Nebraska Statewide Groundwater-Level Monitoring Report

2023

Aaron R. Young, Mark E. Burbach, Susan Olafsen Lackey, R.M. Joeckel, Nawaraj Shrestha, and Jeffrey P. Westrop

Conservation and Survey Division
School of Natural Resources

131 YRS CSD 1893-2024

Nebraska Water Survey Paper Number 92

Institute of Agriculture and Natural Resources
University of Nebraska–Lincoln

Nebraska Statewide Groundwater-Level Monitoring Report 2023

Aaron R. Young,
Mark E. Burbach, Susan Olafsen Lackey,
R.M. Joeckel, Nawaraj Shrestha, and Jeffrey P. Westrop
Conservation and Survey Division
School of Natural Resources

Nebraska Water Survey Paper Number 92

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

University of Nebraska–Lincoln

Rodney Bennett, Ph.D., Chancellor, University of Nebraska–Lincoln
Michael J. Boehm, Ph.D., NU Vice President and IANR Harlan Vice Chancellor
Larkin Powell, Ph.D., Director, School of Natural Resources
R.M. Joeckel, Ph.D., Nebraska State Geologist and Director of Conservation and Survey Division; Senior Associate Director, School of Natural Resources

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/.

The University of Nebraska–Lincoln does not discriminate based on gender, age, disability, race, color, religion, marital status, national or ethnic origin or sexual orientation. The University of Nebraska–Lincoln is an equal opportunity educator and employer with a comprehensive plan for diversity.
March 2024

ISBN 978-1-56161-094-5

Suggested citation for this report:
Young, A.R., Burbach, M.E., Lackey, S.O., Joeckel R.M., Shrestha, N., Westrop, J.P., 2023, Nebraska Statewide Groundwater-Level Monitoring Report 2023. University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 92, 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 2023 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.

CONTENTS

FIGURES

FOREWORD

Nebraska Water Issues of Interest in 2023

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

Surface water

The Nebraska Department of Natural Resources (NDNR) issued a January 2023 update of the proposed Perkins County Canal, which would utilize flow from the South Platte River in Colorado. NDNR announced the completion of a study mandated by the Nebraska legislature in its LB1012 and concluded that the "canal is cost-effective…and would provide direct benefits of approximately $698 - $986M" (Nebraska Department of Natural Resources, 2023). In March, Colorado's state engineer expressed skepticism about the viability of the project, which is an outcome of a century-old compact between the two states (Booth, 2023). The South Platte River attained bankfull stage and exceeded actions stage in the North Platte area by June 21 (van Kampen, 2023). Particularly wet weather in eastern Colorado, where several places experienced some of the wettest Junes on record (Sylte, 2023), was responsible for high water on the South Platte during mid- to late June. Flow in the Platte River in central Nebraska had dwindled substantially by the beginning of September, however, it exposed much of the river's bed for the second summer in a row and after 20 months of drought conditions in that part of the state (Olberding, 2023). The Crane Trust, Nature Conservancy, and other environmental groups sent Governor Jim Pillen an open letter urging him to deny a permit for a requested transfer of excess flows from the Platte River through various canals to a tributary of the Republican River (Anderson, 2023). This letter followed within a month after an early October 2023 opinion issued by the Nebraska Supreme Court regarding the regulation of high-flow diversions from the Platte River to the Republican Basin. (Nebraska Supreme Court, 2023).

Groundwater, water-supply and environmental issues

The Santee Sioux Reservation in northeastern Nebraska has lacked a safe onsite drinking water supply since 2019 due to high manganese levels and a no-drink order issued by the Environmental Protection Agency (EPA). At the end of 2023, the tribal government is preparing to request $40 million in federal funds to build a supply pipeline from South Dakota after partial funding from the state was indefinitely postponed and Bureau of Indian Affairs grant funds for bottled water were expended (Beach, 2023a, 2023b).

A July report on water quality by the Nebraska Department of Environment and Energy (NDEE) indicated that 98% of public water systems in the state were fully compliant with nitrate regulations (6 News Staff, 2023), although nitrate problems persist in some places (Hammel, 2023). An article in the Flatwater Free Press observed that 16 of 27 livestock facilities operated by Pillen Family Farms have registered groundwater nitrate levels over 50 ppm—well more than the EPA's 10 ppm maximum contaminant level for public water supplies—at least once each in local monitoring wells; a few of these operations have also violated livestock waste-control rules, which have the potential to contribute to groundwater contamination (Xu, 2023). The environmental firm NewFields removed approximately 10% of the pesticide-contaminated solid waste from the AltEn plant near Mead to a landfill near Bennington during fall 2023 (Dunker, 2023a).

Thirty-six school groups (780 students) participated in the 2023 Nebraska Children's Groundwater Festival, hosted by the Central Platte Natural Resources District (CPNRD, undated).

Legislation

LB241 (Change provisions relating to transfers of water to another state) was introduced in the Nebraska Legislature in January 2023 and carried over into the 2024 session. The change proposed in the bill would prohibit the transportation of groundwater from Nebraska more than 10 mi (16 km) outside of the state's boundaries. Other water-related bills proposed in 2023 and carried over into 2024 are LB40 (Adopt the Riparian and Water Quality Practices Act) and LB273 (Adopt the Public Water and Natural Resources Project Contracting Act) and LB506, which proposes NDEE grants from money appropriated out of federal funds for a second water supply to serve "a city of the primary class" (i.e., Lincoln) and the installation of reverse-osmosis treatment systems in small and rural communities testing above 10 ppm nitrate (Nebraska Legislature, undated).

Nebraska's U.S. Senator Deb Fischer secured $10 million under the Interior, Environment, and Related Agencies appropriations bill for many water-related projects in Nebraska, including the contamination-troubled Cedar-Knox Rural Water Project (Dunker, 2023b). The Clean Water Act of 2023, which is intended to continue the 1972 Clean Water Act (CWA), was cosponsored by Democrats in the house of Representatives. This action was prompted in large measure by the U.S. Supreme Court's May 2023 Sackett v. Environmental Protection Agency ruling in May (Supreme Court of the United States, 2023), which decreased the number of bodies of water that are protected under the 1972 CWA and, in the opinions of several experts, significantly weakens the original act.

SELECT RECENT PUBLICATIONS INVOLVING CSD PERSONNEL

Burbach, M.E., Eaton, W.M., Delozier, J., 2023. Boundary spanning in the context of stakeholder engagement in collaborative water management. Socio-Ecological Practice Research, 5, 79-92 [https://doi.org/10.1007/s42532-023-00138-w].

Burbach, M.E., Kennedy, S., Eaton, W.M., Brasier, K.J., 2023. Foundational conditions enabling participatory river management in watersheds of two regulatorily disparate states: A mixed methods study. River Research and Applications, Early view, January 23, 2023. [https://doi.org/10.1002/rra.4108].

Caner Z., Mittelstet, A.R., **Gilmore, T.E.**, Zlotnik, V., Solomon, D.K., Genereux, D.P., C. Humphrey, E., **Shrestha, N.**, 2023. Modeling groundwater transit time distributions and means across a Nebraska watershed: Effects of heterogeneity in the aquifer, riverbed, and recharge parameters, Journal of Hydrology, 617, Part A, 128891, ISSN 0022-1694, [https://doi.org/10.1016/j.jhydrol.2022.128891].

Chaffee, M., Mittelstet, A. R., Comfort, Steve, Messer, T., **Shrestha, N.**, Eskridge, K., McCoy, J., 2023. Monitoring temporal chlorophyll-a using Sentinel-2 imagery in urban retention ponds receiving a biological-chemical treatment, Ecological Engineering, 197, 107123, ISSN 0925-8574, [https://doi.org/10.1016/j.ecoleng.2023.107123].

Chavez-Jimenez, C.M., Salazar-Lopez, L.A., Chapman, K., **Gilmore, T.**, Sanchez-Ante, G., 2023. Feature Analysis and Selection for Water Stream Modeling. In A.Y. Rodríguez-González, H. Pérez-Espinosa, J.F. Martínez-Trinidad, J.A. Carrasco-Ochoa, & J. A. Olvera-López (Eds.), Pattern Recognition (pp. 3–12). Cham: Springer Nature Switzerland. [https://doi.org/10.1007/978-3-031-33783-3_1].

Eaton, W.M., Brasier, K.J., **Burbach, M.E.**, Kennedy, S., Delozier, J.L., Bonilla Anariba, S.E., Whitley, H.T., Whitmer, W., Santangelo, N., 2023. A new approach for studying social, behavioral, and environmental change through stakeholder engagement in water resource management. Journal of Environmental Studies and Sciences, 13, 389-403. [https://doi.org/10.1007/s13412-023-00835-8].

Jensen, C.R., Genereux, D.P., **Gilmore, T.E.**, Solomon, D.K., 2023. Modified Tracer Gas Injection for Measuring Stream Gas Exchange Velocity in the Presence of Significant Temperature Variation. Water Resources Research, 59(6), e2023WR034495. [https://doi.org/10.1029/2023WR034495].

Kawo, N.S., **Korus, J.T.**, Gulbrandsen, M.L., 2023. Multiple-Point Statistical (MPS) modeling of 3D glacial aquifer heterogeneity for improved groundwater management. Hydrogeology Journal. [https://doi.org/10.1007/s10040-023-02658-x].

Kishawi, Y., Mittelstet, A.R., **Gilmore, T.E.**, Twidwell, D., Roy, T., **Shrestha, N.**, 2023. Impact of Eastern Redcedar encroachment on water resources in the Nebraska Sandhills. Science of The Total Environment, 858, Part 1, 159696, ISSN 0048-9697, [https://doi.org/10.1016/j.scitotenv.2022.159696].

Tilahun, T.A., **Korus, J.T.**, 2023. 3D hydrostratigraphic and hydraulic conductivity modeling using supervised machine learning. Applied Computing and Geosciences 19, 100122: [https://doi.org/10.1016/j.acags.2023.100122].

Vituri Santarosa, L., Gastmans, D., **Gilmore, T.E.**, Boll, J., Balbin Betancur, S., Monteiro Gonçalves, V.F., 2023. Baseflow and water resilience variability in two water management units in southeastern Brazil. International Journal of River Basin Management, 21, 3, 387-400, [https://doi.org/10.1080/15715124.2021.2002346].

Westrop, Jeffrey P., Yadav, P.., Nolan, P.J., Campbell, Kate M., Singh, Rajesh.; Bone, Sharon E., Chan, A.H.; Kohtz, A.J.; Pan, D.A.; Healy, O., Bargar, J., Snow, D.D.; Weber, K.A., 2023. Nitrate-stimulated release of naturally occurring sedimentary uranium. Environmental Science and Technology [https://doi.org/10.1021/acs.est.2c07683].

Zlotnik, V.A., Solomon, D.K., Genereux, D.P., **Gilmore, T.E.**, Humphrey, C.E., Mittelstet, A.R., Zlotnik, A.V., 2023. Theory of an automatic seepage meter and ramifications for applications. Water Resources Research, 59(10), e2023WR034766. [https://doi.org/10.1029/2023WR034766].

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 Conservation and Survey Division (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 to survey the state's groundwater resources and observe changes in its availability on a regular basis. The CSD and USGS cooperatively developed, maintained, and operated an observation-well network throughout the state. These two agencies were responsible for collecting and archiving this information, and for making it available to the citizens.

Although CSD and USGS still occupy the central roles 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 most 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 can 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 pressures steadily increase. 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%

Figure 1. Nebraska Natural Resources Districts

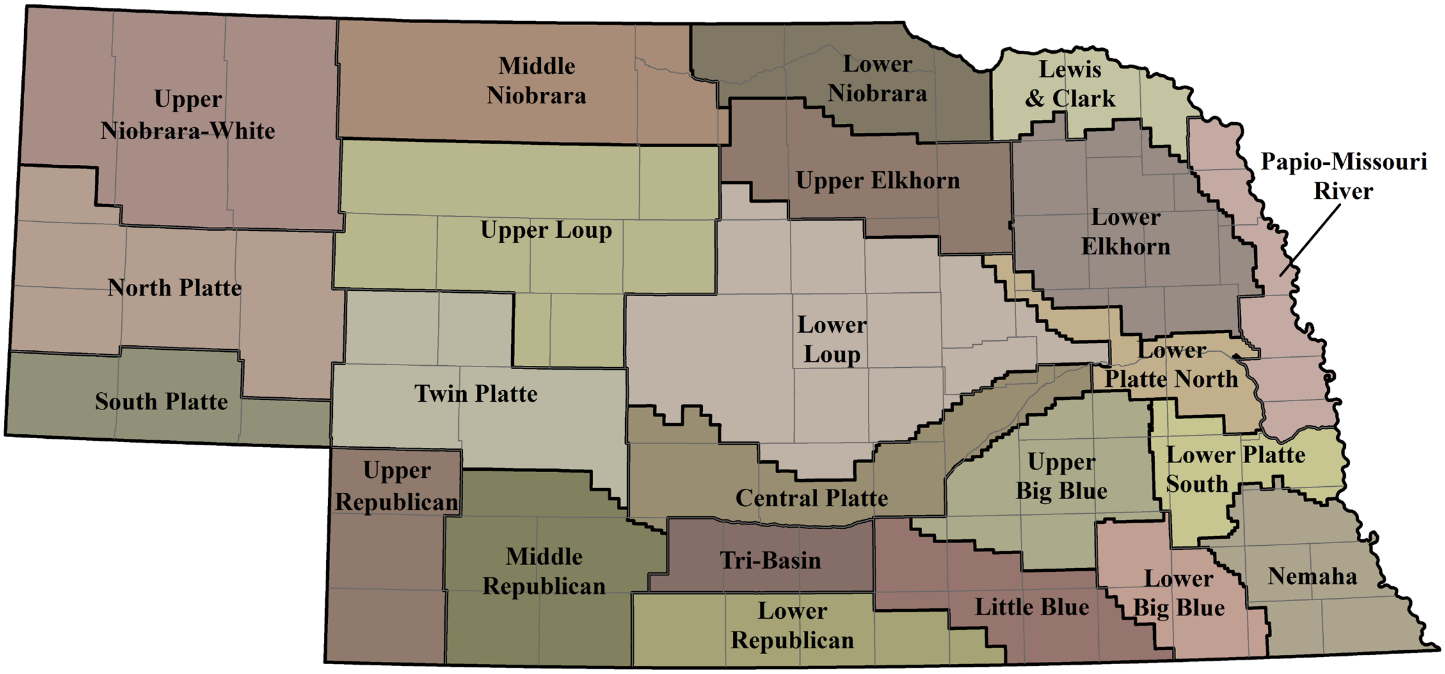
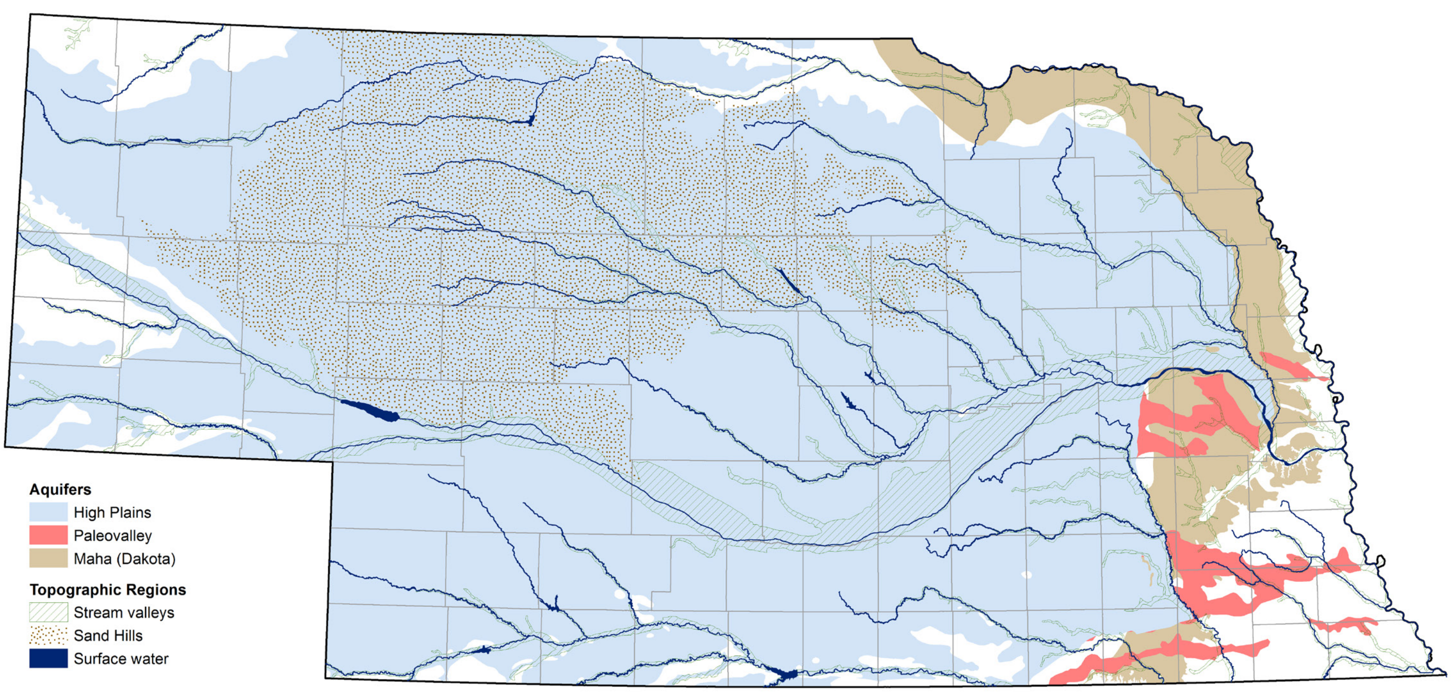


Figure 2. Important Aquifers and Topographic Regions of Nebraska



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

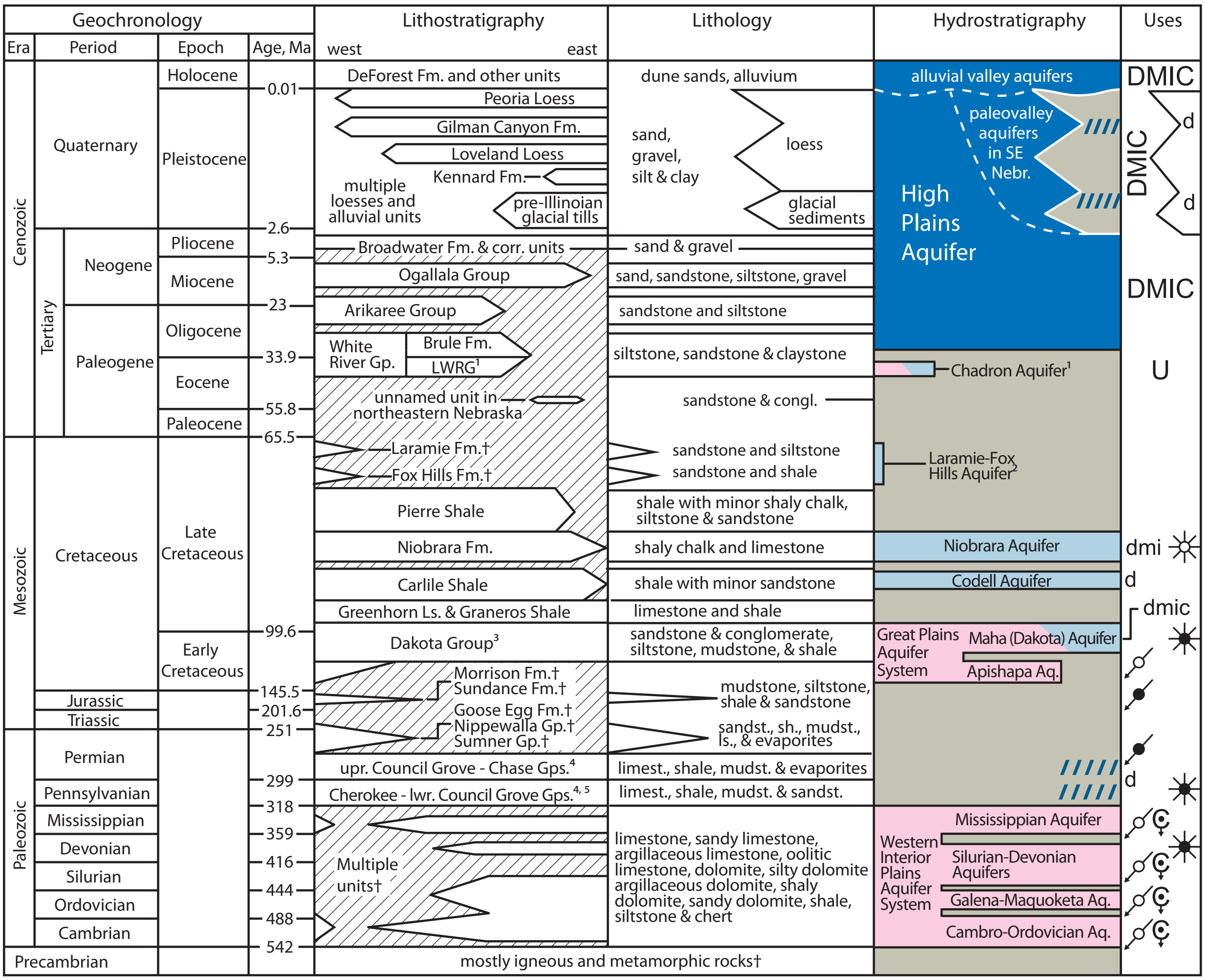


Diagram is not to scale relative to geologic time and stratigraphic thicknesses.

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

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

From Korus and Joeckel (2011)

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 U.S. 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.

This report summarizes changes in Nebraska's groundwater levels over periods of one and ten years prior to 2023, as well as from predevelopment times (generally pre-1960) to 2023. 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 the maps in this report and, indeed, they cannot be represented with accuracy at the scale of the maps.** The reader is referred to Figures 1 through 4 for the boundaries of NRDs and the locations of rivers, aquifers, and counties mentioned in the text.

The one- and ten-year changes are presented in the spring 2022 to spring 2023 and spring 2013 to spring 2022 maps, respectively. Groundwater levels measured from thousands of wells throughout the state during the spring of 2023 (Fig. 5) were compared to levels measured in the same wells in the spring of the preceding target year. For the one- 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 at various scales 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 dissected by deeply entrenched parts of the Niobrara, Republican, and Platte River valleys.

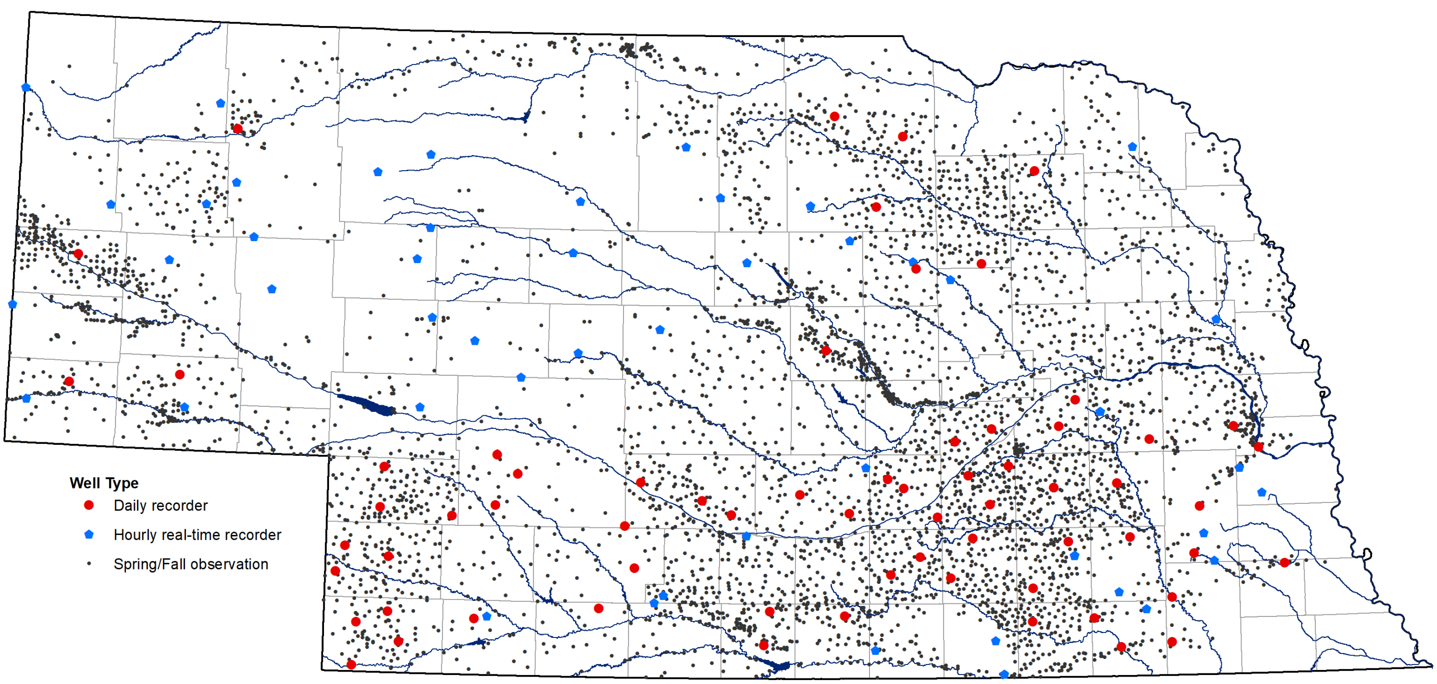
For the predevelopment to spring 2023 map, groundwater levels from wells measured in 2023 were compared to estimated predevelopment groundwater levels in the same wells. An estimated predevelopment groundwater level is the approximate average groundwater level at a well site prior to any development 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 1991-2020. 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.

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

Factors Causing Groundwater-Level Changes

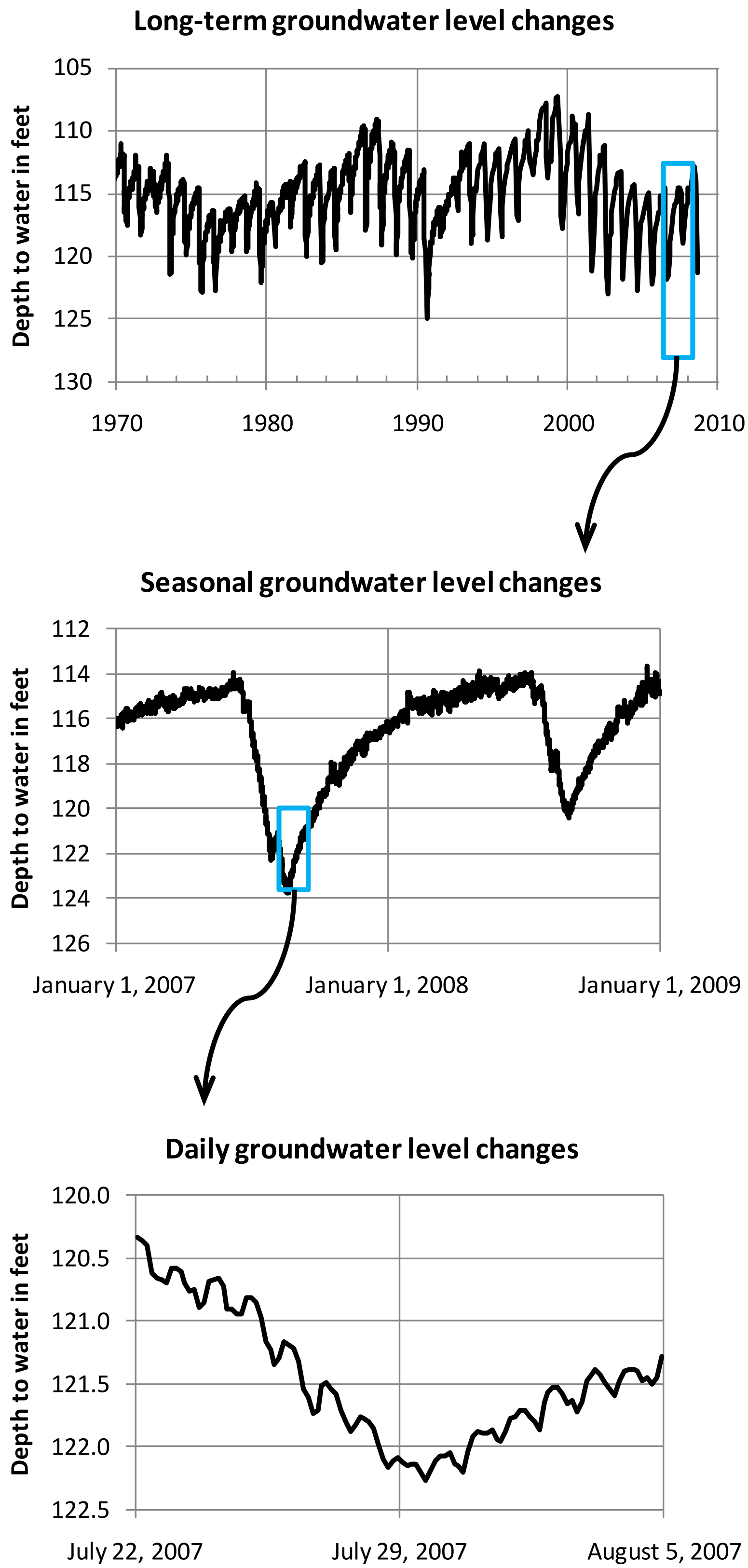
Long-term groundwater-level changes result from the changing balance between recharge to, discharge from, and storage in an aquifer. If recharge and discharge are in balance, such as they were before widespread irrigation development, groundwater levels are generally steady because the amount of water 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 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 they 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 2022 TO SPRING 2023

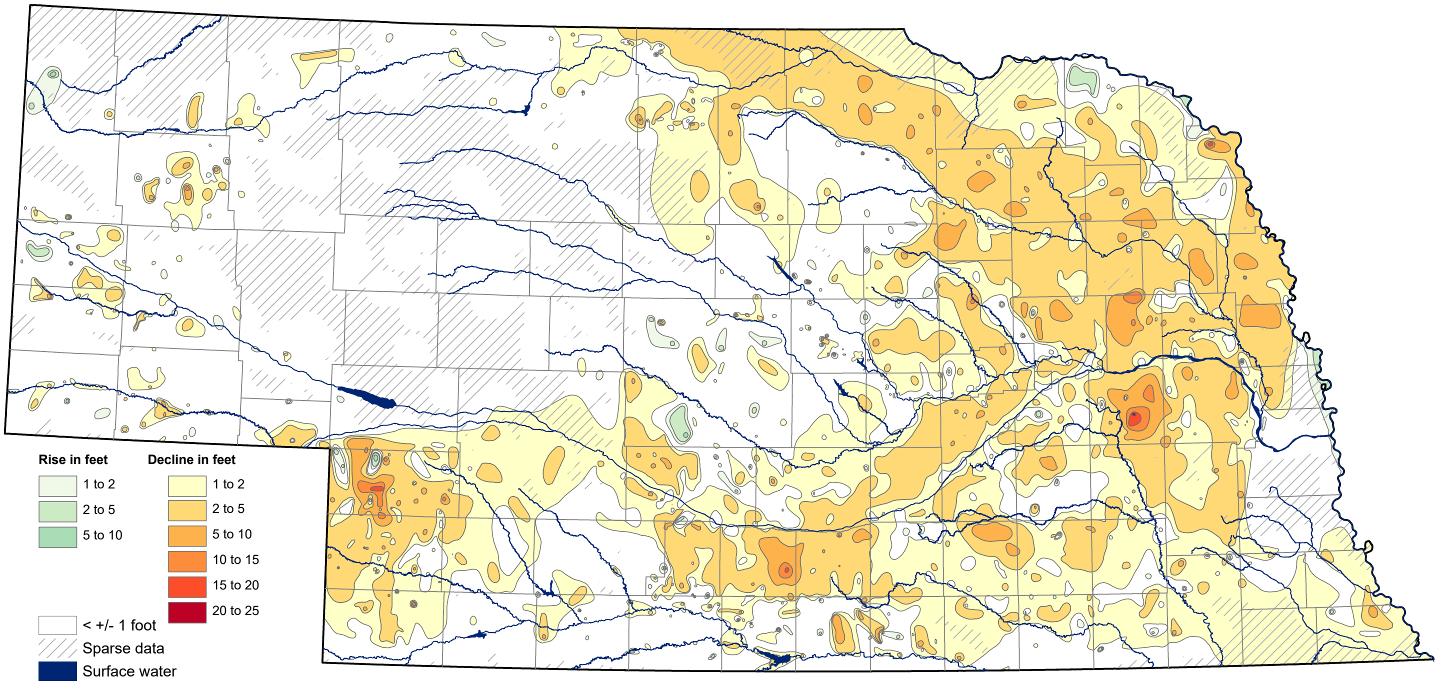
From the spring of 2022 to the spring of 2023, Groundwater levels in Nebraska recorded an average decline of 1.65 feet following several years of persistent drought.

Groundwater levels in Nebraska declined from the spring of 2022 to the spring of 2023. In total, 4,822 wells were measured consecutively in the spring of 2022 and spring 2023. Groundwater-level declines were recorded in 85% of measured wells, and 58% of all measured wells experienced a decline of greater than one foot (Fig. 7). Groundwater-level rises were recorded in 14% of measured wells, and only 4% of all measured wells recorded a rise greater than one foot. Approximately 1% of wells experienced no change from spring of 2022 to spring of 2023. The average groundwater-level change for all measured wells in Nebraska in the spring of 2023 was a decline of 1.65 feet. From January 2022 to January 2023, precipitation values for all 189 reporting stations were below the 30-year normal (Fig. 8).

With drought conditions persisting over much of Nebraska since mid-2020, groundwater-levels have declined significantly over the past 3 years. Since the Spring of 2020, on average groundwater levels measured in wells in Nebraska have declined by 3.15 feet statewide. As drought conditions continue, some areas of Nebraska have experienced significant one-year water level declines. From spring 2022 to spring 2023, the greatest declines recorded in Nebraska exceeded 20 feet in central Butler County, with declines of more than 15 feet recorded in parts of Perkins, Dakota, and Phelps counties. Additionally, most of eastern Nebraska, as well as parts of Chase and Dundy Counties experienced declines of 1-5 feet.

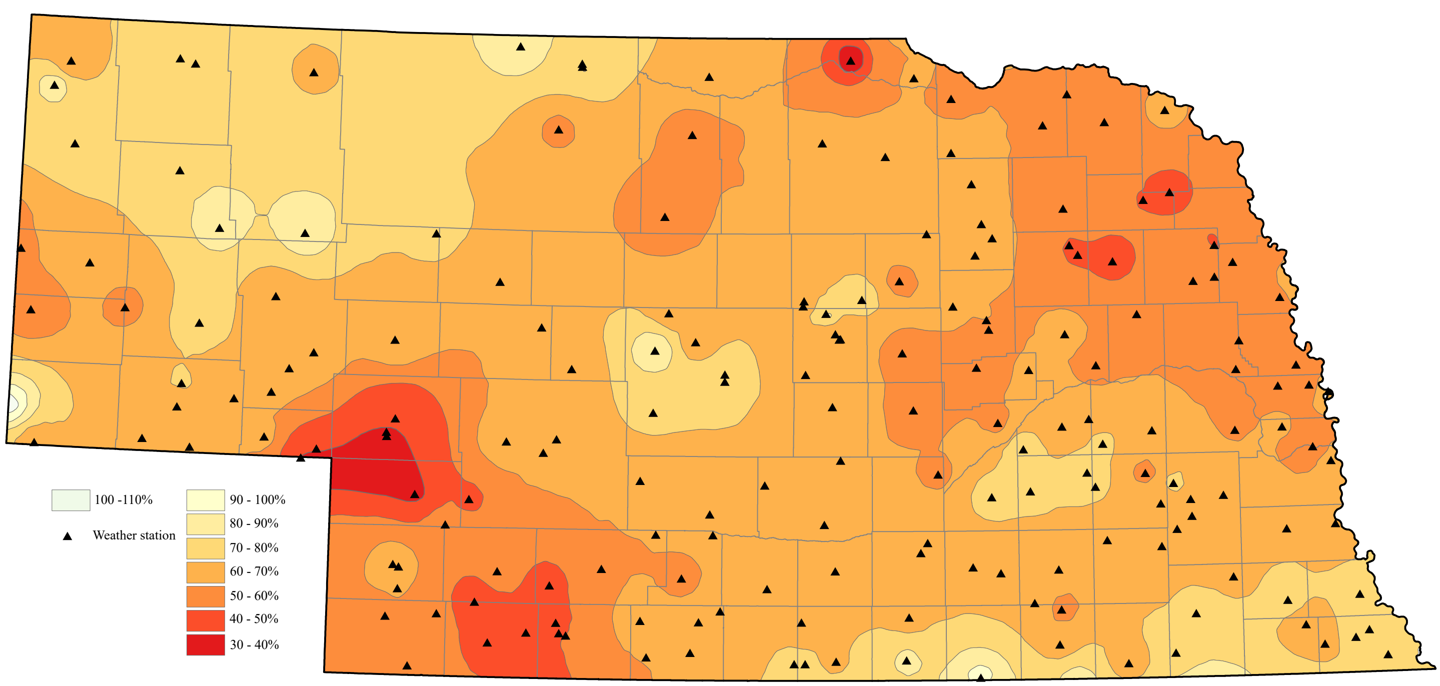
From the spring of 2022 to the spring of 2023 few spatially significant areas of Nebraska recorded groundwater-level rises. A few localized rises were recorded along the Missouri River, and in Custer and northern Cedar counties. Other field-scale rises were recorded throughout the state, and generally correspond to crop rotations, changing irrigation patterns or localized precipitation events.

Figure 7. Groundwater-Level Changes in Nebraska - Spring 2022 to Spring 2023



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 2022 to January 2023



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

CHANGES IN GROUNDWATER LEVELS, SPRING 2013 TO SPRING 2023

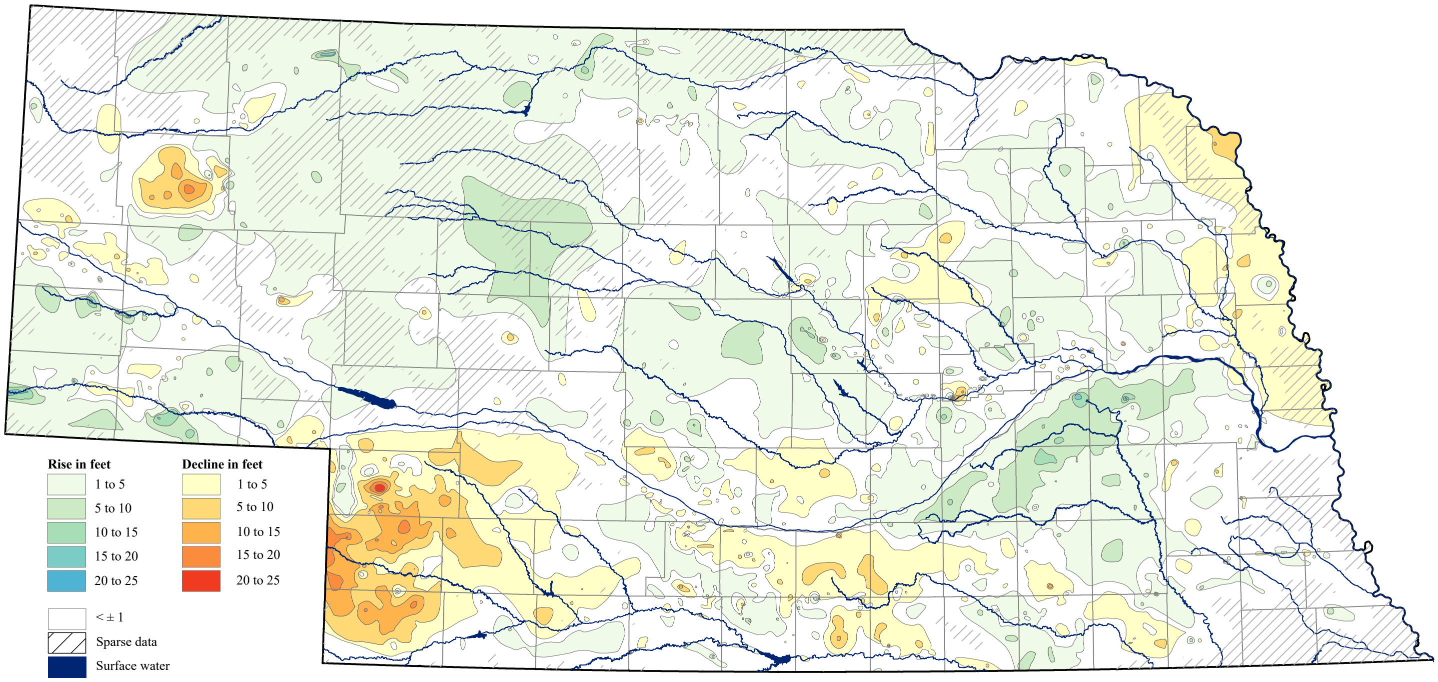
Following major shifts in weather conditions from record setting drought to record setting rainfall, modest groundwater-level rises were recorded throughout Nebraska over the last 10 years.

Of 4,093 wells measured in both the spring of 2013 and the spring of 2023, 58% of wells recorded groundwater-level rises, with 41% of wells rising more than one foot (Fig. 9). Groundwater-level declines were recorded in 41% of wells measured in Nebraska from the spring of 2013 to spring 2023, and 26% of measured wells experienced declines of greater than one foot. Groundwater levels in wells have increased by an average of 0.36 foot statewide over the last 10 years.

Weather conditions from the spring of 2013 to the spring of 2023 ranged from record-setting drought to periods of much above-average precipitation. From the spring of 2012 through the spring of 2013, Nebraska experienced the driest single year on record, resulting in groundwater-level declines that 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. Recently, beginning in early 2020, weather stations in Nebraska have generally recorded below average precipitation for most of the state. Following several years of drought, precipitation values for Nebraska have generally been near to slightly below the 30-year average over the last 10 years, ranging from 90-115% statewide (Fig. 10).

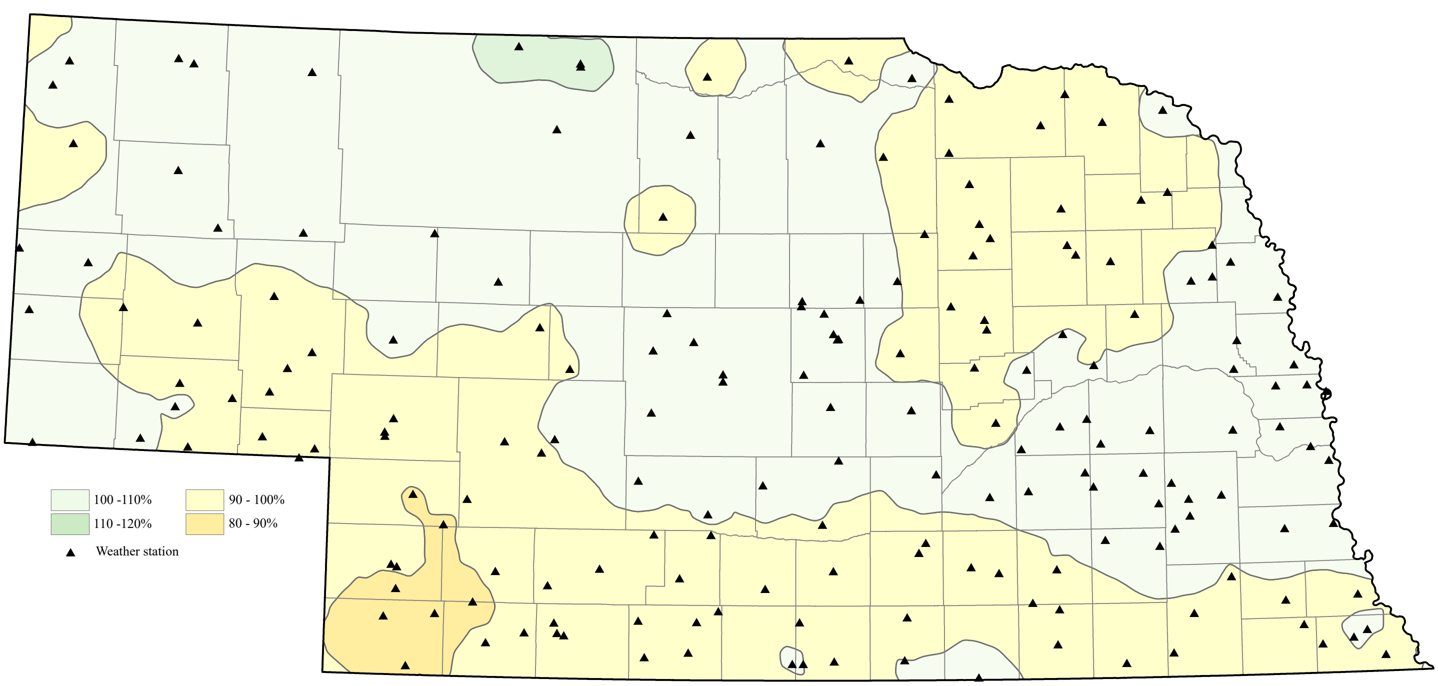
From the spring of 2013 to the spring of 2023, groundwater levels have fluctuated regionally, despite near-average precipitation statewide. The regional patterns of groundwater-level changes may have resulted from: (1) extreme regional variability in year-to-year precipitation and associated irrigation pumping rates, (2) delayed reaction time of aquifers to climate trends, (3) increased runoff during brief, high-intensity rainfall events, and (4) continued pumping of irrigation wells in areas of the state that receive minimal recharge to aquifers. 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, Polk and York counties, and steadily decreasing levels in known problem areas such as Box Bute County, and the south west corner of the State, 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 9. Groundwater-Level Changes in Nebraska - Spring 2013 to Spring 2023



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 10. Percent of Normal Precipitation - January 2013 to January 2023



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

CHANGES IN GROUNDWATER LEVELS, PREDEVELOPMENT TO SPRING 2023

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 2023 groundwater levels indicate both long-term declines and long-term rises from predevelopment in certain areas of Nebraska (Fig. 11). Almost all 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. 12). The greatest decline from predevelopment to 2023 is approximately 129 feet, in Box Butte County just north of the city of Alliance. Notable groundwater-level declines from predevelopment to spring 2023 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 almost 130 feet from predevelopment levels (Fig. 11). 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).

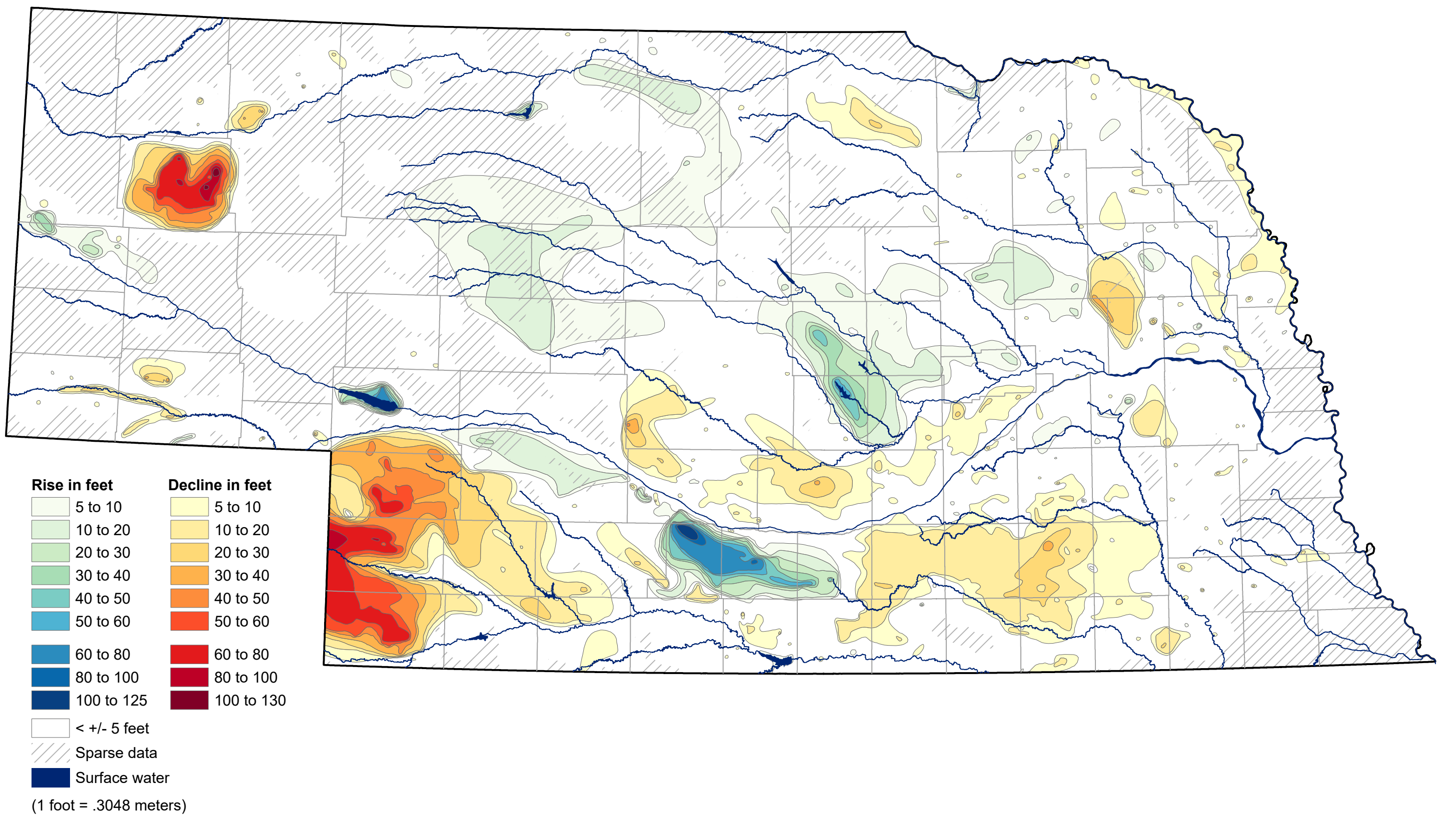
Much of southeastern to south-central Nebraska has experienced long-term groundwater-level declines since predevelopment times (Fig. 11). Predevelopment water levels in this area are generally representative of the approximate average water levels prior to 1950. Groundwater levels in large parts of this 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. Recently, groundwater fluctuations in this region have been closely tied to fluctuations in the regional climate, however levels seem to be stabilizing over the long term.

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 120 feet (Fig. 11). 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.

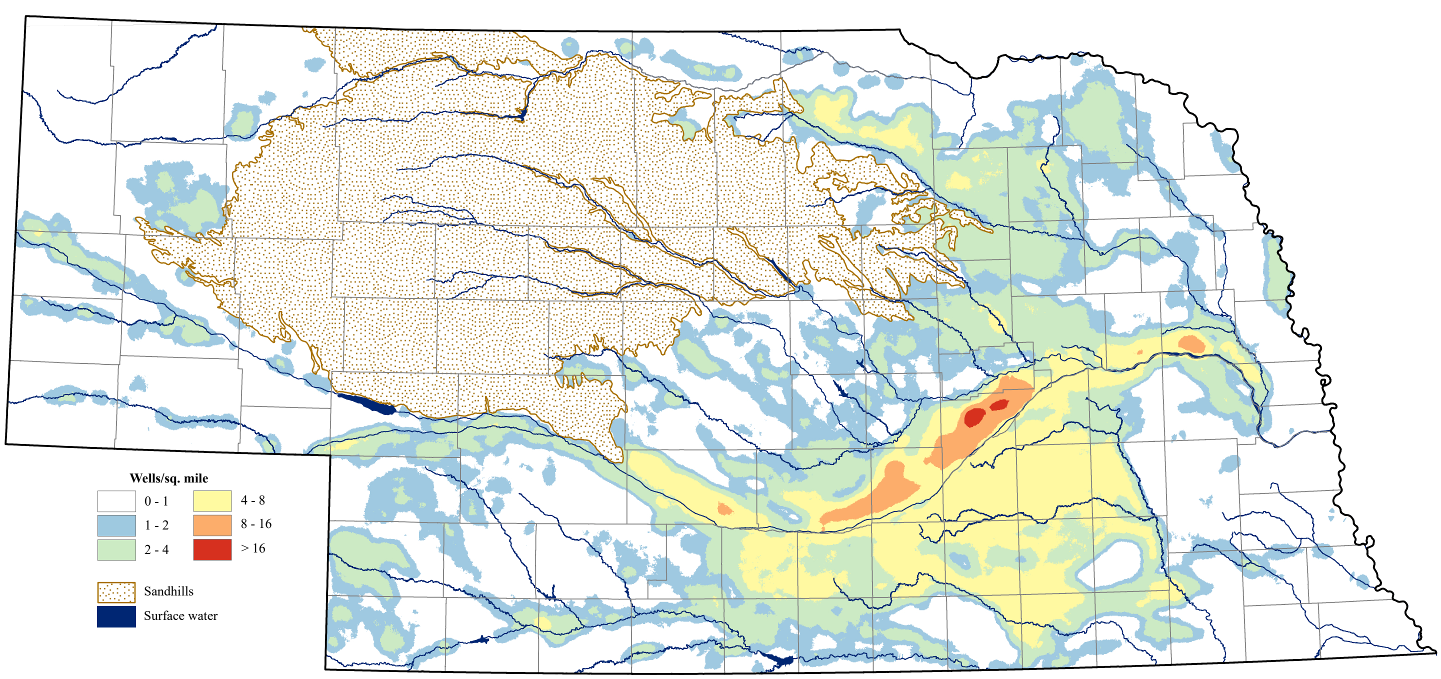
Groundwater-level rises of 10 to more than 50 feet occurred in portions of central Nebraska (Fig. 11). The highest groundwater-level rises occurred in Valley, Sherman, and Howard counties in response to sustained seepage from irrigation canals, Sherman and Davis Creek reservoirs, and the deep percolation of irrigation water applied to crops.

Figure 11. Groundwater-Level Changes in Nebraska - Predevelopment to Spring 2023



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. Density of Active Registered Irrigation Wells - December 2023



Source: Nebraska Department of Natural Resources

REFERENCES

6 News Staff, 2023. Nebraska Department of Environment and Energy Releases Report on Drinking Water. 6 News, 28 July 2023. [https://www.wowt.com/2023/07/28/nebraska-department-environment-energy-releases-report-drinking-water/]. Accessed January 22, 2024

Alley, W.M., and Leake S.A., 2004. The Journey from Safe Yield to Sustainability. Ground Water, v. 42, p. 12-16. [https://doi.org/10.1111/j.1745-6584.2004.tb02446.x]

Anderson, J., 2023. Groups Ask Pillen to Deny Water Transfer after Nebraska Court Puts Decision in State's Hands. Lincoln Journal Star, 2 November 2023. [https://journalstar.com/news/state-regional/government-politics/groups-ask-pillen-to-deny-water-transfer-after-nebraska-court-puts-decision-in-states-hands/article_91ce5b25-86f6-5171-9786-d7ffc44c409b.html]. Accessed January 22, 2024.

Beach, B., 2023a. 'Everyone's Sympathetic,' But After 4 Years Without Safe Drinking Water, Sympathy Isn't Enough for the Santee Sioux Nation. Nebraska Public Media, 11 September 2023. [https://nebraskapublicmedia.org/es/news/news-articles/everyones-sympathetic-but-after-4-years-without-safe-drinking-water-sympathy-isnt-enough-for-the-santee-sioux-nation/]. Accessed January 22, 2024.

Beach, B., 2023b. Santee Sioux Nation Makes Progress on Water Pipeline as Bottled Water Grant Funding Runs Out. Nebraska Public Media, 20 November 2023. [https://nebraskapublicmedia.org/en/news/news-articles/santee-sioux-nation-makes-progress-on-water-pipeline-as-bottled-water-grant-funding-runs-out//]. Accessed January 22, 2024.

Booth, M., 2023. Colorado Replies in Nebraska Canal War: There Won't be Much Water Left to Take. The Colorado Sun, 21 March 2023 [https://coloradosun.com/2023/03/21/nebraska-canal-colorado-response-water-rights-drought/].

Bredehoeft, J.D., 1997. Safe Yield and the Water Budget Myth. Ground Water, v. 35, p. 929. [https://doi.org/10.1111/j.1745-6584.1997.tb00162.x]

CPNRD, undated. 2023 Festival: 17 Schools Across Nebraska Attended the Nebraska Children's Groundwater Festival. [https://www.cpnrd.org/education/activities-events/].

Dunker, C., 2023a. AltEn Cleanup Making Progress Despite Setbacks; Contractor Says There's 'Room for Improvement'. Lincoln Journal Star, 13 August 2023. [https://journalstar.com/news/state-regional/former-ethanol-plant-alten-cleanup/article_a5e09c06-9b5f-11ee-b086-6fc41e952577.html]. Accessed January 22, 2024.

Dunker, C., 2023b. Rural Water System in Northeast Nebraska Looks For Alternatives Amid Contaminant Concerns. Lincoln Journal Star, 13 August 2023. [https://journalstar.com/news/state-regional/rural-water-system-in-northeast-nebraska-looks-for-alternatives-amid-contaminant-concerns/article_4ad7da22-388b-11ee-ad92-e3f0d33e0f33.html]. Accessed January 22, 2024.

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 pp.

Hammel, P., 2023. Law Passed Last Year to Reduce Nitrates in Nebraska Water 'Hasn't Left the Ground,' Sponsor Says. Nebraska Examiner, 31 July 2023 [https://nebraskaexaminer.com/2023/07/31/law-passed-last-year-to-reduce-nitrates-in-nebraska-water-hasnt-left-the-ground-sponsor-says/]. Accessed January 23, 2024.

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

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

Korus, J.T., 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. [https://doi.org/10.1111/j.1745-6584.2004.tb02739.x]

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. [https://doi.org/10.3133/sir20125177]

National Climatic Data Center, National Oceanic and Atmospheric Administration, 2023. Online Climate Data. [https://www.ncdc.noaa.gov/cdo-web/datasets]. Data Retrieved August 16th, 2023.

Nebraska Department of Natural Resources, 2023. South Platte Fact Sheet #4. Perkins County Canal Project—January 2023 Update [https://dnr.nebraska.gov/sites/dnr.nebraska.gov/files/doc/about/News/PerkinsCountyCanal/FactSheet4Draft20230110.pdf]. Accessed January 25, 2024.

Nebraska Legislature, undated. The Official Site of the Nebraska Unicameral Legislature [https://nebraskalegislature.gov/]. Accessed January 22, 2024.

Nebraska Supreme Court, 2023. Nebraska Supreme Court Advance Sheets 315: 311–335.

Olberding, M., 2023. Platte River Dries Out Again in Central Nebraska. Lincoln Journal Star, 8 September 2023 [https://journalstar.com/news/state-regional/weather/platte-river-dries-out-again-in-central-nebraska/article_69b90256-4e87-11ee-9bab-2fba4bb2a6c9.html]. Accessed January 23, 2024.

Sophocleous, M.A., 1997. Managing Water Resources Systems: Why "Safe Yield" is not Sustainable. Ground Water, v. 35, p. 561. [https://doi.org/10.1111/j.1745-6584.1997.tb00116.x]

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. [https://doi.org/10.1016/S0022-1694(00)00263-8]

Supreme Court of the United States, 2023. Sackett et. ux. v. Environmental Protection Agency et al. Certiorari to the United States Court of Appeals for the Ninth Circuit. No. No. 21–454. Argued October 3, 2022—Decided May 25, 2023, 8 pp.

Sylte, A., 2023. Tornadoes, Hail and Drought-Busting Rain: 4 Highlights from Colorado's Record-Setting June. Colorado State University College News 12 July 2023 [https://source.colostate.edu/colorado-june-rain-records-tornadoes-hail/]. Accessed January 24, 2024.

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.

van Kampen, T., 2023. Dry From Drought Last Year, South Platte River Rushes Bank-Full as 2023 Summer Begins. The North Platte Telegraph, 21 June 2023 [https://nptelegraph.com/news/local/weather/south-platte-river-levels-western-nebraska/article_30091054-1062-11ee-b09d-7f8a12ae3589.html]. Accessed January 23, 2023.

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

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

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
2020	Nebraska Water Survey Paper 88	Young, A.R., Burbach, M.E., Howard, L.M., Lackey, S.O., Joeckel R.M., 2020
2021	Nebraska Water Survey Paper 90	Young, A.R., Burbach, M.E., Lackey, S.O., Joeckel R.M., 2021
2022	Nebraska Water Survey Paper 91	Young, A.R., Burbach, M.E., Lackey, S.O., Joeckel R.M., Westrop, J.P., 2022

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

ISBN 978-1-56161-091-4