Nebraska Statewide Groundwater-Level Monitoring Report

2020

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

Conservation and Survey Division
School of Natural Resources

128 YRS
CSD
1893-2021

Nebraska Water Survey Paper Number 88

Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

Nebraska Statewide Groundwater-Level Monitoring Report 2020

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

Conservation and Survey Division
School of Natural Resources

Nebraska Water Survey Paper Number 88

Conservation and Survey Division
School of Natural Resources
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

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/.

February 2021

ISBN 1-56161-087-9
ISBN-13 978-1-56161-087-7

Suggested citation for this report:
Young, A.R., Burbach, M.E., Howard, L.M., Lackey, S.O., Joeckel R.M., 2020, Nebraska Statewide Groundwater-Level Monitoring Report 2020. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 88, 24 pp.

To purchase more copies of this report, please contact:
Nebraska Maps and More Store
101 Hardin Hall
3310 Holdrege Street
University of Nebraska–Lincoln
Lincoln, NE 68583-0961
Phone: 402-472-3471
Fax: 402-472-2946
Email: snrsales@unl.edu
Website: nebraskamaps.unl.edu

ACKNOWLEDGMENTS

The cooperation and assistance of the following agencies and associations in collecting and providing groundwater-level data during 2020 are gratefully acknowledged: U.S. Bureau of Reclamation; Central Nebraska Public Power and Irrigation District; U.S. Geological Survey; and the following Natural Resources Districts; Lower Republican, Middle Republican, Upper Republican, Upper Big Blue, Little Blue, Lower Big Blue, Lower Platte South, Lower Platte North, Central Platte, Twin Platte, North Platte, South Platte, Lower Niobrara, Middle Niobrara, Upper Niobrara-White, Lower Loup, Upper Loup, Lower Elkhorn, Upper Elkhorn, Papio-Missouri River, Lewis and Clark, Nemaha, and Tri-Basin. We also thank the many hundreds of landowners who graciously allowed these agencies to collect groundwater-level information from their wells and install observation wells on their land. Thanks to Dee Ebbeka for assisting with the preparation of this report.

CONTENTS

FIGURES

FOREWORD

Nebraska Water Issues of Interest

R.M. Joeckel, Nebraska State Geologist and Director of the Conservation and Survey Division;
Senior Associate Director, School of Natural Resources

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 proud 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 2020

Surface water

The U.S. Army Corps of Engineers (USACE) doubled its wintertime release of water from Gavins Point Dam in February in order to mitigate anticipated springtime floods along the Missouri River (Hytrek, 2020). Nevertheless, flooding in Nebraska in 2020 was significantly lesser than anticipated and, overall, minor in comparison with 2019. Ice-jam flooding occurred in February 2020 in Dodge County (Conley, 2020; Gaarder, 2020a, Rowher, 2020). An eight-inch rainfall event during the overnight hours of May 24th 2020 drove flash flooding in Kearney, Buffalo and Hall counties (Associated Press, 2020). The same storm produced flooding on the Little Blue River, which led to severe road damage (Heckt, 2020).

The remediation of damages incurred by the historic spring 2019 floods continued through 2020. Levees along the Missouri River were monitored and repaired, and work will extend into 2021 (Swanson, 2020). USACE also awarded more than $2.9 million in contracts to repair bank and levee erosion on the Platte River near Fremont and Plattsmouth during 2020 (Johnson, 2020; Spilinek, 2020). Continuing flood mitigation efforts in the Bellevue area include not only the reinforcement of levee systems, but also a feasibility study for a permanent floodwater pumping station, on which work may begin as early as the spring of 2021 (Pimper, 2020). The Nebraska Department of Transportation announced that all highways and bridges affected by the 2019 floods had opened by early February 2020 (Conley, 2020), but the Mormon Canal Bridge on Nebraska Highway 12, which had been washed away, was not officially reopened until early September (Wessendorf, 2020). The Federal Emergency Management Agency (FEMA) announced in early February 2020 that only 16.2% of high-risk properties in Nebraska (those on 100-year floodplains) had flood insurance by October of the previous year (Gaarder, 2020b).

Health Alerts for harmful algal blooms were issued by the Nebraska Department of Energy and Environment (NDEE) during June to October 2020 for Calamus, Oliver, and Willow Creek reservoirs and Bluestem, Iron Horse Trail, Kirkman's Cove, Maple Creek, Rockford, Swan Creek, and Wagon Train lakes.

Groundwater, water-supply, and environmental issues

The Nebraska Department of Health and Human Services (NDHHS) issued a press release on March 17, 2020 assuring Nebraskans that public drinking water supplies were safe during the COVID-19 pandemic (NDHHS, 2020). From April onward, University of Nebraska researchers investigated wastewater testing for the SARS-CoV-2 virus (Gayman, 2020).

Nitrate contamination in groundwater is an ongoing problem in Nebraska. The Environmental Working Group reported that elevated levels of nitrate ($\geq$ 3 mg/L) in the tap-water supplies of 349 Nebraska communities during the period 2003−2017, and potentially impacting some 1.4 million Nebraskans (Schechinger, 2020). Drinking-water nitrate warnings continue to be issued and some communities are making significant investments in water-supply infrastructure in order to address nitrate contamination. Nitrate concentrations in Genoa slightly exceeded established nitrate drinking water standard (10 mg/l) during September 2020, leading the NDHHS to issue a warning (Anonymous, 2020). As of May 2020, and in response to nitrate contamination, Edgar was building a 12-mile (19.3-km) water-supply line from nearby Fairfield at a cost of nearly three million dollars, subsidized by federal grants and loans (Walsh, 2020). This project had been under discussion at least as early as 2018.

Several industrial operations in Nebraska raised concern over potential impacts on water. September 2020 saw operations begin at a new chicken-processing plant at Fremont, about which concerns over potential water-pollution and other environmental concerns were raised as early as 2016. Monolith Materials proposed carbon-black manufacturing plant near Hallam, Nebraska, the first phase of which has already been completed, met with concerns about groundwater supply because the plant will use 2.3 to 4.6 billion gallons per year; the proposed discharge of water from the plant is also under review (Hammel, 2020). The Henningsen Foods egg plant in David City will spend more than $2.8 million in a settlement resolving alleged violations of the Clean Water Act (Oberding, 2020). The EPA notified Bellevue property owners of potential groundwater and soil-gas contamination in a 15-block downtown area known as the PCE Carriage Cleaners Superfund Site; the EPA also held informational meetings about the site in early 2020 (Ristau, 2020). EPA also finalized a Record of Decision for the Hastings Groundwater Contamination Superfund Site, Operable Unit 1 – Colorado Ave. Groundwater (EPA, 2020).

During early spring 2020, a year after the historic 2019 floods, the Lincoln well field near Ashland still lacked 15% of its pumping capacity while repairs to five wells taken offline during the flood, as well as repairs to related infrastructure, continued; the total cost of wellfield remediation was estimated at $24 million (Johnson, 2020).). Forty-four community and non-community water systems in the state were impacted by exceptional flooding during 2019, but 92% of those returned to normal operations by late June 2020 (NDHHS Drinking Water Division, 2020). Five of those systems, however, had been inactivated. During 2019, the NDHHS also reported 265 violations from 175 public water systems for exceeding a maximum contaminant level or failing to properly monitor (NDHHS Drinking Water Division, 2020).

Legislation

During 2020, the Nebraska Legislature voted in favor of resolution LR288, directed toward the Congress and the USACE, requesting the prioritization of flood control over fish and wildlife protection in future master water control manuals and levee standards within the Missouri River basin. A natural resources omnibus bill (LB632), passed by the Legislature in August, contains mended provisions that require a statewide flood mitigation plan to be created by the NDEE and incorporated within Nebraska Emergency Management Agency's state hazard mitigation plan. In April, EPA issued a finalized The Navigable Waters Protection Rule, considered by some interests to be a major rollback of longstanding environmental regulations. June saw it become effective. At the same time, the EPA's Clean Water Act Section 401 Certification Rule was finalized.

SELECT RECENT GROUNDWATER PUBLICATIONS AND RESOURCES

Online Resources

go.unl.edu/groundwater

CSD Interactive Data Map

The CSD interactive Data map is an online mapping application for viewing up-to-date depth to groundwater, groundwater-level change, test-hole and other associated spatial and geologic information in Nebraska. The map can be accessed through https://go.unl.edu/interactivemap

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.

Nebraska GeoCloud

The Nebraska GeoCloud (NGC) is an internet platform for storing, integrating, and sharing Nebraska's hydrogeological data. The NGC stores multiple databases that house airborne electromagnetic (AEM) surveys, images, GIS, test-hole, and other hydrogeological data. These data can all be combined through GeoScene3D to produce virtual models, mapping, and data exploration. More information can be found at: http://go.unl.edu/geocloud

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.

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 Resources 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 provides vital 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 mi^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 2017 US Census of Agriculture, Nebraska leads the nation in irrigated acres with more than 8.6 million acres. Without proper oversight, irrigation pumping on this scale can rapidly deplete aquifers and lead to large-scale economic hardship. The present report illustrates the changes in groundwater levels in Nebraska at different time scales, resulting from both natural and anthropogenic influenced changes. This information is important to both state and local lawmakers in assessing the current state of Nebraska's groundwater resources, and to local producers in making land management decisions.

Figure 1. Nebraska Natural Resources Districts

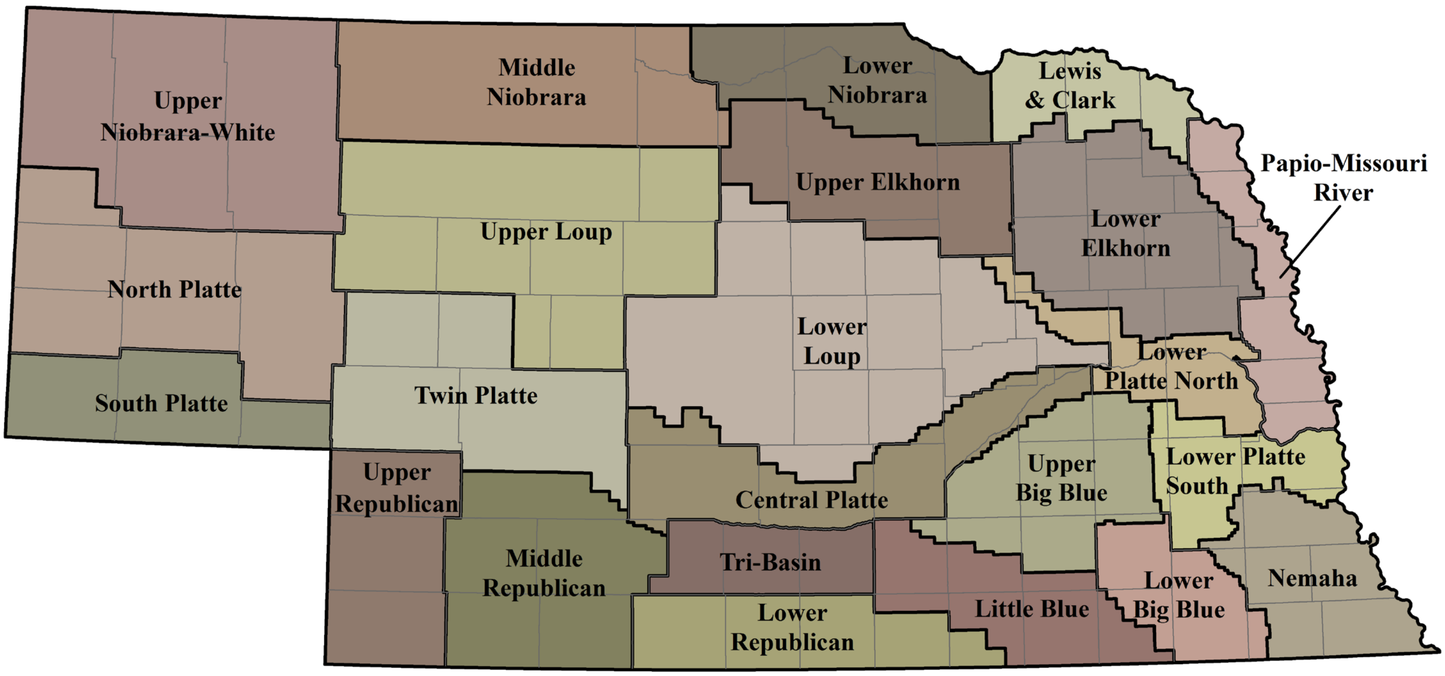
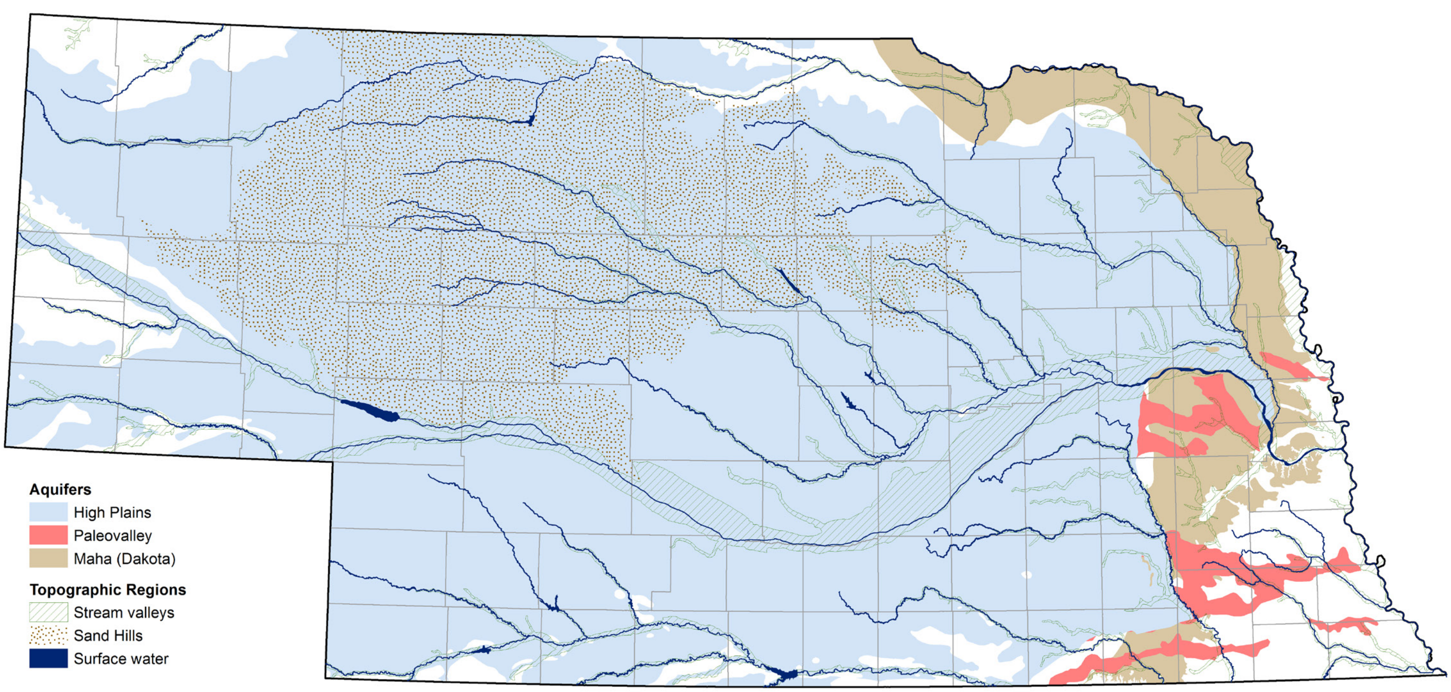


Figure 2. Important Aquifers and Topographic Regions of Nebraska



Note: The aquifer units shown here may contain little or no saturated thickness in some areas.

Figure 3. Generalized Geologic and Hydrostratigraphic Framework of Nebraska

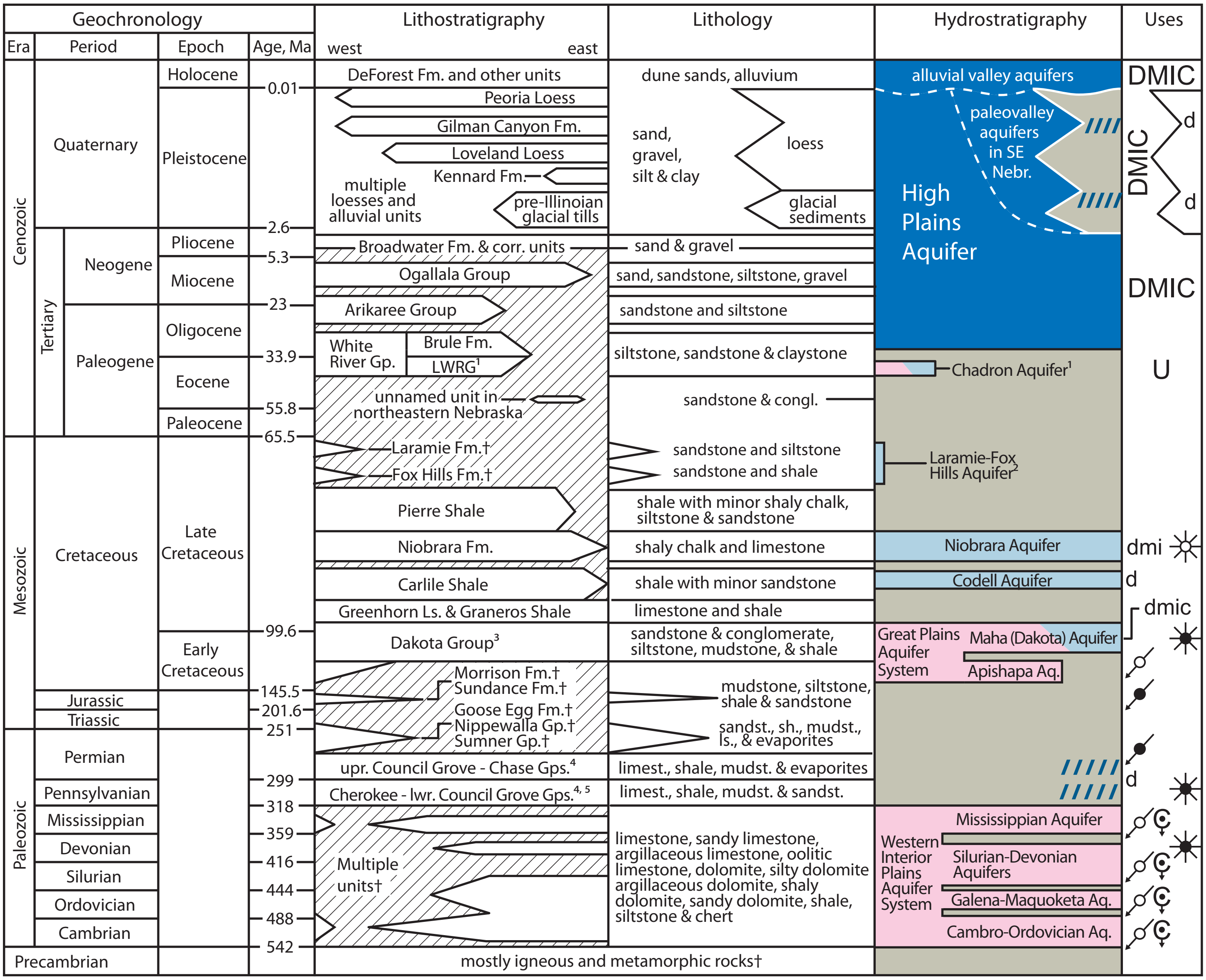


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

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

This report summarizes changes in Nebraska's groundwater levels over periods of one, five, and ten years prior to 2020, as well as from 1981 to 2020, predevelopment to 1981 and predevelopment to 2020. 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 at this scale. 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 2019 to spring 2020, spring 2015 to spring 2020, and spring 2010 to spring 2020 maps, respectively. Groundwater levels measured from thousands of wells throughout the state during the spring of 2020 (Fig. 5) were compared to levels measured in the same wells in the spring of the preceding target 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 1:557,000 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 2020 map, computer interpolation was impractical because data were sparse in many areas. Accordingly, contours were drawn manually at a scale of 1:500,000 to incorporate the major hydrogeologic boundaries listed above.

For the predevelopment to spring 2020 and predevelopment to spring 1981 maps, groundwater levels from wells measured in 2020 and 1981 were compared to estimated predevelopment groundwater levels in the same wells. An estimated predevelopment groundwater level is the approximate average groundwater level at a well site prior to any development that significantly affects groundwater levels. Predevelopment groundwater 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 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 ft (500 m) 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.

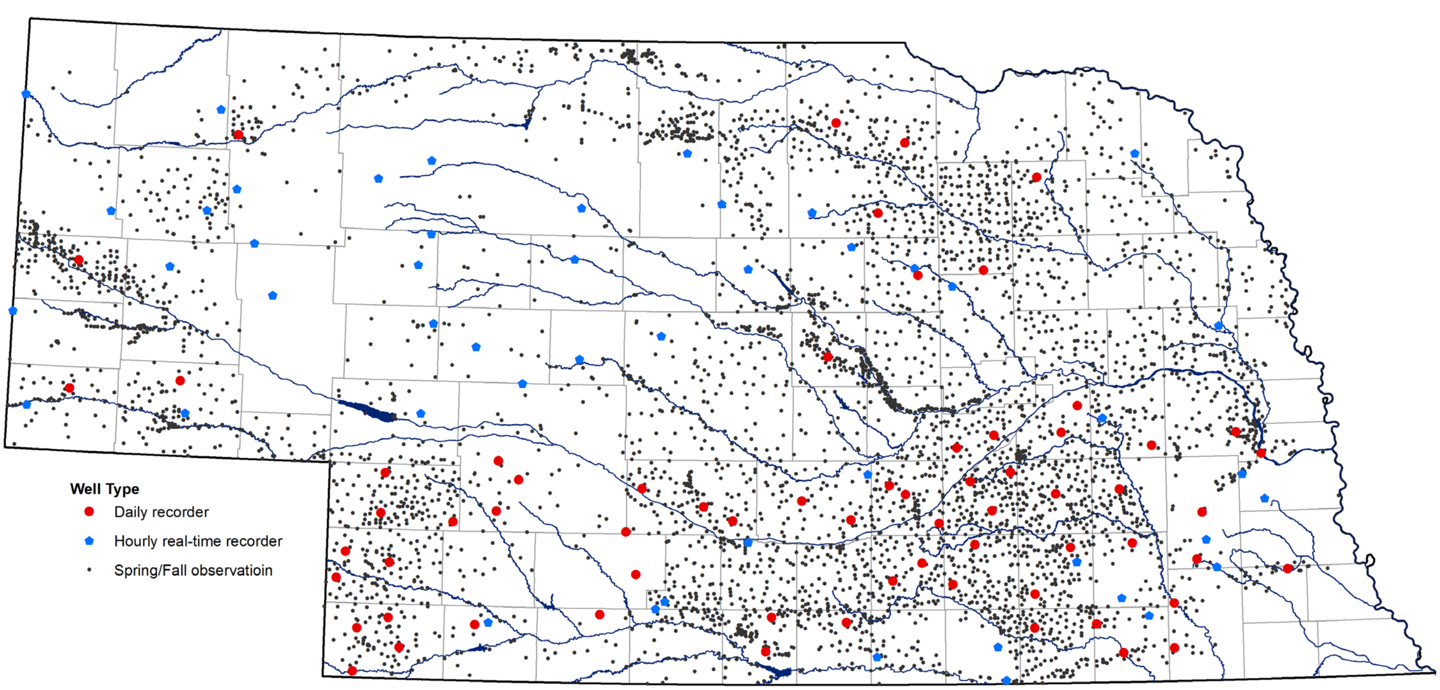
Factors Causing Groundwater-Level Changes

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 properties and all sources of recharge and discharge must

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

Figure 5. Location of Observation Wells by Type

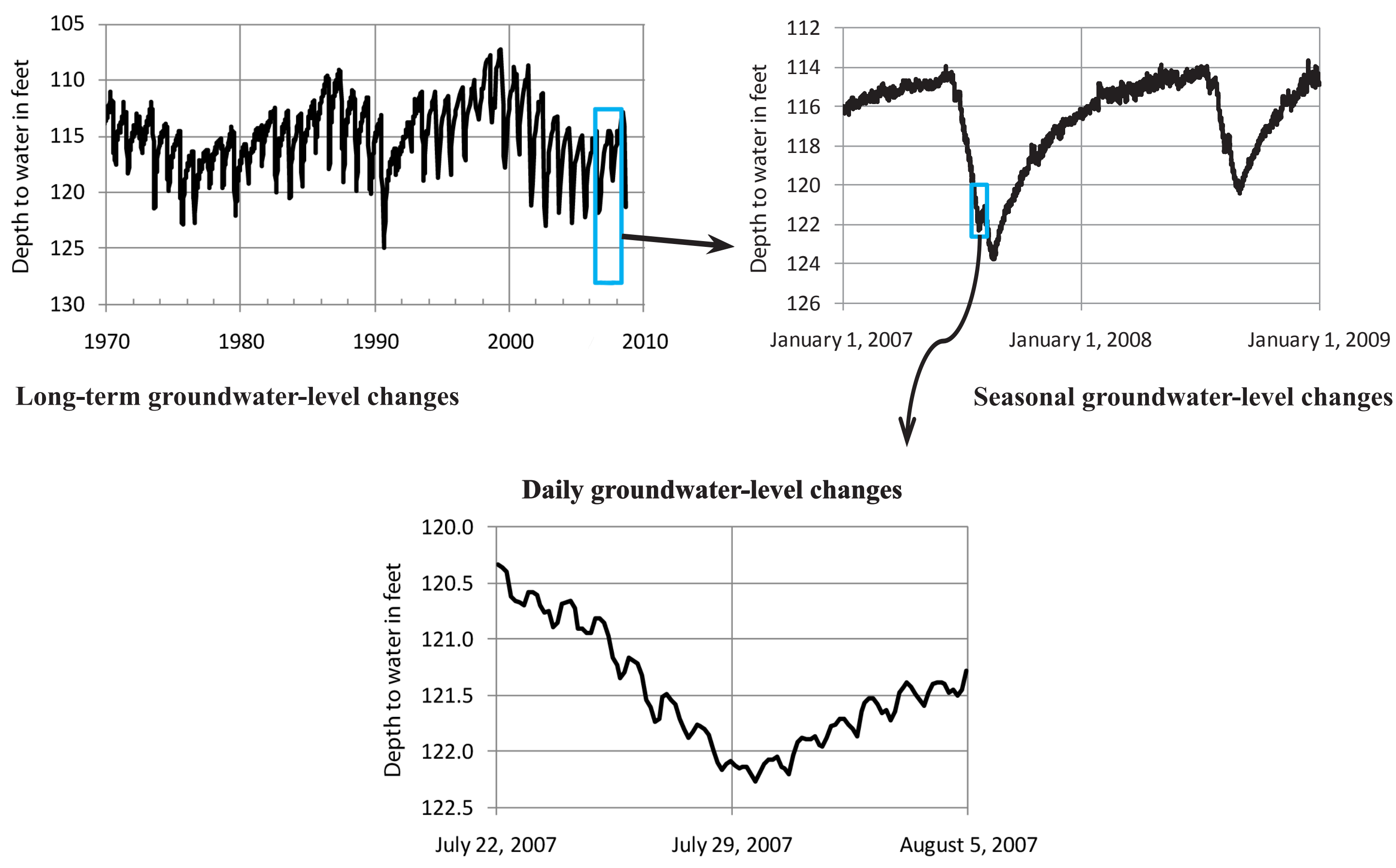


Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District; Conservation and Survey Division, School of Natural Resources, University of Nebraska–Lincoln 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 1:557,000 or 1:500,000. **They are intended solely to identify regional conditions and trends at varying time scales throughout the entire state of Nebraska, and not at the local scale.** 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



Data from Plymouth Recorder well, Jefferson County

CHANGES IN GROUNDWATER LEVELS, SPRING 2019 TO SPRING 2020

From the spring of 2019 to the spring of 2020, groundwater levels in Nebraska recorded an average rise of 1.58 feet.

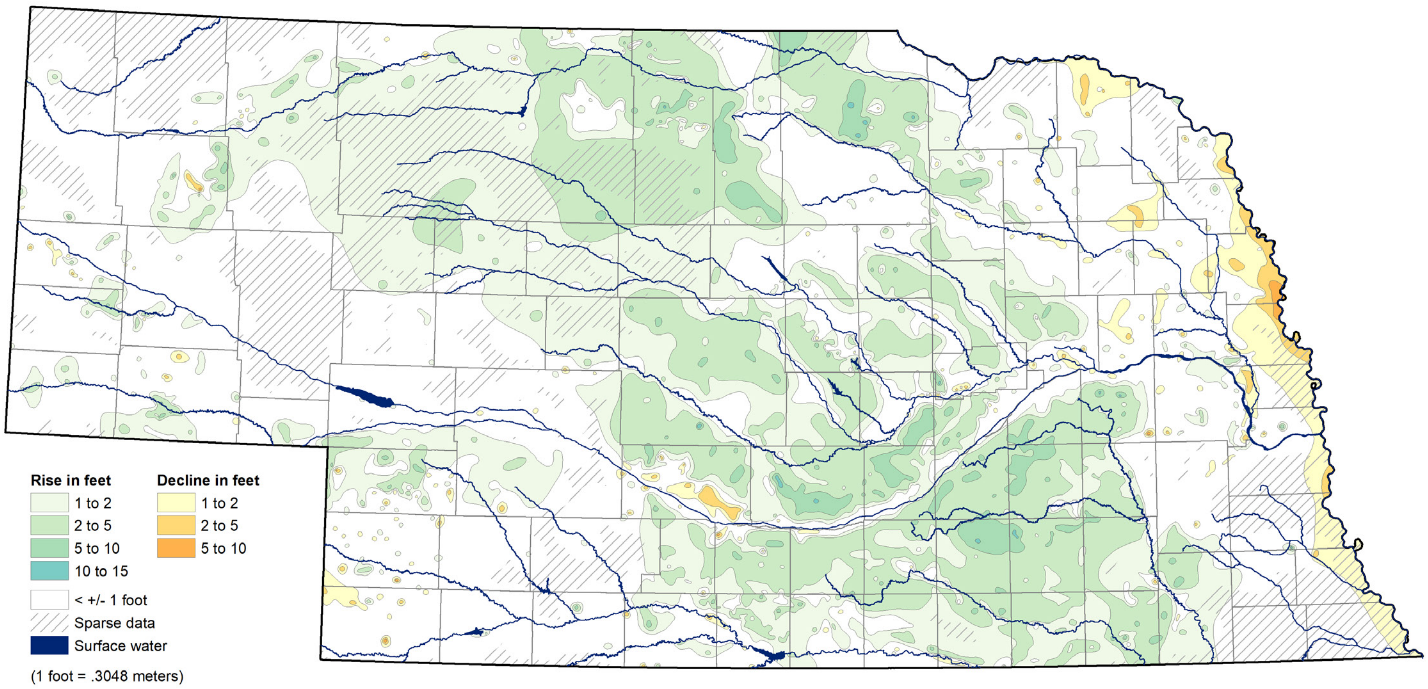
Groundwater levels in Nebraska generally rose from the spring of 2019 to the spring of 2020. In total, 4,970 wells were measured consecutively in the spring of 2019 and spring 2020. Groundwater-level rises were recorded in 79% of measured wells, and 55% of all measured wells recorded a rise greater than one foot (Fig. 7). Groundwater-level declines were recorded in 20% of measured wells, and 6% of all measured wells experienced a decline of greater than one foot. Approximately 1% of measured wells had neither rises nor declines from the spring of 2019 to the spring of 2020. The average groundwater-level change for all measured wells in Nebraska in the spring of 2020 was a rise of 1.58 feet. From January 2019 to January 2020, precipitation values for Nebraska were well above the 30-year normal for 159 of 163 reporting stations in Nebraska (Fig.8). Precipitation values were as high as 212% of the 30-year average in northern Cherry County, and greater than 150% over much of central Nebraska. Much of the precipitation fell in early 2019, which led to severe flooding in many areas. Throughout much of Nebraska, water tables remained high, and roads, streams and fields remained flooded through much of 2019 and into early 2020.

Due to severe flooding in spring 2019 and travel restrictions associated with the ongoing pandemic of 2020, the number of wells used to create Figure 7 dropped from 5,364 in 2018 to 4,970 in the spring of 2020. Many wells in flooded or inaccessible areas could not be measured in 2019, while other wells were not measured in 2020 due to travel restrictions for measuring agencies due to the ongoing pandemic. These omitted measurements created a gap in the serial continuity of measurements from 2018 to 2020. The majority of wells not measured due to 2019 flooding were in the Platte River Valley, in the vicinity of Fremont Nebraska, and in Garden, Kearney, and Frontier Counties, where hundreds of wells could not be measured in 2019. Wells normally measured in some areas were skipped in the spring of 2020 sporadically throughout the state. Therefore, projected groundwater-level changes may over-or underestimate actual changes in groundwater levels reported in 2020, particularly in regions of the state with low data density.

From the spring of 2019 to the spring of 2020, groundwater levels continue to rise throughout most of Nebraska following several years of above average precipitation. The greatest groundwater-level rises were recorded in the central one–third of Nebraska, where rises of more than 14 feet were recorded. Rises in this region are directly associated with much above-normal precipitation values received in early 2019 through spring 2020.

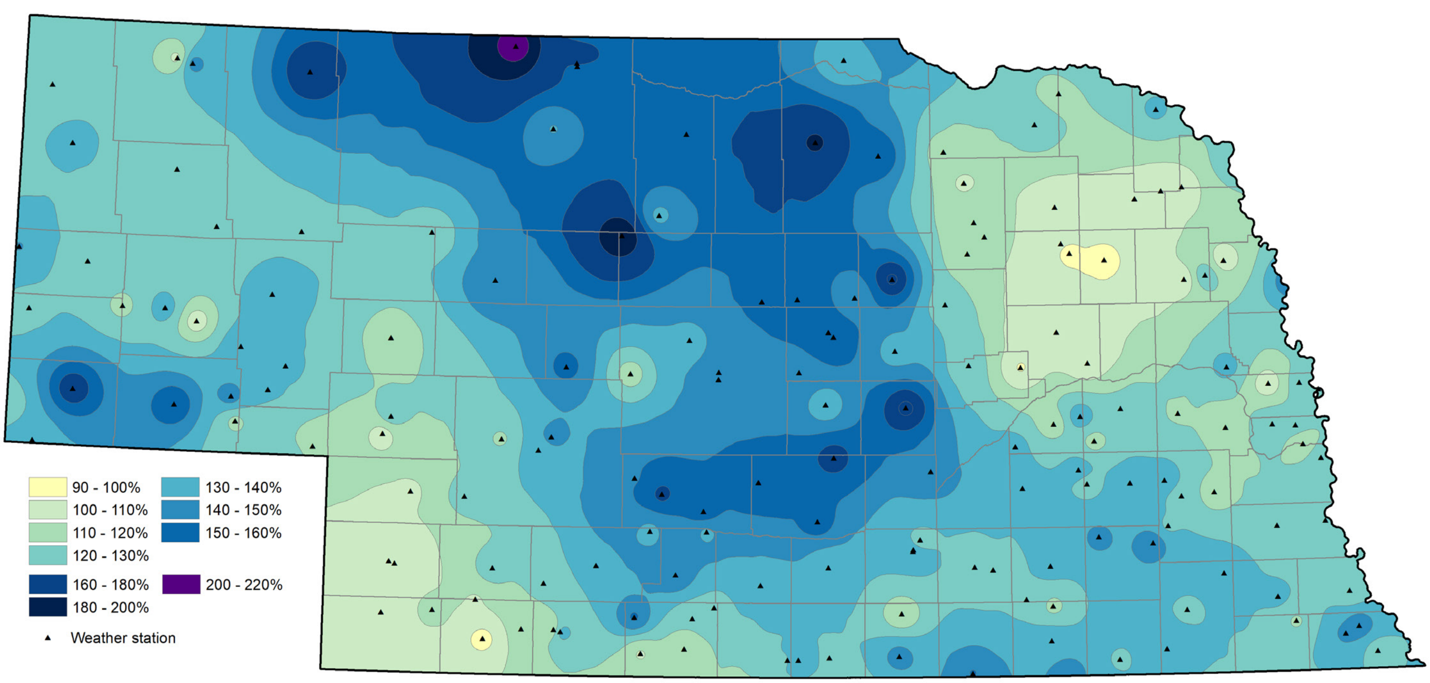
From spring 2019 to spring 2020, localized groundwater-level declines were recorded in the Missouri River valley and Dawson County in central Nebraska. These declines are limited to areas that were severely impacted by spring 2019 flooding. Flooding in 2019 caused water levels to rapidly rise to abnormally high levels while wells were being measured in spring 2019, thus the recorded declines in these areas are a return to average seasonal levels rather than long-term water-level decline. Other small areas of declines were recorded in the panhandle, Chase and Dundy Counties, and the eastern one-third of the State. Most of these declines appear to be restricted to small areas, or to the vicinity of a single well. Possible causes for these minor fluctuations include: (1) varying pumping schedules due to local precipitation patterns, (2) changes in land use and crop rotation from well to well, (3) pumping of nearby wells around the time of measurement, or (4) local variation in precipitation, especially in areas of high well density.

Figure 7. Groundwater-Level Changes in Nebraska - Spring 2019 to Spring 2020



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 2019 to January 2020



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

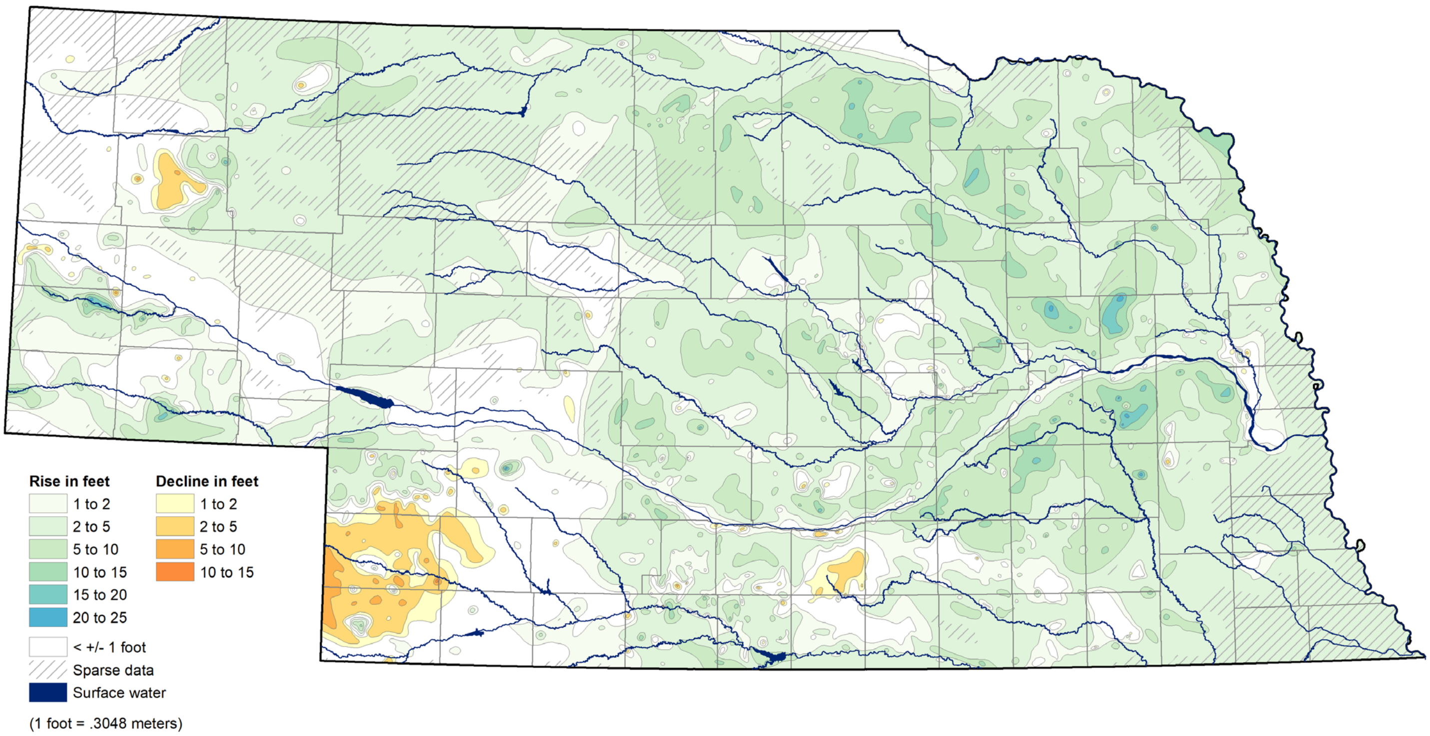
CHANGES IN GROUNDWATER LEVELS, SPRING 2015 TO SPRING 2020

On average, groundwater levels in Nebraska increased by 3.59 feet statewide between the spring of 2015 and the spring of 2020.

The five-year groundwater-level change map was developed on the basis of 4,533 wells which were measured consecutively in spring 2015 and spring 2020. Of these wells, 86% recorded groundwater-level rises, and 74% of wells recording rises greater than one foot. Over the past five years, average groundwater levels have risen by an average of 3.59 feet statewide. The rises depicted in Figure 9 are partly associated with recovery following the record-setting drought of 2012, and partly due to much above-average precipitation over the last 5 years (Fig. 10). Of the 163 reporting stations in Nebraska, 159 reported above-average precipitation values. The 5-year average precipitation values were especially high in north central Nebraska which experienced significant flooding in early 2019.

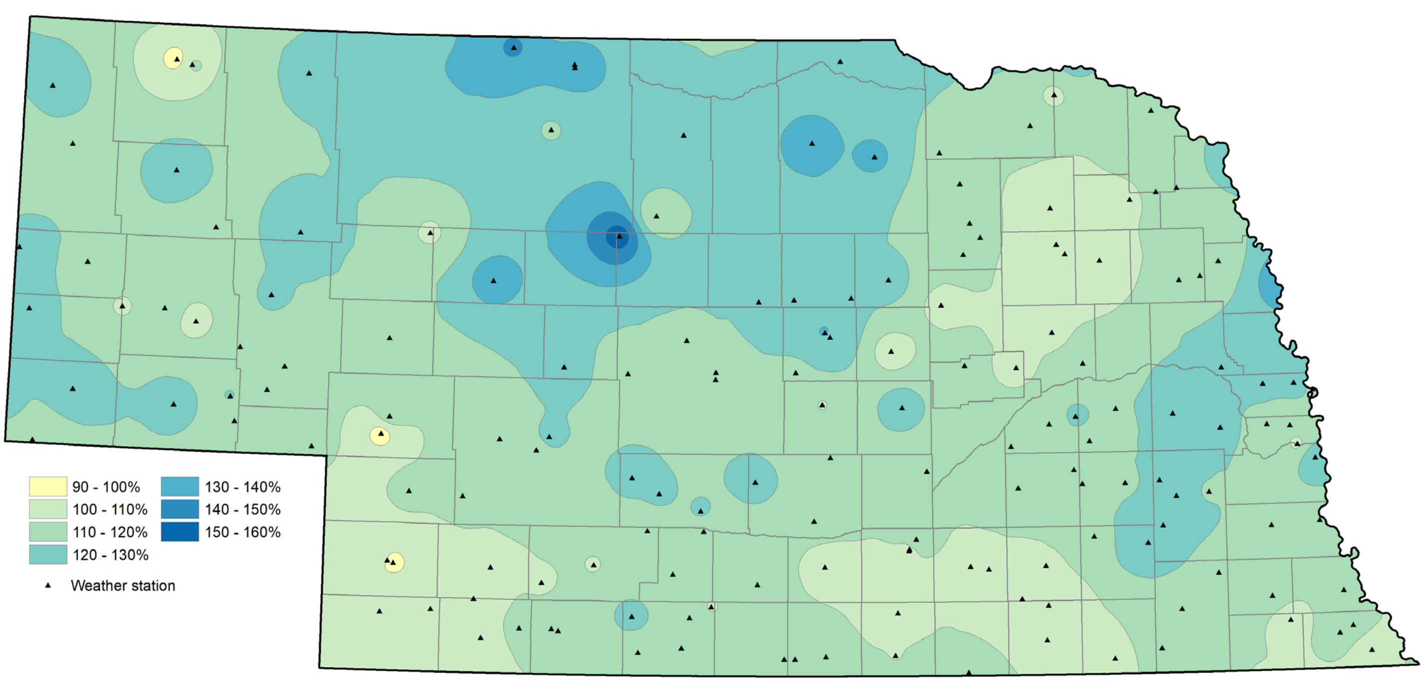
Of the 4,533 wells measured in 2020, 13% exhibited declines, and 7% of all measured wells recorded declines of greater than one foot. Spatially significant declines occurred in Box Butte, Chase, Dundy and Kearney counties. Declines in these counties may be the results of: (1) localized precipitation patterns, (2) patterns of known long-term continued drawdowns, or (3) changes to water storage or transport in canal systems. Other localized areas of groundwater-level decline appear across the state. Most of these areas are associated with a single well; thus, these declines likely resulted from changes in pumping schedules or recent pumping prior to the measurements of water levels within them.

Figure 9. Groundwater-Level Changes in Nebraska - Spring 2015 to Spring 2020



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 2015 to January 2020



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2010 TO SPRING 2020

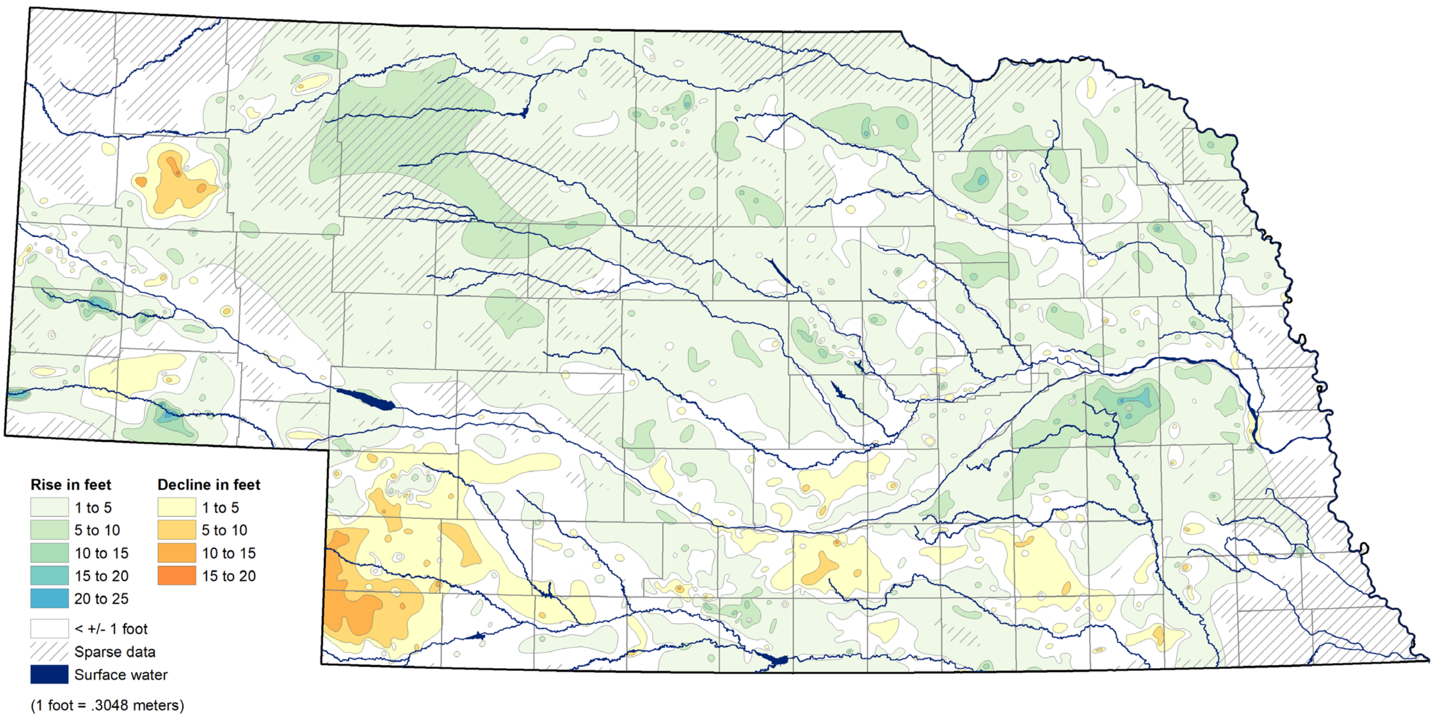
Despite major shifts in weather conditions and record setting drought, modest groundwater-level rises were recorded throughout much of Nebraska over the last 10 years

Weather conditions from the spring of 2010 to the spring of 2020 ranged from record-setting drought to periods of much above-average precipitation. Water levels in the 2010 to 2020 period were also impacted by weather conditions in the previous decade as much of the Midwest, and all of Nebraska were in a period of drought from 2000 to about 2007. Groundwater-level declines were recorded throughout the state during this period (Burbach, 2007). Precipitation was above-normal between 2007 and early 2012, restoring groundwater levels to pre-drought conditions 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 high-rainfall years between 2007 and early 2012. Precipitation values over most of Nebraska were near the long-term average in late 2013 and 2014. Between 2014 and 2019, precipitation levels generally remained near or slightly above the 30-year average. Precipitation values in early 2019 were well above the 30-year average for much of central and northern Nebraska, with some stations recording nearly double average annual precipitation amounts (Fig. 8). Despite the major year-to-year fluctuations in precipitation extremes, precipitation values have generally remained near the 30-year average for Nebraska over the last 10 years (Fig. 12).

Of 4,255 wells measured in both spring of 2010 and spring of 2020, 71% recorded groundwater-level rises, with 54% rising more than one foot (Fig. 11). Groundwater-level declines were recorded in 29% of wells measured in Nebraska from the spring of 2009 to spring 2019, and 17% of measured wells experienced declines of greater than one foot. Groundwater levels in wells have risen by an average of 1.69 feet statewide over the last 10 years.

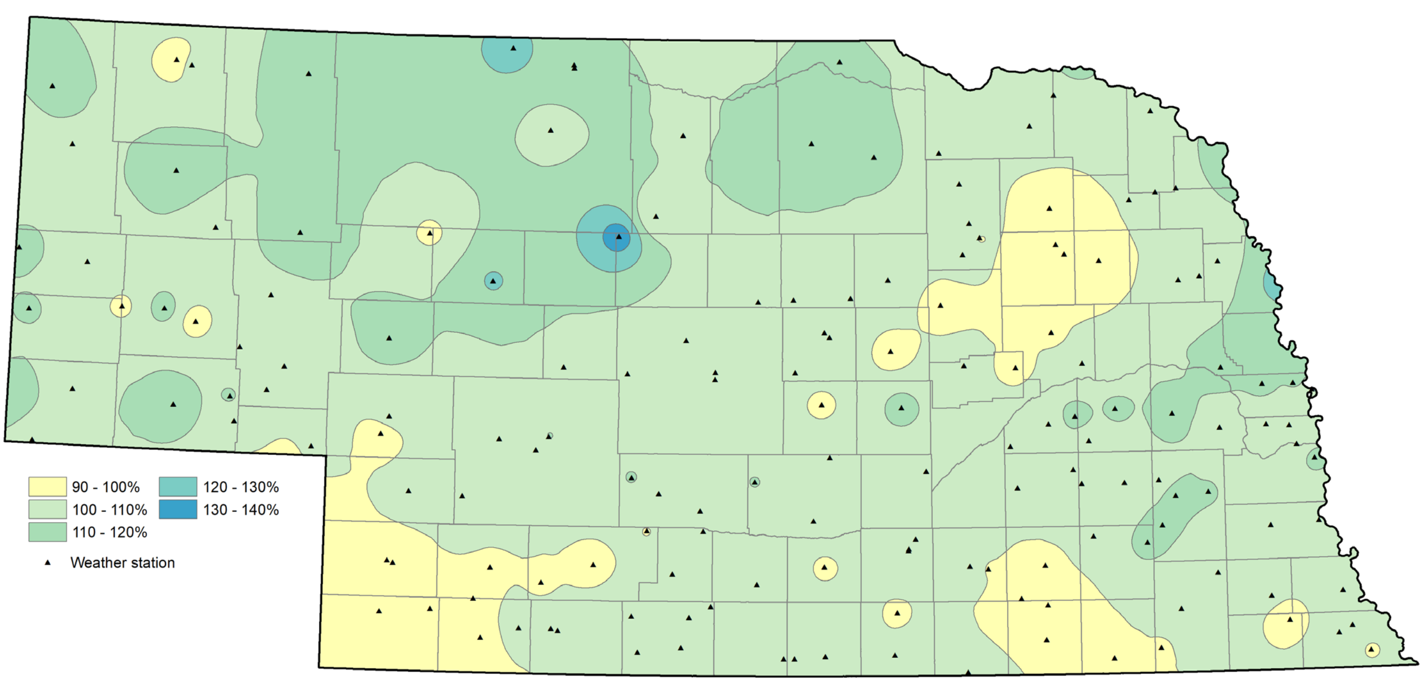
From the spring of 2010 to the spring of 2020, groundwater levels have fluctuated regionally, despite near-average precipitation statewide. The regional patterns of groundwater-level changes may have resulted from: (1) extreme regional variability in year-to-year precipitation and associated irrigation 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, steadily rising levels in Butler and Polk counties, and steadily decreasing levels in known problem areas, groundwater levels have fluctuated from year to year due to extreme variations in yearly rainfall, recharge, and evapotranspiration over the past 10 years. Groundwater-level changes mapped in Figure 12, therefore, may exhibit the effects of short-term extremes rather than long-term trends.

Figure 11. Groundwater-Level Changes in Nebraska - Spring 2010 to Spring 2020



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 12. Percent of Normal Precipitation - January 2010 to January 2020



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

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 2020

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 2020 groundwater levels indicate both long-term declines and long-term rises from predevelopment in certain areas of Nebraska (Fig. 13). Almost all of the areas of significant groundwater-level declines correspond to high irrigation-well densities in aquifers that are deep and have little direct connection to surface water (Fig. 14). The greatest decline from predevelopment to 2020 is approximately 125 feet, in Box Butte County just north of the city of Alliance. Notable groundwater-level declines from predevelopment to spring 2020 have 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 in southeast to south-central Nebraska reflects slight depletion of the High Plains Aquifer. The largest groundwater-level 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 groundwater levels prior to 1953. A general trend of declining groundwater levels that began around 1966 correlates temporally with the intensive use of groundwater for irrigation. The approximate average groundwater levels prior to 1938 were utilized as predevelopment values for the groundwater-level change map in Box Butte County. Intensive groundwater development for irrigation since 1950 has caused groundwater levels to decline by 5 feet to more than 125 feet from predevelopment levels (Fig. 13). Records from wells in both the southwestern counties and in Box Butte County indicate that rates of decline have been essentially steady, despite subsequent changes in groundwater management practices, water use allocations, and fluctuations in the amount of annual precipitation (Korus and Burbach, 2009b).

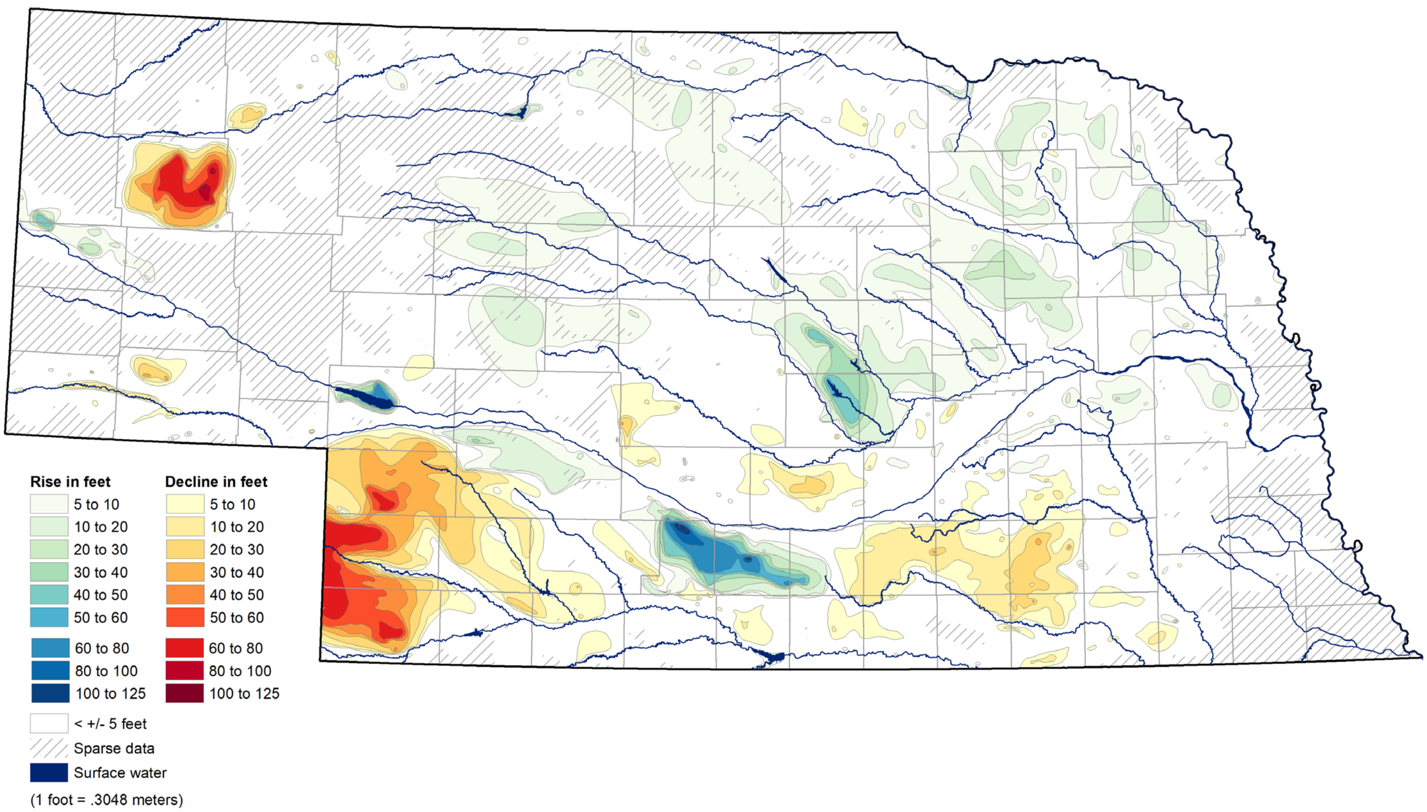
Much of southeastern to south-central Nebraska has experienced long-term groundwater-level declines since predevelopment times (Fig. 13). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this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

Groundwater-level declines also occurred in large areas between the Platte and Loup or South Loup rivers and in the Republican River Valley and the Panhandle. Irrigation-well densities are high in some, but not all, of the aforementioned areas. Aquifer characteristics, rates of recharge, and irrigation scheduling may have contributed to these declines as well.

Groundwater-level rises from predevelopment generally occurred in areas of surface-water-irrigation systems. Storage of water in Lake C. W. 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 C. W. 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. The deep percolation of water from these irrigation-distribution systems and from excess water applied to crops has gradually increased groundwater levels by more than 100 feet (Fig. 13). Groundwater levels have also risen in response to seepage from Sutherland Reservoir, Lake Maloney, and their associated canals in eastern Keith and central Lincoln counties. Similarly, there are groundwater-level rises of as much as 60 feet associated with irrigation canals in southern Sioux, Scotts Bluff, and western Morrill counties.

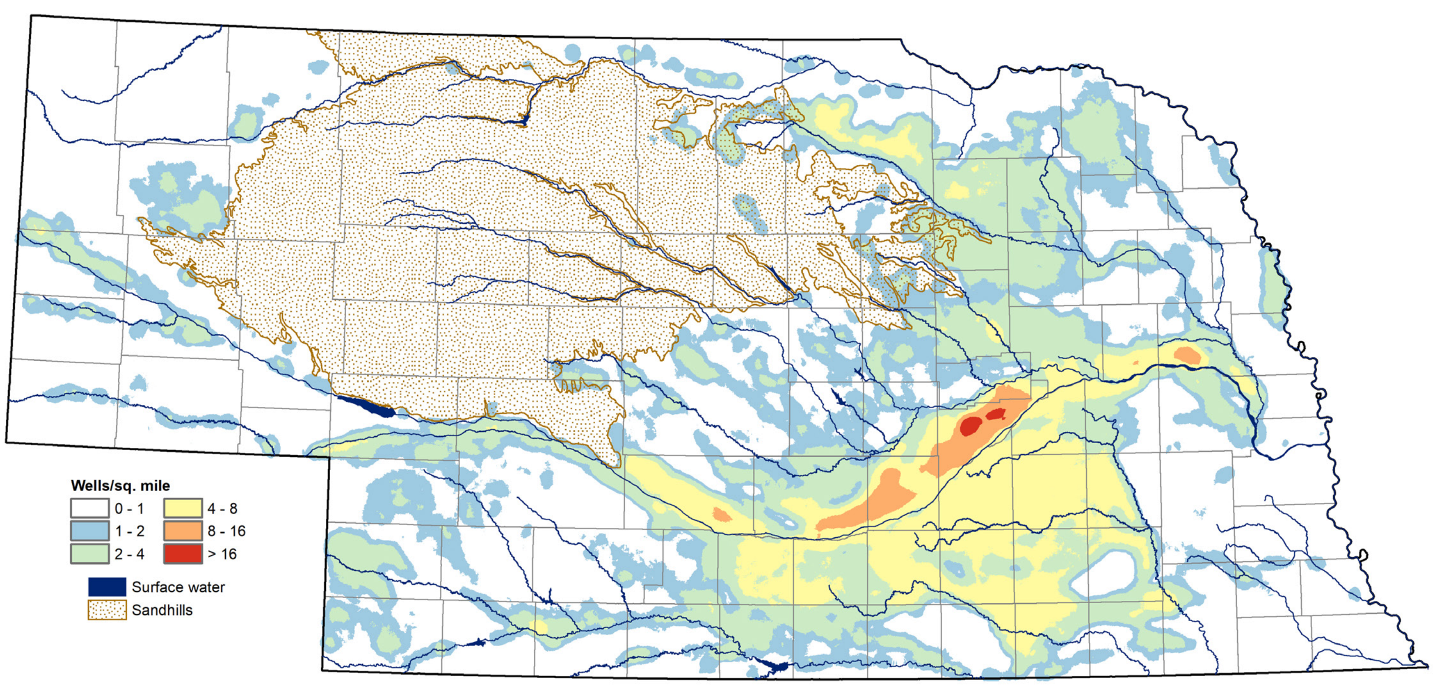
Groundwater-level rises of 10 to more than 50 feet occurred in portions of central Nebraska (Fig. 13). The highest groundwater-level rises occurred in Valley, Sherman, and Howard counties in response to sustained seepage from irrigation canals, Sherman and Davis Creek reservoirs, and the deep percolation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

Figure 13. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2020



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 2020



Source: Nebraska Department of Natural Resources

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 1981 AND SPRING 1981 TO SPRING 2020

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.

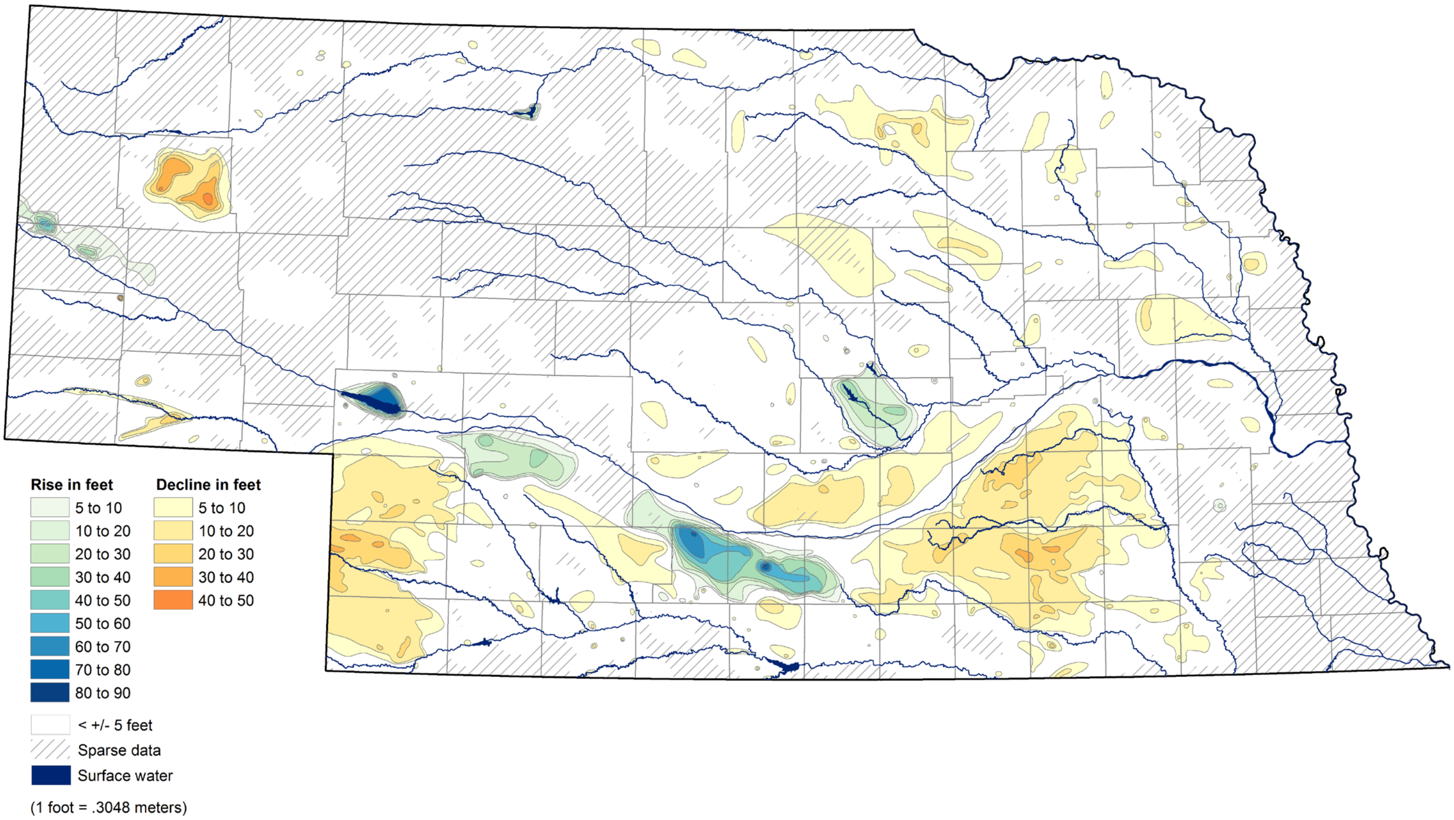
Groundwater-level changes from predevelopment to spring 1981 reflect the responses of aquifers to the spread of groundwater and surface-water-irrigation systems in Nebraska. Areas of significant groundwater-level declines exhibit a general correspondence with dense irrigation wells (cf. Johnson and Pederson, 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 southwestern, south-central and southeastern 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 of some magnitude. 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 can be related to 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 this area locally exceeds 50 feet. The groundwater-level rise in Cherry County is associated with seepage from Merritt Reservoir since the mid-1960s. It exceeds 20 feet immediately adjacent to the reservoir. Seepage from Lake C. W. McConaughy since 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). Groundwater 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 two-county area by 1981.

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 times until 1981 subsequently experienced rises of 5 feet to more than 20 feet from 1981 to 2020. This pattern of pre-1981 decline and post-1981 recovery is evident 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 and southeastern Nebraska since the drought of 2012, thereafter, water levels in this region have fluctuated yearly.

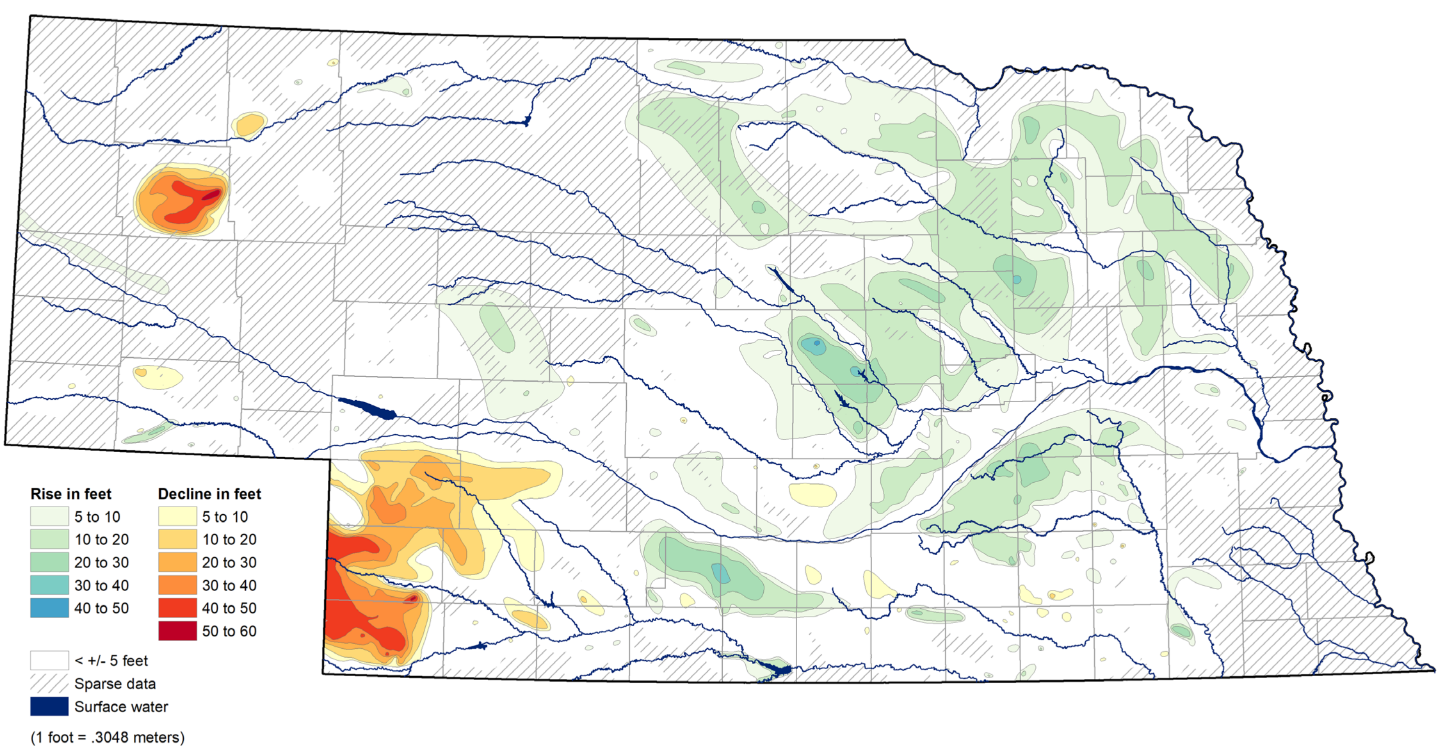
Declines in south-central and southeastern Nebraska reached a maximum in 1981 and then recovered. Declines in some parts of these two regions of the state are now less than 5 to 10 feet relative to predevelopment levels (Figs 13, 15, 16). Groundwater levels in most of south-central and southeastern Nebraska combined, however, remain below predevelopment levels. The post-1981 recovery of groundwater levels in south-central and southeastern 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 the over application of water and deep percolation, which artificially 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 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. Excess irrigation water pumped from the deep aquifer probably recharged the primary aquifer wherever the confining layer is discontinuous or semipermeable. Under these circumstances, surface water

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

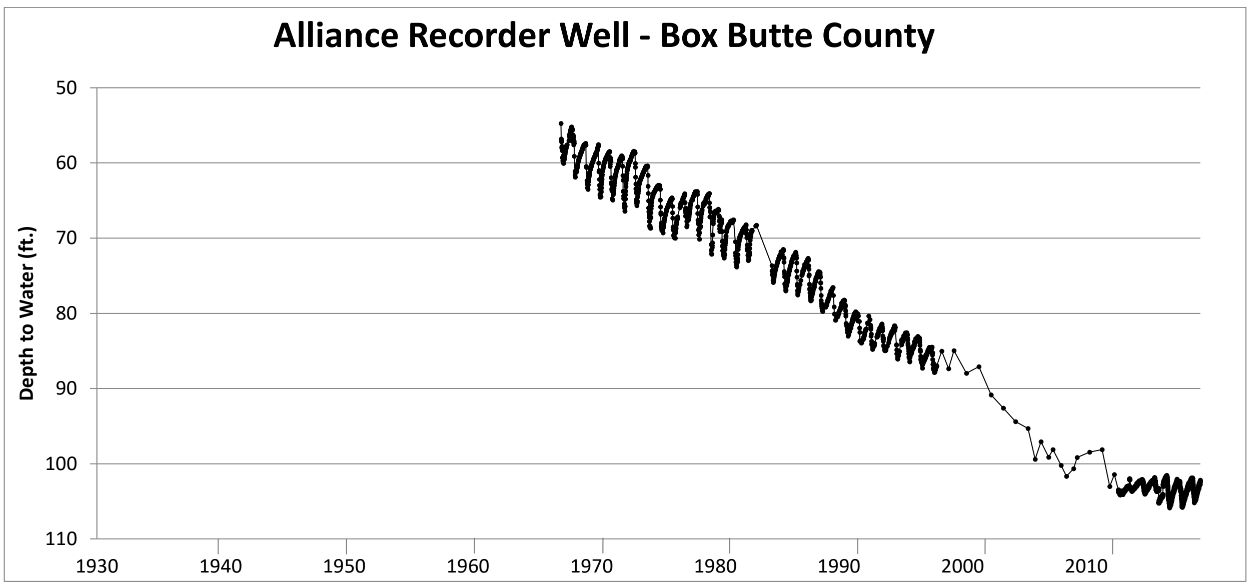
Figure 16. Groundwater-Level Changes in Nebraska - Spring 1981 to Spring 2020

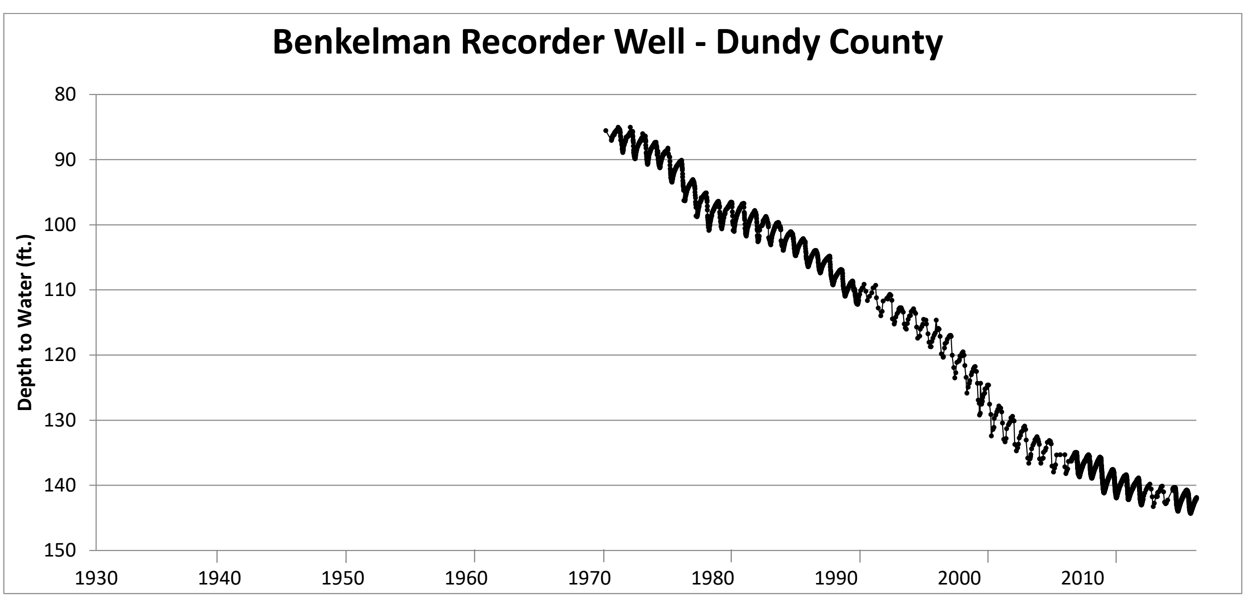


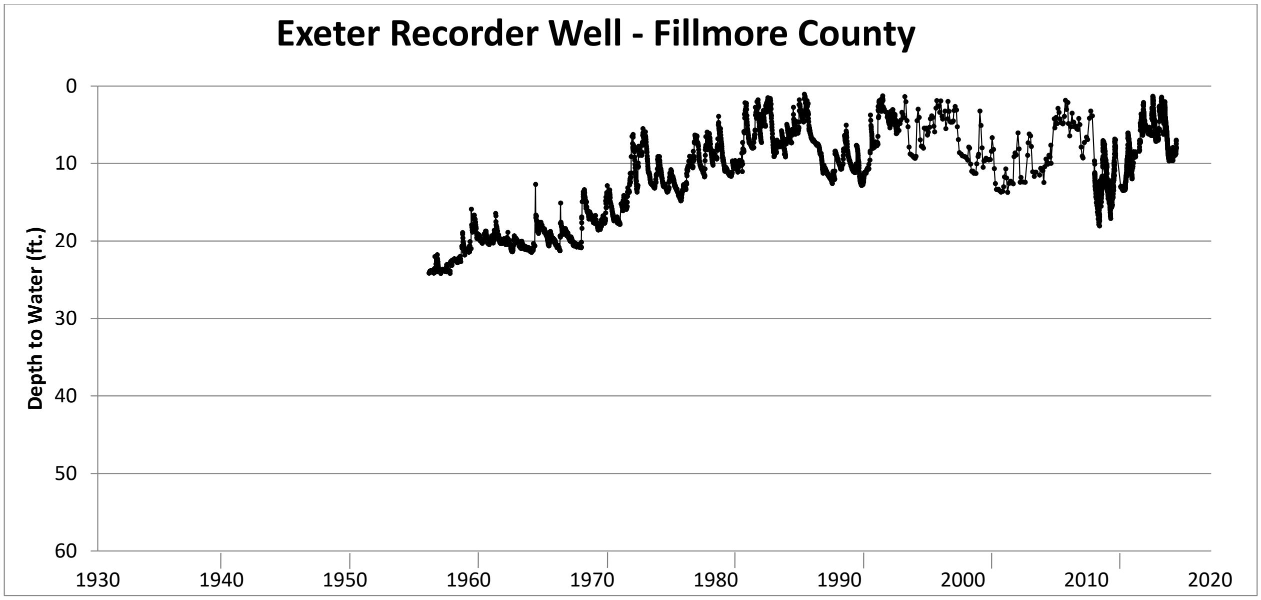
Sources: U.S. Geological Survey, Nebraska Water Science Center; U.S. Bureau of Reclamation, Kansas-Nebraska Area Office; Nebraska Natural Resources Districts; Central Nebraska Public Power and Irrigation District would percolate slowly down to the primary aquifer over a long period of time.

In contrast to the groundwater-level rises in the east, levels continued to decline in parts of western Nebraska from 1981 to 2020 (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 southwestern 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.

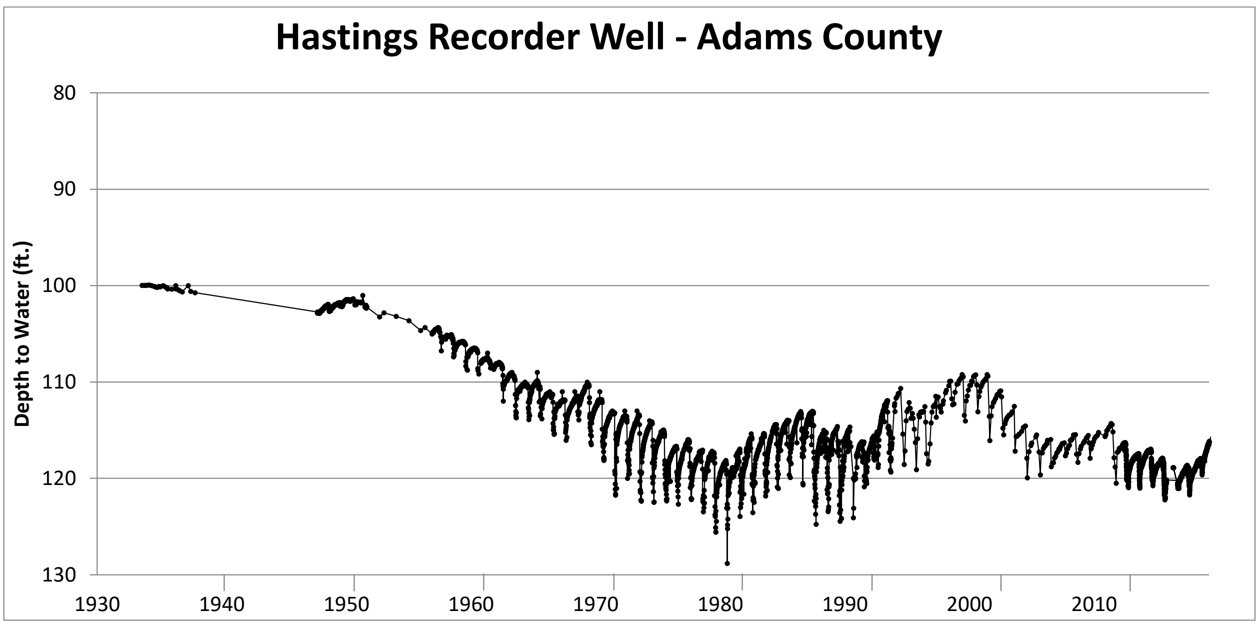
Figure 17. Groundwater-Level Hydrographs Typical of Southwestern and Southeastern Nebraska

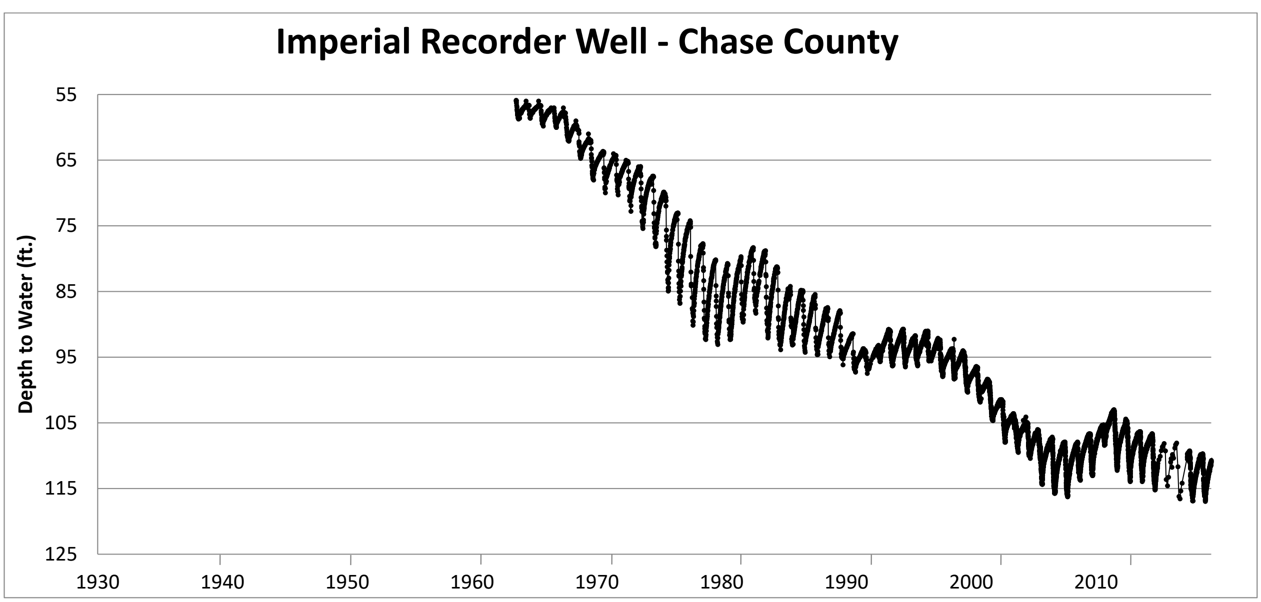






Groundwater level measurements for the Exeter recorder well were discontinued in July 2018





REFERENCES

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

Anonymous, 2020. “Health department issues warning over Genoa’s drinking water.” News Channel Nebraska, 25 September, 2020 [https://www.newschannelnebraska.com/story/42683937/health-department-issues-warning-over-genoas-drinking-water]. Accessed December 12, 2020.

Associated Press, 2020. “Flash flood warning for parts of south-central Nebraska.” U.S. News and World Report, 25 May, 2020 [https://www.usnews.com/news/best-states/nebraska/articles/2020-05-25/flash-flood-warning-for-parts-of-south-central-nebraska]. Accessed December 12, 2020.

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

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

Conley, A., 2020. “Ice jams cause Elkhorn River to flood over Dodge County highway.” Omaha World-Herald, 7 February, 2020 [https://omaha.com/news/local/ice-jams-cause-elkhorn-river-to-flood-over-dodge-county-highway/article_393a36aa-f76e-5d81-8074-5314773ba73f.html]. Accessed December 12, 2020.

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

Environmental Protection Agency (EPA), 2020. “Public notice: Hastings Groundwater Contamination Superfund Site, Hastings, Adams County, Nebraska.” [https://www.epa.gov/ne/hastings-groundwater-contamination-superfund-site-hastings-adams-county-nebraska-0]. Accessed December 12, 2020.

Gaarder, N., 2020a. “30 cabins flooded, 2 people rescued in ice jam flooding on Platte River in Dodge County.” Omaha World-Herald, 16 February, 2020 (updated 17 February, 2020) [https://omaha.com/state-and-regional/30-cabins-flooded-2-people-rescued-in-ice-jam-flooding-on-platte-river-in-dodge/article_37e28851-a62f-5126-8deb-50e62b1be67c.html]. Accessed December 12, 2020.

Gaarder, N., 2020b. “Most high-risk properties in Nebraska and Iowa don’t have flood insurance.” Omaha World-Herald, 17 February, 2020 [https:// omaha.com/state-and-regional/most-high-risk-properties-in-nebraska-and-iowa-dont-have-flood-insurance/article_1541cdd1-1a5c-5447-ad72-d91484068435.html]. Accessed December 12, 2020.

Gayman, D., 2020. “Bartelt-Hunt searching sewage for COVID-19.” Nebraska Today, 25 September, 2020 [https://news.unl.edu/newsrooms/today/article/bartelt-hunt-searching-sewage-for-covid-19/]. Accessed December 12, 2020.

Heckt, S., 2020. “Adams County suffers severe flood damage to roads.” 10 11 Now KOLN/KGIN, 22 May, 2020 [https://www.1011now.com/content/news/Adams-County-suffers-severe-flood-damage-to-roads-570712931.html]. Accessed December 12, 2020.

Hytrek, N., 2020. “Corps ups Gavins Point releases for flood-control flexibility.” Sioux City Journal, 6 February, 2020 [https://siouxcityjournal.com/news/local/state-and-regional/corps-ups-gavins-point-releases-for-flood-control-flexibility/article_91a9173a-8c84-5a7a-b671-ab9b3cccca23.html]. Accessed December 12, 2020.

Hammel, P., 2020. “Groundwater needs raise concerns about $100 million-plus manufacturing plant near Lincoln.” Omaha World-Herald, 29 July, 2020 [https://omaha.com/news/state-and-regional/groundwater-needs-raise-concerns-about-100-million-plus-manufacturing-plant-near-lincoln/article_19461fc7-fae8-58f4-b9da-776d8909c7a1.html]. Accessed December 12, 2020.

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

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

Johnson, N., 2020. “$1.26 million contract awarded to begin work on Ames Dike.” Fremont Tribune, 24 February, 2020 (updated 31 March, 2020) [https://fremonttribune.com/news/local/1-26-million-contract-awarded-to-begin-work-on-ames-dike/article_bb2dce07-9fe5-5f4c-87af-e196344a6fac.html]. Accessed December 12, 2020.

Johnson, R., 2020. “2019 FLOODS: Construction, repairs new normal at Lincoln’s wellfield system near Ashland.” Lincoln Journal Star, 15 March, 2020 (updated 21 April, 2020) [https://journalstar.com/news/local/govt-and-politics/2019-floods-construction-repairs-new-normal-at-lincolns-wellfield-system-near-ashland/article_84a389f6-c366-52e8-83b4-feb08932a74b.html]. Accessed December 12, 2020.

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

Korus, J.T., and Burbach, M.E., 2009b. Nebraska Statewide Groundwater-Level Monitoring Report 2009. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 76, 8 p.

Korus, J.T., Howard, L.M., Young, A.R., Divine, D.P., Burbach, M. E., Jess, J.M., and Hallum, D. H., 2013. The Groundwater Atlas of Nebraska. Conservation and Survey Division, School of Natural Resources, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln. Resource Atlas 4b/2013. 64 p.

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

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

McGuire, V.L., Lund, K.D., and Densmore, B.K., 2012, Saturated Thickness and Water in Storage in the High Plains Aquifer, 2009, and Water-Level Changes and Changes in Water in Storage in the High Plains Aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009. U.S. Geological Survey Scientific Investigations Report 2012–5177, 28 p.

National Climatic Data Center, National Oceanic and Atmospheric Administration, 2020. Online Climate Data. [https://www.ncdc.noaa.gov/cdo-web/datasets]. Data Retrieved September 22, 2020.

Nebraska Department of Health and Human Services (NDHHS), 2020. “Drinking water safe during COVID-19 pandemic.” 17 March, 2020. [http://dhhs.ne.gov/Pages/Drinking-Water-Safe-During-COVID-19-Pandemic.aspx]. Accessed December 12, 2020.

Nebraska Department of Health and Human Services (NDHHS) Drinking Water Division, 2020. Nebraska Public Water Supply Program Summary Report 2019.

Olberding, M., 2020. “David City egg plant to pay nearly $3 million in settlement.” Lincoln Journal Star, 7 July, 2020 (updated 23 September, 2020) [https://journalstar.com/business/local/david-city-egg-plant-to-pay-nearly-3-million-in-settlement/article_9fcc54be-7a01-58a7-81c0-ab880250fcd6.html]. Accessed December 12, 2020.

Pimper, S., 2020. “City still working with FEMA, reinforcing levee systems.” Omaha World-Herald, 19 March, 2020 (updated 15 July, 2020) [https:// omaha.com/community/bellevue/city-still-working-with-fema-reinforcing-levee-systems/article_adb019ce-3cbd-5c90-a388-56e7f96efd21.html]. Accessed December 12, 2020.

Ristau, R., 2020. “EPA notifies 125 Bellevue property owners of contamination near former dry cleaners.” Omaha World-Herald, 16 January, 2020 [https://omaha.com/news/local/epa-notifies-125-bellevue-property-owners-of-contamination-near-former-dry-cleaners/article_6797c3c3-961e-5909-942a-5ff06f450cc6.html]. Accessed December 12, 2020.

Rowher, T., 2020. “Corps hires firm to fix Platte River breach.” The Plattsmouth Journal, 7 January, 2020 (updated 14 March, 2020) [https://fremonttribune.com/community/cass-news/news/corps-hires-firm-to-fix-platte-river-breach/article_7414fb7a-d331-5dd6-ad3b-1ee63cbbfee6.html]. Accessed December 12, 2020.

Schechinger, A.W., 2020. “EWG investigation: Across farm country, nitrate pollution of drinking water for more than 20 million Americans is getting worse.” [https://www.ewg.org/interactive-maps/2020-nitrate-pollution-of-drinking-water-for-more-than-20-million-americans-is-getting-worse/]. Accessed December 12, 2020.

Sophocleous, M.A., 1997. Managing Water Resources Systems: Why "Safe Yield" is not Sustainable. Ground Water, v. 35, p. 561.
Sophocleous, M.A., 1998. On the Elusive Concept of Safe Yield and the Response of Interconnected Stream-Aquifer Systems to Development. In Perspectives on Sustainable Development of Water Resources in Kansas, ed. M.A. Sophocleous, p. 6-85. Kansas Geological Survey Bulletin 239. KGS, Lawrence, KS.
Sophocleous, M.A., 2000. From Safe Yield to Sustainable Development of Water Resources–the Kansas Experience. Journal of Hydrology, v. 235, p. 27-43.
Spilinek, C., 2020. "Flood repairs going along smoothly near Platte River." Fremont Tribune, 21 February, 2020 (updated 27 March, 2020) [https://fremonttribune.com/news/local/flood-repairs-going-along-smoothly-near-platte-river/article_ed728aac-628f-58b0-bfb2-1b92ba56e2ae.html]. Accessed December 12, 2020.
Swanson, D., 2020. "River navigation season ends in December, flood repairs continue through 2021." News Channel Nebraska, 1 December, 2020 [https://www.newschannelnebraska.com/story/42988550/river-navigation-season-ends-in-december-flood-repairs-continue-through-2021]. Accessed December 12, 2020.
United States Department of Agriculture, 2017. Census of Agriculture. [URL Https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf/]. Accessed January 20, 2021.
Walsh, J.F., 2020. "Nebraskans pay millions to fight nitrates as water bills go up." The Omaha World Herald, 1 May, 2020 [https://omaha.com/state-and-regional/nebraska-towns-pay-millions-to-fight-nitrates-as-water-bills-go-up/article_5a810bb0-1437-5538-aab9-e50546672f60.html]. Accessed December 12, 2020.
Wessendorf, J., 2020. "Mormon Canal Bridge west of Niobrara officially opened." Norfolk Daily News, 2 September, 2020 [https://norfolkdailynews.com/news/mormon-canal-bridge-west-of-niobrara-officially-opened/article_b9d054a0-ed29-11ea-87da-dbb58c200d35.html]. Accessed December 12, 2020.

Groundwater-Level Changes in Nebraska Map Series

Available online at http://snr.unl.edu/data/water/groundwatermaps.asp

Year	Publication and Number	Author(s) and year published
pre 1954	U.S.G.S. Open-File Rpt. 54-138	Keech, C.F.; Case, R.L., 1954
1954	U.S.G.S. Open-File Rpt. 55-80	Keech, C.F.; Case, R.L., 1955
1955	U.S.G.S. Open-File Rpt. 56-70	Keech, C.F., 1956
1956	U.S.G.S. Open-File Rpt. 57-61	Keech, C.F., 1957
1957	Nebraska Water Survey Paper 4*	Keech, C.F., 1958
1958	Nebraska Water Survey Paper 5*	Keech, C.F., 1959
1959	Nebraska Water Survey Paper 6	Keech, C.F., 1960
1960	Nebraska Water Survey Paper 9	Keech, C.F., 1961
1961	Nebraska Water Survey Paper 12	Keech, C.F.; Hyland, J.B., 1962
1962	Nebraska Water Survey Paper 13	Emery, P.A.; Malhoit, M.M., 1963
1963	Nebraska Water Survey Paper 14	Emery, P.A.; Malhoit, M.M., 1964
1964	Nebraska Water Survey Paper 17	Emery, P.A.; Malhoit, M.M., 1965
1965	Nebraska Water Survey Paper 18	Emery, P.A.; Malhoit, M.M., 1966
1966	Nebraska Water Survey Paper 20*	Keech, C.F., 1967
1967	Nebraska Water Survey Paper 23	Keech, C.F., 1968
1968	Nebraska Water Survey Paper 24*	Keech, C.F.; Svoboda, G.R., 1969
1969	Nebraska Water Survey Paper 26*	Keech, C.F., 1970
1970	Nebraska Water Survey Paper 28*	Keech, C.F., 1971
1971	Nebraska Water Survey Paper 33	Keech, C.F., 1972
1972	Nebraska Water Survey Paper 34	Ellis, M.J., 1973
1973	Nebraska Water Survey Paper 36	Ellis, M.J., 1974
1974	Nebraska Water Survey Paper 40*	Ellis, M.J., 1975
1975	Nebraska Water Survey Paper 43*	Ellis, M.J.; Pederson, D.T., 1976
1976	Nebraska Water Survey Paper 44	Ellis, M.J.; Pederson, D.T. 1977
1977	Nebraska Water Survey Paper 45	Ellis, M.J.; Pederson, D.T., 1978
1978	Nebraska Water Survey Paper 49	Pederson, D.T.; Johnson, M.S., 1979
1979	Nebraska Water Survey Paper 50*	Johnson, M.S.; Pederson, D.T., 1980
1980	Nebraska Water Survey Paper 51	Johnson, M.S.; Pederson, D.T., 1981
1981	Nebraska Water Survey Paper 52	Johnson, M.S.; Pederson, D.T., 1982
1982	Nebraska Water Survey Paper 56	Johnson, M.S.; Pederson, D.T., 1983
1983	Nebraska Water Survey Paper 57	Johnson, M.S.; Pederson, D.T., 1984
1984	Nebraska Water Survey Paper 59	Ellis, M.J.; Pederson, D.T., 1985
1985	Nebraska Water Survey Paper 61	Ellis, M.J.; Pederson, D.T., 1986
1986	Nebraska Water Survey Paper 62	Ellis, M.J.; Dreeszen, V.H., 1987
1987	Nebraska Water Survey Paper 65	Ellis, M.J.; Wigley, P.B, 1988
1988	Nebraska Water Survey Paper 66	Ellis, M.J.; Steele, G.V.; Wigley, P.B., 1989
1989	Nebraska Water Survey Paper 67	Ellis, M.J.; Steele, G.V.; Wigley, P.B., 1990
1990	Nebraska Water Survey Paper 69	Steele, G.V.; Wigley, P.B., 1991
1991	Nebraska Water Survey Paper 71	Steele, G.V.; Wigley, P.B., 1992
1992	Nebraska Water Survey Paper 72	Steele. G.V.; Wigley, P.B., 1994
1994	Nebraska Water Survey Paper 74	Chen, A.H.; Wigley, P.B., 1996
1996	Nebraska Water Survey Paper 75	Chen, A.H.; Khisty, M.J., 1999
2009	Nebraska Water Survey Paper 76	Korus, J.T.; Burbach, M.E. 2009
2010	Nebraska Water Survey Paper 77	Korus, J.T.; Burbach, M.E.; Howard, L.M.; Joeckel, R.M.,2010
2011	Nebraska Water Survey Paper 79	Korus, J.T.; Burbach, M.E.; Howard, L.M.; 2011
2012	Nebraska Water Survey Paper 80	Young, A.R.; Burbach, M.E.; Korus, J.T.; Howard, L.M.; 2012
2013	Nebraska Water Survey Paper 81	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2013
2014	Nebraska Water Survey Paper 82	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2014
2015	Nebraska Water Survey Paper 83	Young, A.R.; Burbach, M.E.; Howard, L.M.; 2015
2016	Nebraska Water Survey Paper 84	Young, A.R.; Burbach, M.E.; Howard, L.M.; Waszgis M.M.; Joeckel R.M.; Lackey, S.O., 2016
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
2019	Nebraska Water Survey Paper 87	Young, A.R.; Burbach, M.E.; Howard, L.M.; Lackey, S.O., Joeckel R.M., 2019

*** Out of print, but available for study.** **See page 3 for ordering information.**

UNIVERSITY OF Nebraska Lincoln

Conservation and Survey Division
School of Natural Resources
Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

ISBN 1-56161-087-9
ISBN-13 978-1-56161-087-7