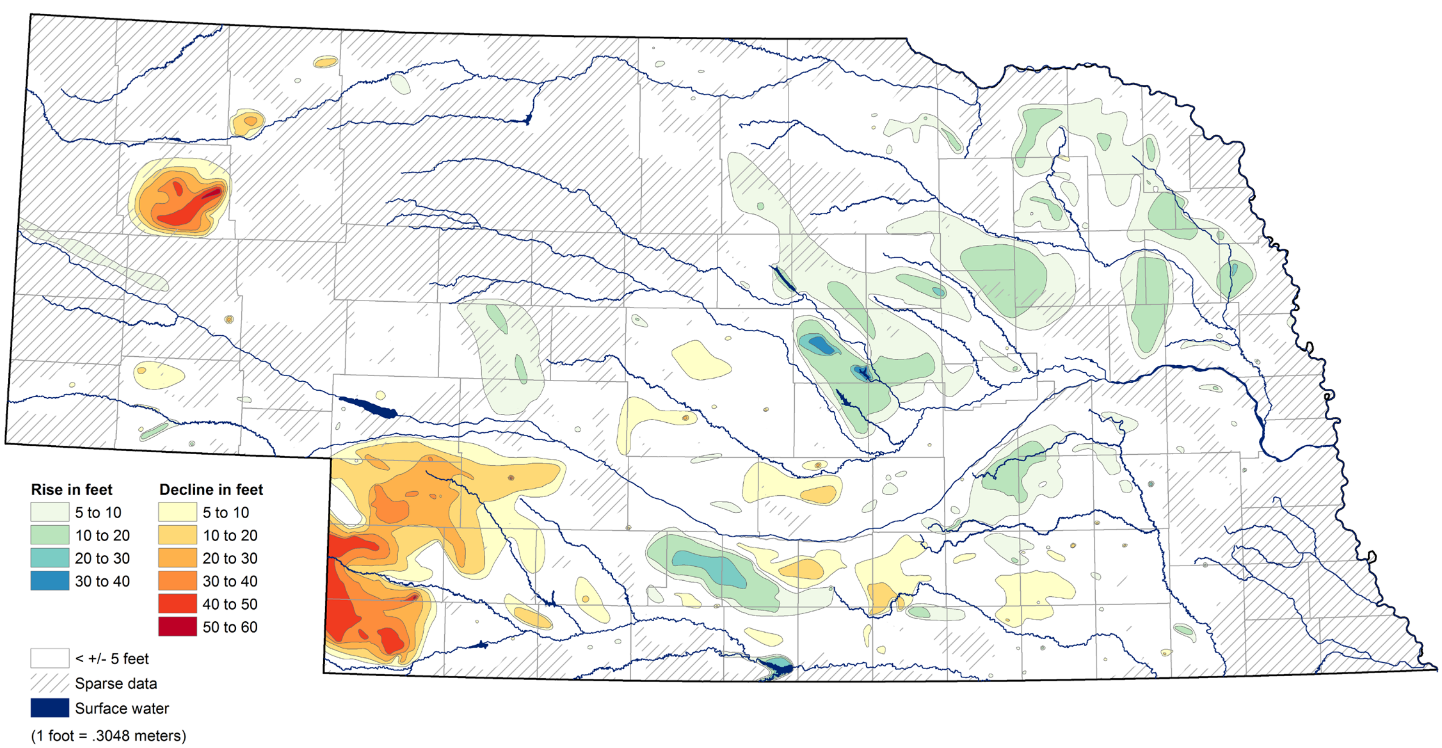
Declines in south central/southeast Nebraska reached a maximum in 1981 and had recovered such that declines in some areas are now less than 5-10 feet compared to predevelopment levels (Figs 14, 16, 17). Groundwater levels in most of this area, however, remain below predevelopment levels. The post-1981 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. 18). The steady

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



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

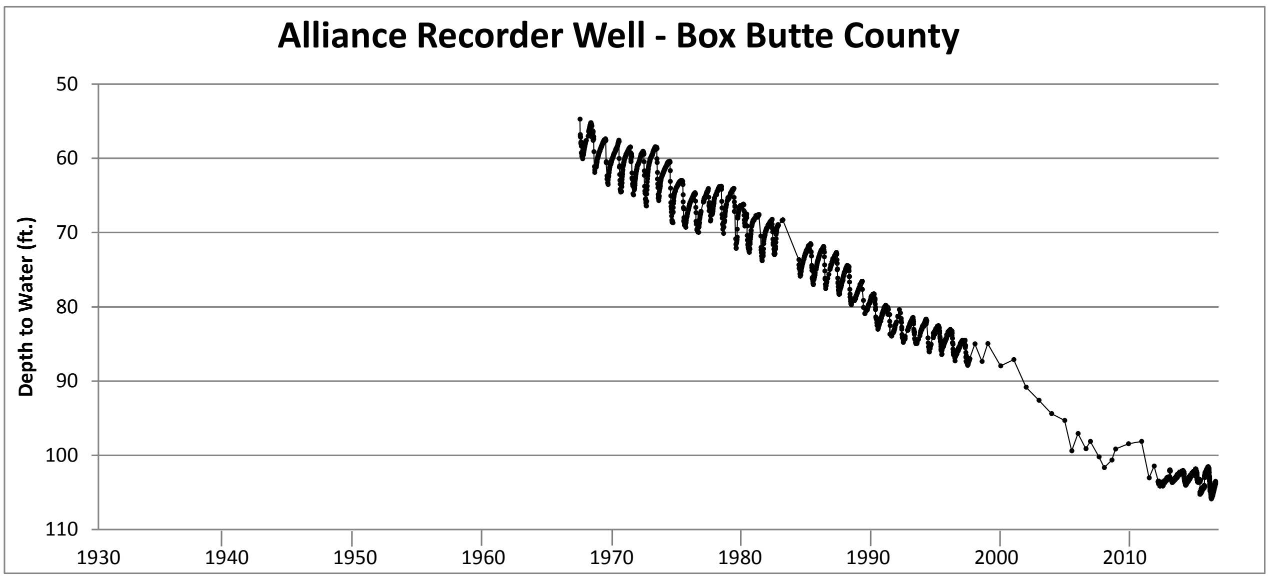
Figure 17. Groundwater-Level Changes in Nebraska - Spring 1981 to Spring 2017

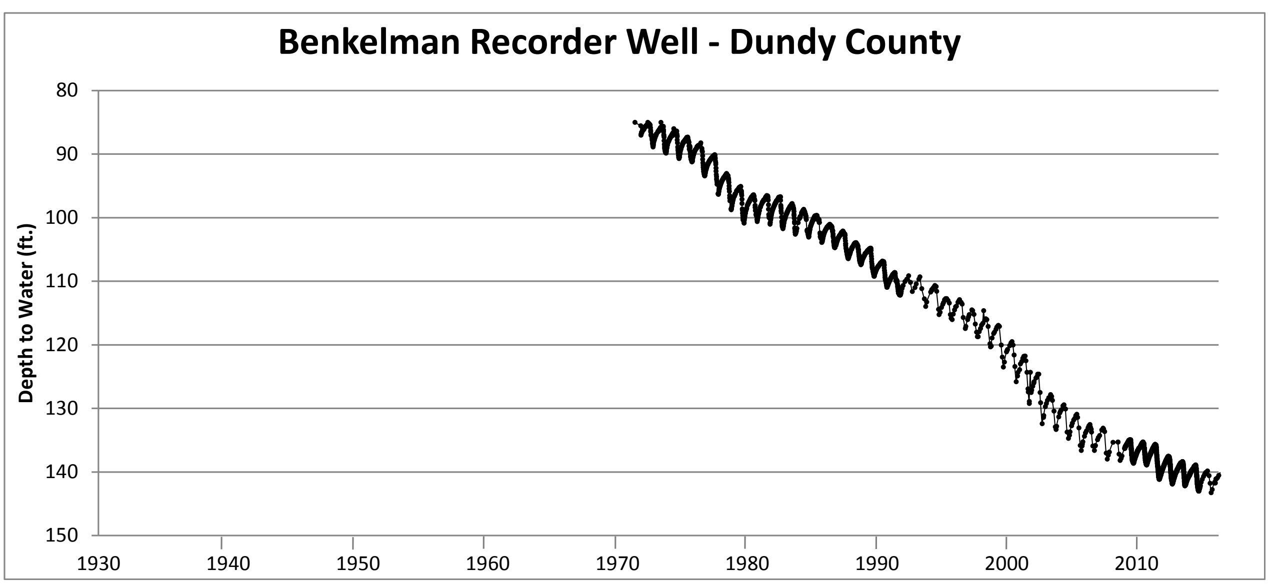


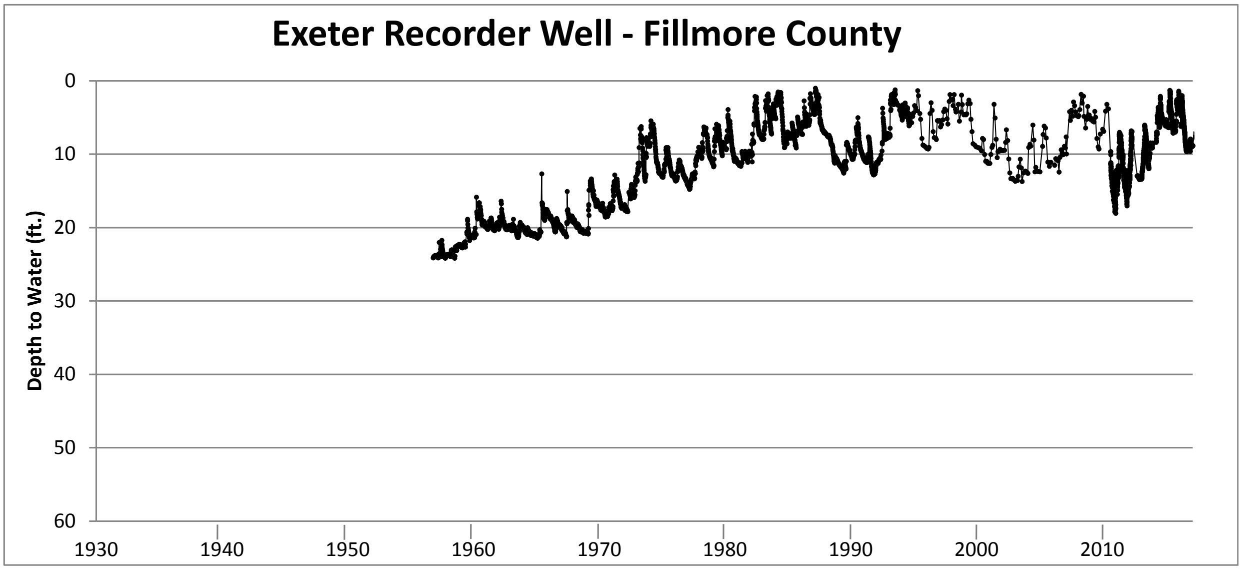
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District groundwater-level rise in this well between 1956 and 1981 temporally corresponds to the 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.

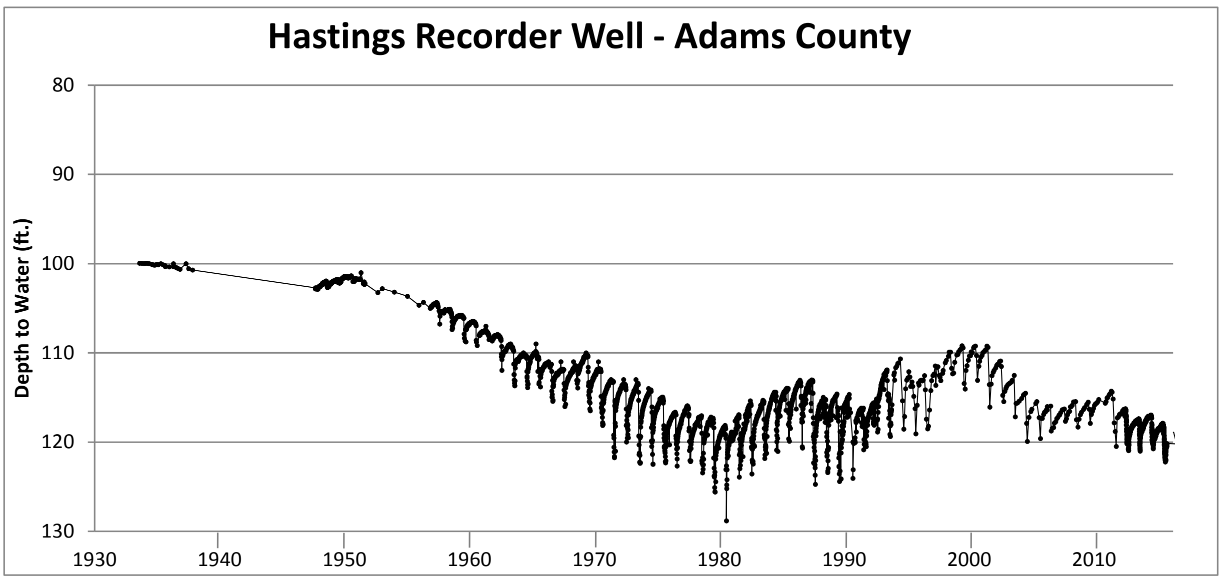
In contrast to the groundwater-level rises in the east, levels continued to decline in parts of western Nebraska from 1981 to 2017 (Fig. 17). The Alliance, Benkelman, and Imperial Recorder wells show declines of 50 to 60 feet in just 50 years, an average of about 1 foot per year (Fig. 18). Brief periods of unchanging or rising groundwater levels occurred, but the rates of decline were steady overall despite changes in groundwater management practices, water use allocations, and fluctuations in the amount of annual precipitation over the past 30 years. The pattern of long-term groundwater-level decline over a large region, such as southwest Nebraska or Box Butte County, is a normal response of an aquifer to irrigation development. Such declines reflect the release of water from storage in the aquifer and the adjustment of the water table to new hydrological stresses (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 recharge.

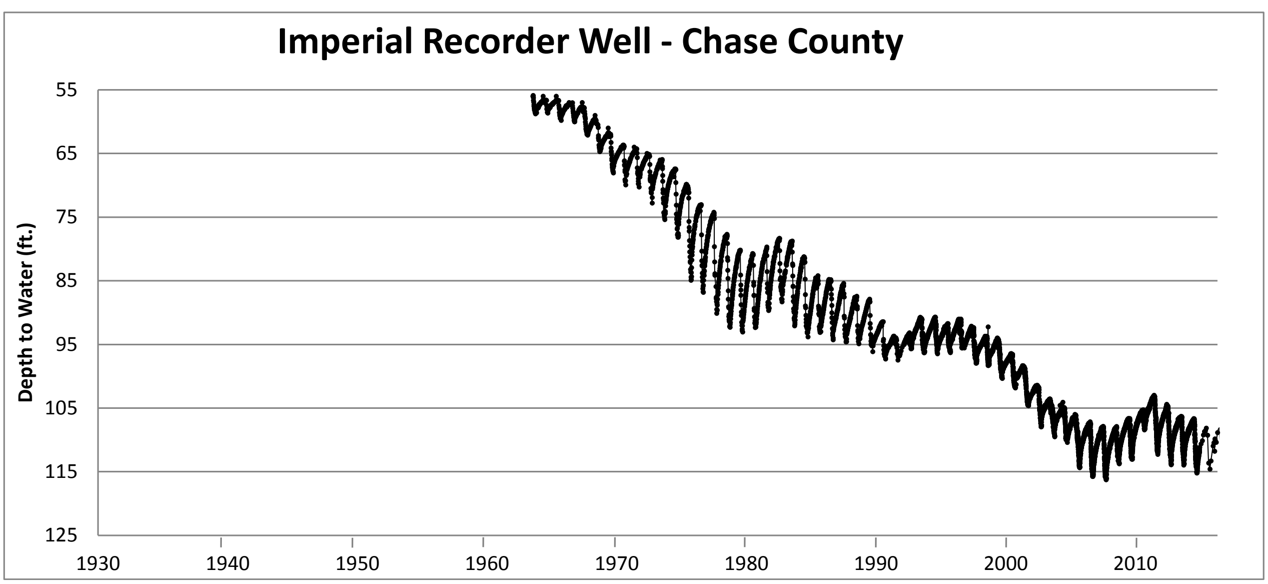
Figure 18. Groundwater-Level Hydrographs Typical of Southeast and Southwest Nebraska






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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