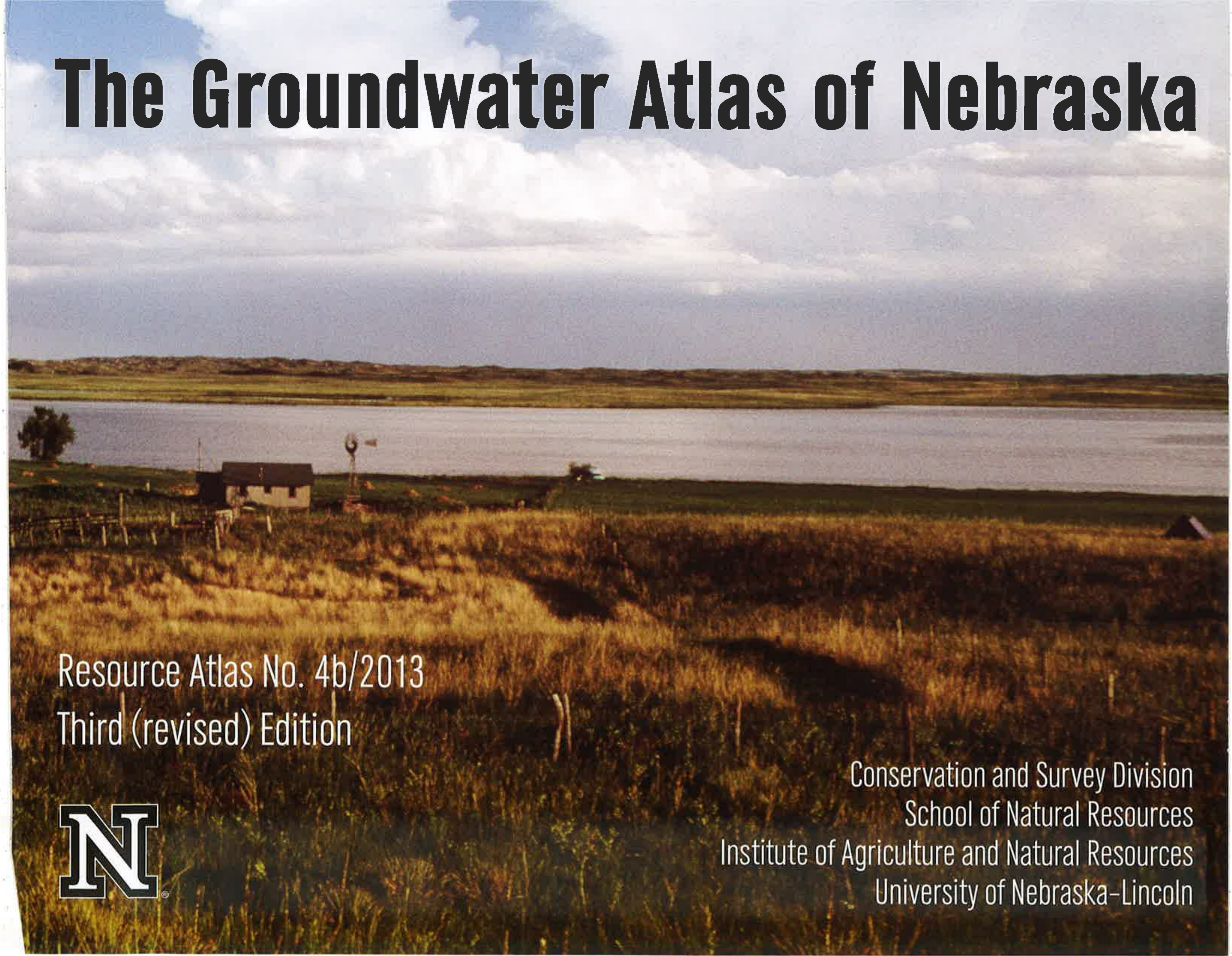

# The Groundwater Atlas of Nebraska

Resource Atlas No. 4b/2013
Third (revised) Edition

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

# The Groundwater Atlas of Nebraska

Resource Atlas No. 4b/2013
Third (revised) edition

Jesse T. Korus, Leslie M. Howard, Aaron R. Young, Dana P. Divine,
Mark E. Burbach, J. Michael Jess, and Douglas R. Hallum

with contributions from R. F. Diffendal, Jr. and R. M. Joeckel
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Conservation and Survey Division
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*Cover photo:* *Swan Lake, Cherry County. Photo credit: Jim Swinehart, Conservation and Survey Division, University of Nebraska–Lincoln.*

# ACKNOWLEDGMENTS

This edition of the Groundwater Atlas of Nebraska was made possible because of the efforts of dozens of scientists and support staff who came before us at the Conservation and Survey Division. Though many are now retired or deceased, we drew upon the robust record of geological and hydrogeological information generated by their work over many decades. We dedicate this publication to them as a tribute to their service to Nebraskans through research, data collection, and education.

Special thanks are given to Dee Ebbeka for producing the graphics, conducting layout and design, and providing valuable input throughout the entire publication process.

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20
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40
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# FOREWORD

I was asked by the authors of this third edition of The Groundwater Atlas of Nebraska to write the foreword to the new revised edition. I thought to myself, "What could be easier?" I simply had to find copies of the first two editions, compare them to the third, and write a piece on previous history, and on changes and improvements in the new edition. Finding copies of those first two editions was easy because the Conservation and Survey Division (CSD) of the University of Nebraska–Lincoln, which published them, keeps archived copies of its publications.

It was only as I read though the prefaces in the first two editions that I found that nowhere was there mention of why CSD produced the atlases in the first place. I called my former colleague at CSD, Professor Emeritus Robert Kuzelka, who was listed as a project leader for the first edition, and asked him if he knew the answer to this question. He told me that the first edition resulted from work done by a task force of representatives from CSD, the University of Nebraska–Lincoln (UNL) Water Research Center, and several state agencies in the early 1980s. Legislation to establish and to support the work of this group on Nebraska's State Water Planning and Review Process was written and approved by the Nebraska Legislature and signed by the Governor in 1978.

Professor Kuzelka loaned me copies of a contract report done by the Conservation and Survey Division for the Nebraska Natural Resources Commission, Groundwater Reservoir Management Policy Issue Study, published in November of 1981 (Anonymous, 1981a). This report included a separate "Appendix A" titled Atlas Illustrating the Characteristics of Groundwater in Nebraska (Anonymous, 1981b) compiled by Dr. Marvin Carlson of CSD from illustrations produced primarily by CSD professional staff. CSD was designated as the "Task Force Leader" in this report. The atlas consisted of 16 plates with explanatory text and was the precursor of the CSD Resource Atlas 4, the first edition of The Groundwater Atlas of Nebraska (Flowerday, 1986).

Paul Gessaman of the UNL Department of Agricultural Economics also in November of 1981 published a most interesting report, Initial Perspectives on Nebraska's State Water Planning and Review Process, that outlined clearly how the legislation to establish the planning and review process was created and how the studies resulting from this process were scheduled for completion and publication.

I will digress at this point because the project leader and first author of the current revision, Jesse Korus, had told me after I wrote and circulated the first draft of this foreword that one of his co-authors, Aaron Young, had told him that there might be even older atlases than the 1981 version, but no one had copies. After I wrote a later revised draft of the foreword Jesse found a copy of the Ground Water Atlas of Nebraska "reprinted" in June 1969. Reprinted from what and when? A further and deeper search of the very "gray" literature led me to perhaps the only extant copy of the Ground Water Atlas of Nebraska printed in June 1966. Both atlases were published by the UNL Conservation and Survey Division (CSD) and both had anonymous authors. (E.C. Reed and V.H. Dreeszen produced most of the maps in both and could probably be viewed as co-principal authors.) Both atlases include 7 plates, several updated versions of which can also be found in the later 1981, 1986, and 1998 editions. All five versions taken together give any reader a good idea of how our understanding of water quality, saturated thickness, rises and declines in water levels, and other aspects of our Nebraska groundwater resources have changed over the decades as a result of more data becoming available.

The number of printed copies of the original 1981 atlas was limited. I suppose that that limited number and partial fulfillment of part of the CSD legislative mission of informing the citizens of Nebraska about the state's natural resources are what prompted Professor Vincent Dreeszen, then Director of CSD, to authorize publication of the first edition of the CSD Resource Atlas 4 in 1986 with support for printing costs from the Nebraska Bankers Association. The CSD printed 10,000 copies of the atlas, more than 3,000 copies of which were given away to secondary school and college libraries across Nebraska. The CSD made the other copies available for sale to interested parties. The first edition had 22 figures (designated as plates in the 1981 contract report atlas) including a few revised maps at a scale reduced from the originals. In 1998 the second revised edition designated as CSD Resource Atlas 4a was approved for publication by the then CSD Director, Dr. Mark Kuzila, with support from the Groundwater Foundation (Flowerday, 1998). Three thousand five hundred (3,500) copies of the revised second edition were printed. The second edition had 19 figures, reduced in number from the first edition in part by inclusion of more than one of the original figures in a revised figure.

This revised and expanded third edition includes 42 figures. Many of the original figures have been significantly updated using new data since the second edition went to press. These include an updated test holes locations map, a map of irrigation projects, a hypothetical cross section with porosity types, a generalized diagram showing the geologic and hydrostratigraphic framework of Nebraska, and maps showing distributions of several aquifers beneath Nebraska. The revision also includes a discussion and figures about the water cycle, a discussion of natural groundwater quality, and a discussion of human-induced groundwater quality problems not included in the earlier editions.

This third edition of The Groundwater Atlas of Nebraska is both a snapshot in time and an indicator of the progress made in understanding the groundwater resources of Nebraska since the publication of the previous editions. It is a snapshot or moment in time because it contains information on the groundwater resources of the state up to shortly before its publication. Considerable new data and new, refined and revised ideas have been used to produce the information in this revision. This is an important contribution to our understanding and education as citizens about Nebraska's groundwater.

***R.F. Diffendal, Jr., PhD***
*Professor Emeritus*
*Conservation and Survey Division*
*School of Natural Resources*
*University of Nebraska*

# INTRODUCTION

# HISTORY OF WATER DEVELOPMENT IN NEBRASKA

## *Groundwater*

Groundwater has long been important to inhabitants of Nebraska. Native Americans in the Great Plains erected their villages near water sources. Early explorers from Europe and pioneers heading west following river valleys depended on ample freshwater in the Nebraska Territory for drinking water and livestock supplies. These Europeans, however, considered the Nebraska Territory part of "The Great American Desert" and few people had an idea of the vast groundwater resource in Nebraska.

In the second half of the 1800s, groundwater from *artesian* systems, or springs, was used for drinking water, swimming pools, and irrigation in a few localized areas. Artesian wells near what became Beaver Crossing (southwestern Seward County), for instance, were a popular source of water for pioneers and their livestock on the Oregon Trail (Lanik, 2010). The public fountain in downtown Lincoln was supplied by an artesian well. However, artesian wells were not numerous enough to be sources of irrigation water for large tracts of land or drinking water for large populations.

Groundwater irrigation in Nebraska began around 1900, but wasn't widely used by farmers until drilling equipment, pumps, and engines were improved in the 1930s. Likewise, groundwater became a major source of municipal and domestic water supplies in the 1930s. Initially, wells for irrigation were usually dug in river valleys where the water was closer to the surface. The expansion of rural electrification in the 1930s was very influential. The Conservation and Survey Division's test hole drilling program, begun in the 1930s in cooperation with the U.S. Geological Survey, provided important characterization of groundwater resources and helped to identify where groundwater resources were sufficient for irrigation or other uses (Fig. 1). Statewide irrigation increased rapidly after the 1930s. By 1940, there were about 2,500 irrigation wells in the state, irrigating about 40,000 acres (Fig. 2; Kuzelka et al. 1993; NDNR, 2013). By 1950 Nebraska had nearly 7,000 irrigation wells providing water to about 450,000 acres (Fig. 2).

The number of irrigation wells and the number of acres with groundwater irrigation accelerated rapidly in the 1950s due to a multi-year drought and the advent of center pivot irrigation systems (Fig. 2). In the mid-1950s, the number of groundwater irrigated acres surpassed surface water irrigated acres for the first time in Nebraska. While the number of surface water acres increased very modestly and plateaued in the late 1960s, the trend in rapidly increasing groundwater irrigation development continued through the late 2000s.

*Vasey family collection*

*A hand-dug well and pump in the Platte River valley in Dawson County, 1915.*

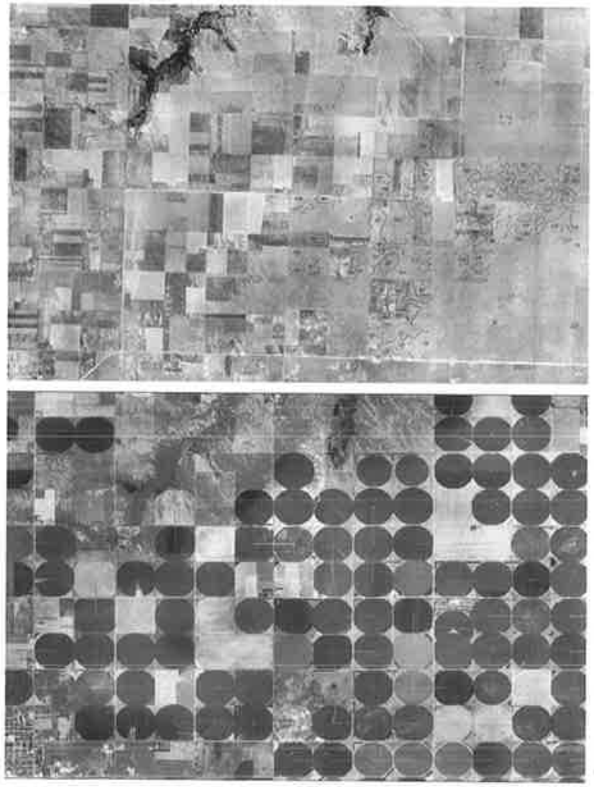
*A flowing artesian well in northeast Nebraska.*
*Photo credit: Jim Goeke, Conservation and Survey Division, UNL*

In the 1970s improved irrigation technology, and high corn prices in particular, led to an unprecedented increase in groundwater irrigation. The number of irrigation wells in 1970 was just over 35,000 and grew to more than 68,000 in 1980 (Fig. 2).

The trend in irrigation development slowed in the mid-1980s during a severe agricultural downturn, but picked up again in the 1990s and remained high through 2008. After 2008 the trend in irrigation development slowed dramatically, in part due to the curtailing of installation of new wells after the designation of fully or over appropriated areas in much of the irrigated areas of the state. As of 2013 there were nearly 95,000 active irrigation wells in the state and more than 7.5 million acres irrigated by groundwater (Fig. 2). About 94% of all groundwater withdrawals are for irrigation. Public water supply is a distant second at about 3%.

Nebraska's Natural Resources Districts (NRDs) were formed during the 1970s. NRDs are local government bodies charged with the management of natural resources, including groundwater. The boundaries of the NRDs are based roughly on watershed boundaries (Fig. 3). Many NRDs established groundwater management plans to deal with the increasing number of irrigation wells in the 1970s.

The natural quality of Nebraska's groundwater is good, with a few local exceptions. Beginning in the 1960s areas with continuously grown corn in highly permeable soils with shallow depths to groundwater began to experience nitrate concentrations above the Maximum Contaminant Level of 10 parts per million (ppm) set by the U.S. Environmental Protection Agency. Many NRDs established groundwater quality management areas in the 1980s to deal with the growing problem of nitrate in groundwater, but the problem persists in some of these areas (NDEQ, 2012). Other anthropomorphic effects on groundwater quality tend to be localized *point sources*.


*Conservation and Survey Division, UNL*

*Air photographs from 1939 (top) and 2007 (bottom) of the same area in Holt County, showing changes in the landscape from center pivot irrigation.*

## *Surface water*

Development of Nebraska's surface water resources did not start with irrigation. Because settlement began in the comparatively humid eastern parts of the state, need for crop watering was not apparent to the earliest residents familiar with other regions where rainfall was more abundant. For them development meant flowing water used for milling grain into flower, operating factories, and generating electric energy. During the winter ice was "harvested" from many mill ponds for commercial refrigeration, railroad transport of fresh produce, and by individuals.

The earliest reported irrigation occurred in Buffalo and Lincoln counties. During the 1850s and 1860s several settlers drew water from the Platte River to irrigate vegetables sold to travelers going to Oregon and California and to soldiers stationed along the immigrant trails. Similar reports from the 1870s mention small ditches diverting water from Lodgepole Creek.

For many homesteaders, sufficient rainfall generally occurred during most of the 1870s and 1880s. Beginning in 1887, however, rainfall was not adequate. As drought persisted, especially west of the 100th meridian west longitude (at Cozad in western Dawson County), need for irrigation gained general acceptance, and plans for a variety of ambitious projects emerged.

Soon after excavation of the Ford-Akers Canal (later renamed Tri-State) began in March 1888, an initial phase of further building activity swept across western and central Nebraska. During the following

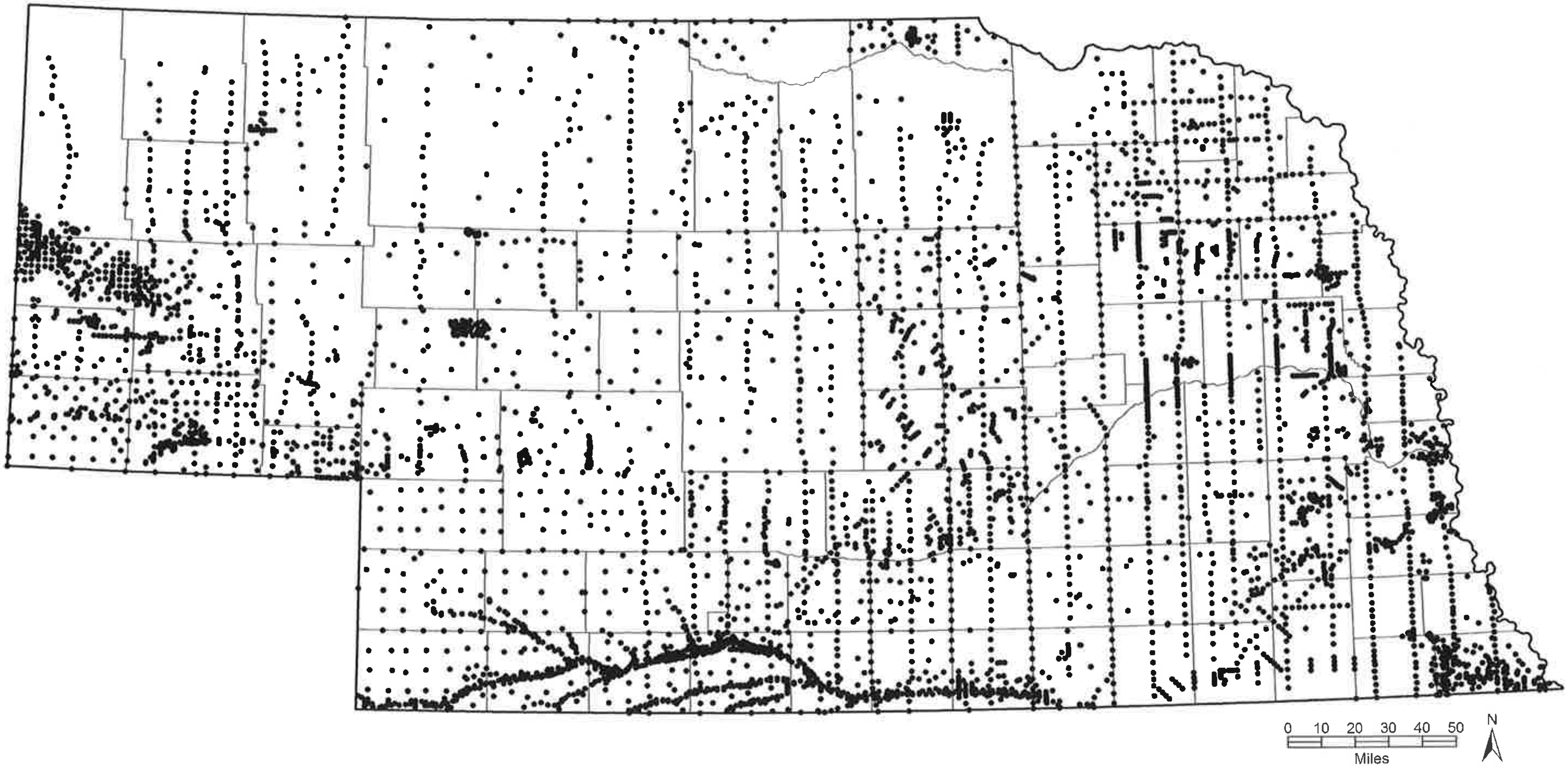


*Figure 1. Locations of exploratory test holes drilled by the Conservation and Survey Division from 1931 to 2012.*

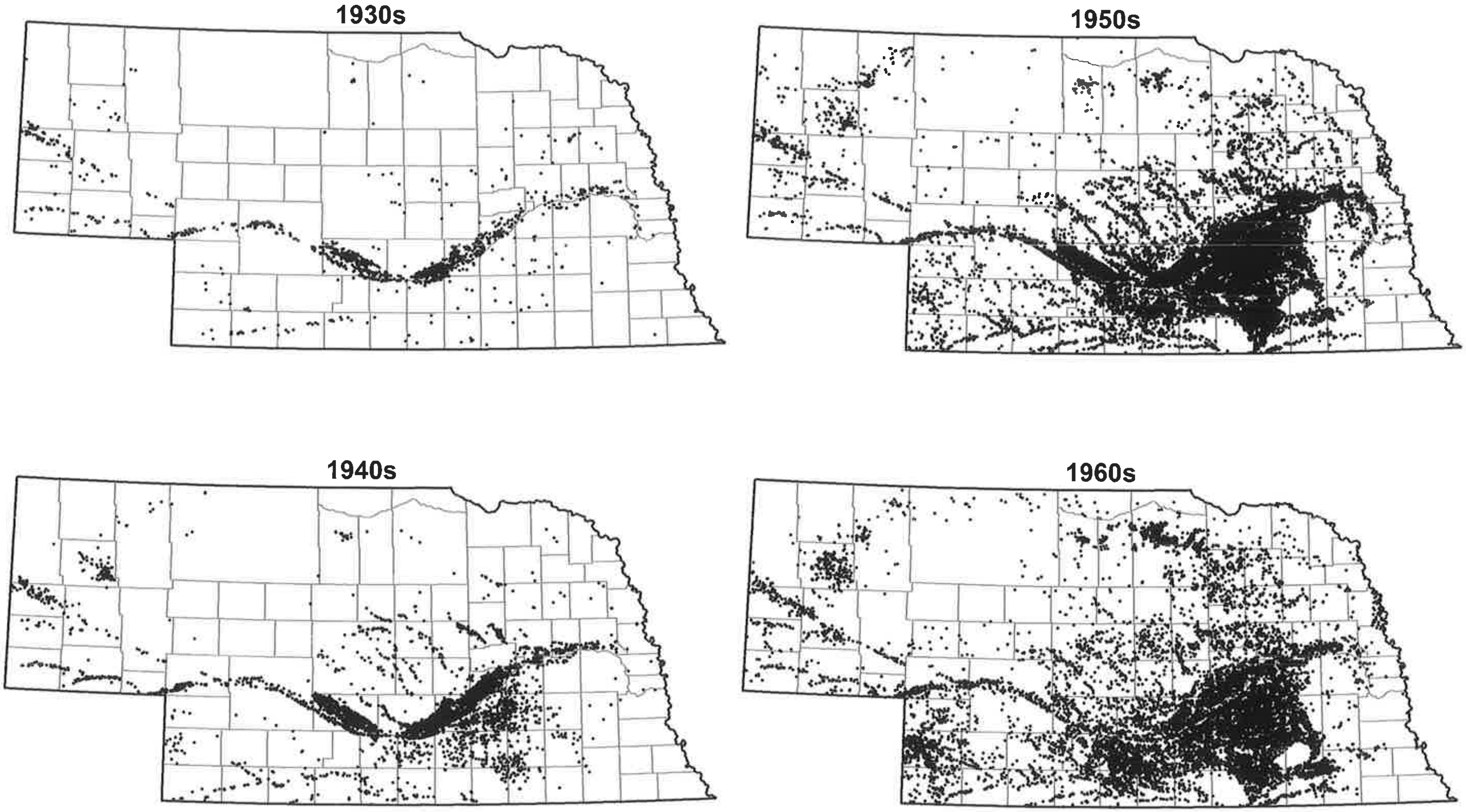


*Figure 2. Locations of registered irrigation wells installed during each of the last eight full decades. Each map shows only those wells that were installed during that decade and not those wells that existed prior to that decade.*

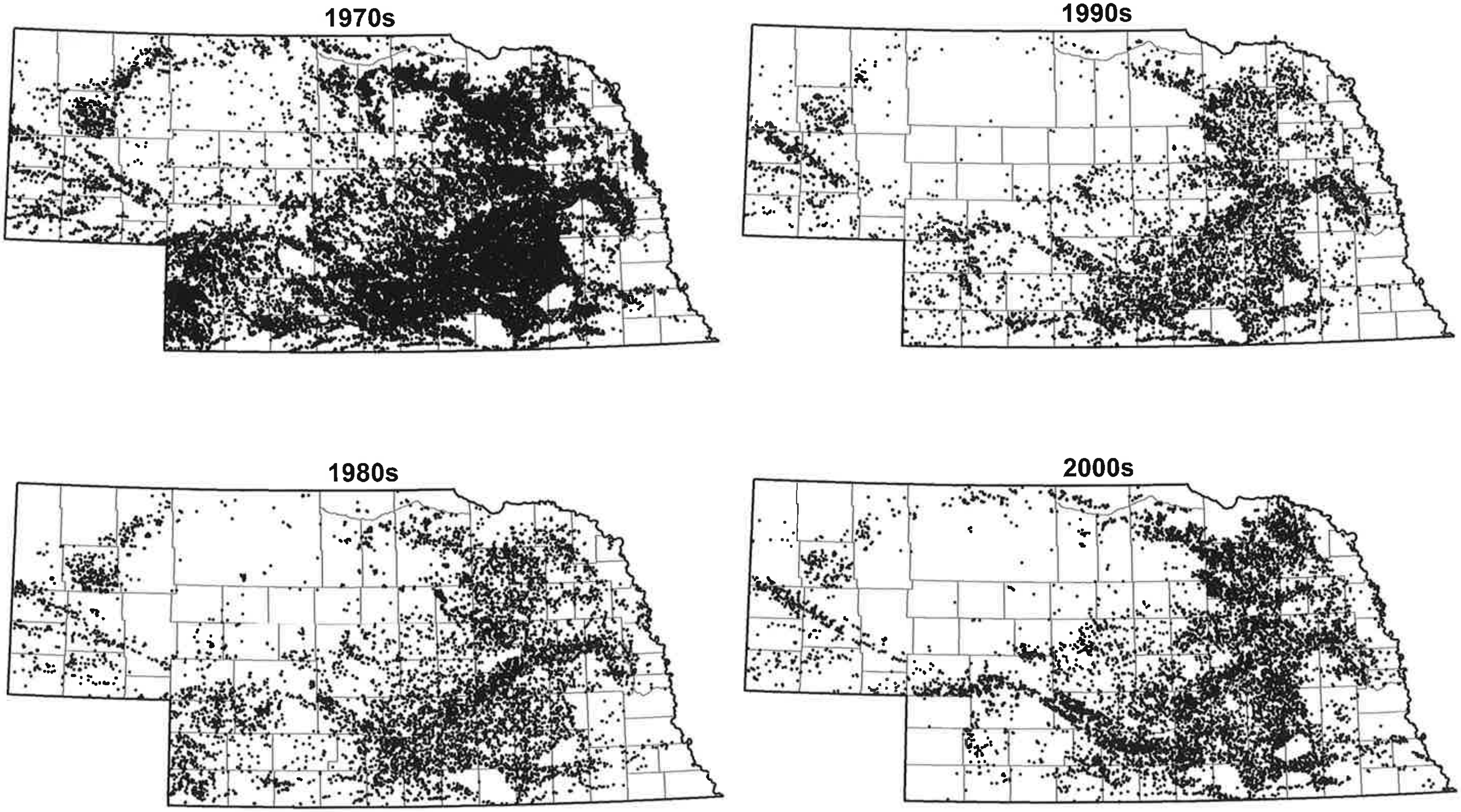


*Figure 2 (continued). Locations of registered irrigation wells installed during each of the last eight full decades. Each map shows only those wells that were installed during that decade and not those wells that existed prior to that decade.*

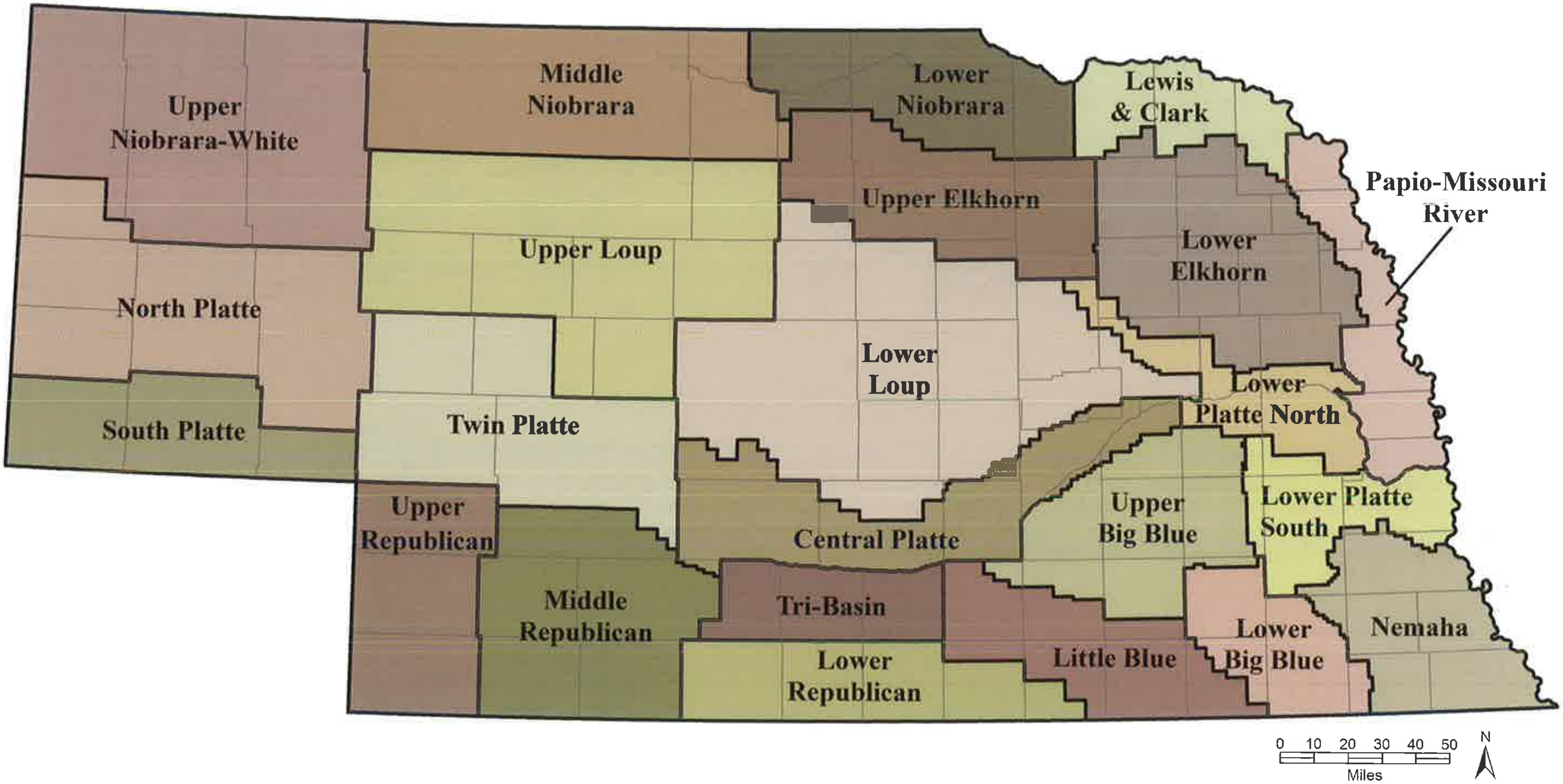


*Figure 3. Names and boundaries of Natural Resources Districts (NRDs).*

four decades, nearly 60 irrigation districts and ditch companies were formed to build diversion dams, canals, and related infrastructure (Fig. 4). While most developments were centered in the North Platte and Platte River valleys, irrigation projects also were completed in the South Platte River valley, along tributaries of the Republican River, and in Dawes County. By the late-1920s many storage reservoirs, diversion structures, and delivery works provided water to nearly 505,000 acres (Fig. 4).

Because knowledge of the geological setting in which the early projects were located was initially limited, the nature and extent of underlying *aquifer* systems were not thoroughly understood. Moreover, hydrological responses to downward percolation of water carried through earthen canals and from irrigated fields were generally not forecast or even monitored. As a result, impacts on local groundwater resources caused by operation of many of the early irrigation projects have been quite significant, but have generally stabilized (Fig. 5). In response to a rise in the *water table*, incidental *recharge* of aquifers in the North Platte Valley caused nearly a dozen formerly intermittent streams to begin flowing year-round (Steele et al., 2002).

As a public response to widespread and prolonged drought and to the economic and social impacts of the Great Depression, a second period of irrigation project construction began during the 1930s. The best known features include Lake McConaughy and the extensive network of canals used for irrigation of table-land farms lying south of the central Platte Valley. Elsewhere, projects in the Loup River basin included diversion and distribution works for two irrigation districts as well as the 33-mile Loup River canal built for hydro-electric generation at Monroe and Columbus (both in southern Platte County). In total, the New Deal projects brought surface water irrigation to approximately 170,000 acres (Fig. 4).

Engineering designs employed during this second phase of irrigation development were based on a better understanding of the geological settings in which the projects were built. While anticipated in many locations, incidental aquifer recharge from unlined canals and irrigated fields has been substantial. The "mound" of groundwater extending generally from Lincoln County to Kearney County is an example of the impact of surface water irrigation on groundwater (Fig. 5).

Under provisions of the Pick-Sloan Missouri Basin Program, a third era of project construction followed World War II. By 1992 storage reservoirs and distribution works in the Republican, Niobrara, Middle Loup and North Loup watersheds were completed. The newest projects provide irrigation water to some additional 235,000 acres (Fig. 4).

During the third era of development, pre-construction investigations more thoroughly identified expected locations where percolation would occur. In conjunction with operation of the Sargent and Farwell irrigation projects, for example, incidental recharge through *sediments* underlying large portions of Howard, Valley and Sherman counties is monitored by local agencies using a comprehensive network of observation wells. Groundwater levels continue to rise under these areas.

*Nebraska State Historical Society*

*A weir in an irrigation canal, probably in Hitchcock County, 1913.*

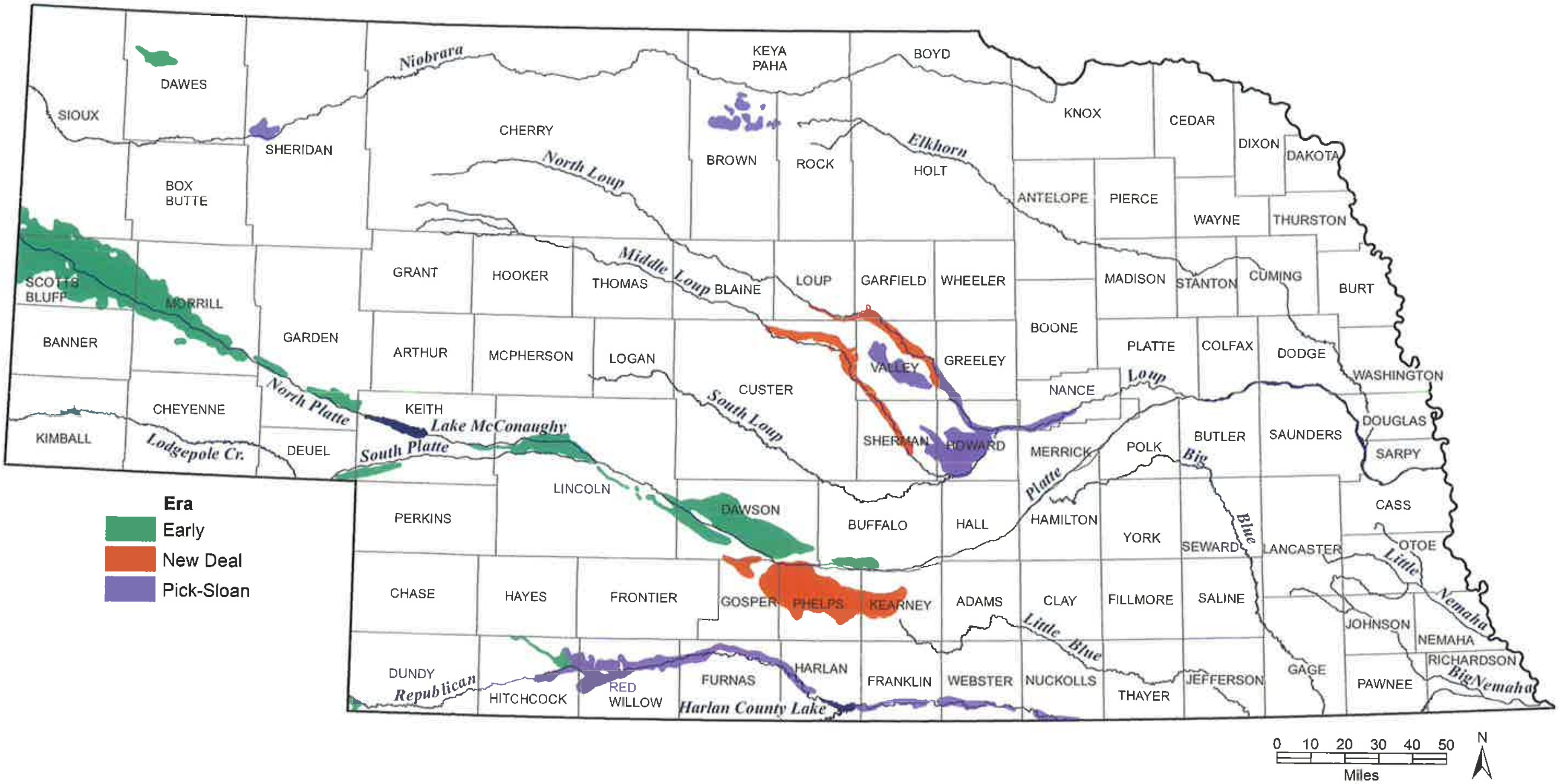


*Figure 4. Areas of Nebraska developed for surface water irrigation. Early development occurred in the 1880s through 1920s. New Deal projects were constructed during the 1930s. Pick-Sloan projects were completed from the late 1940s through 1992.*

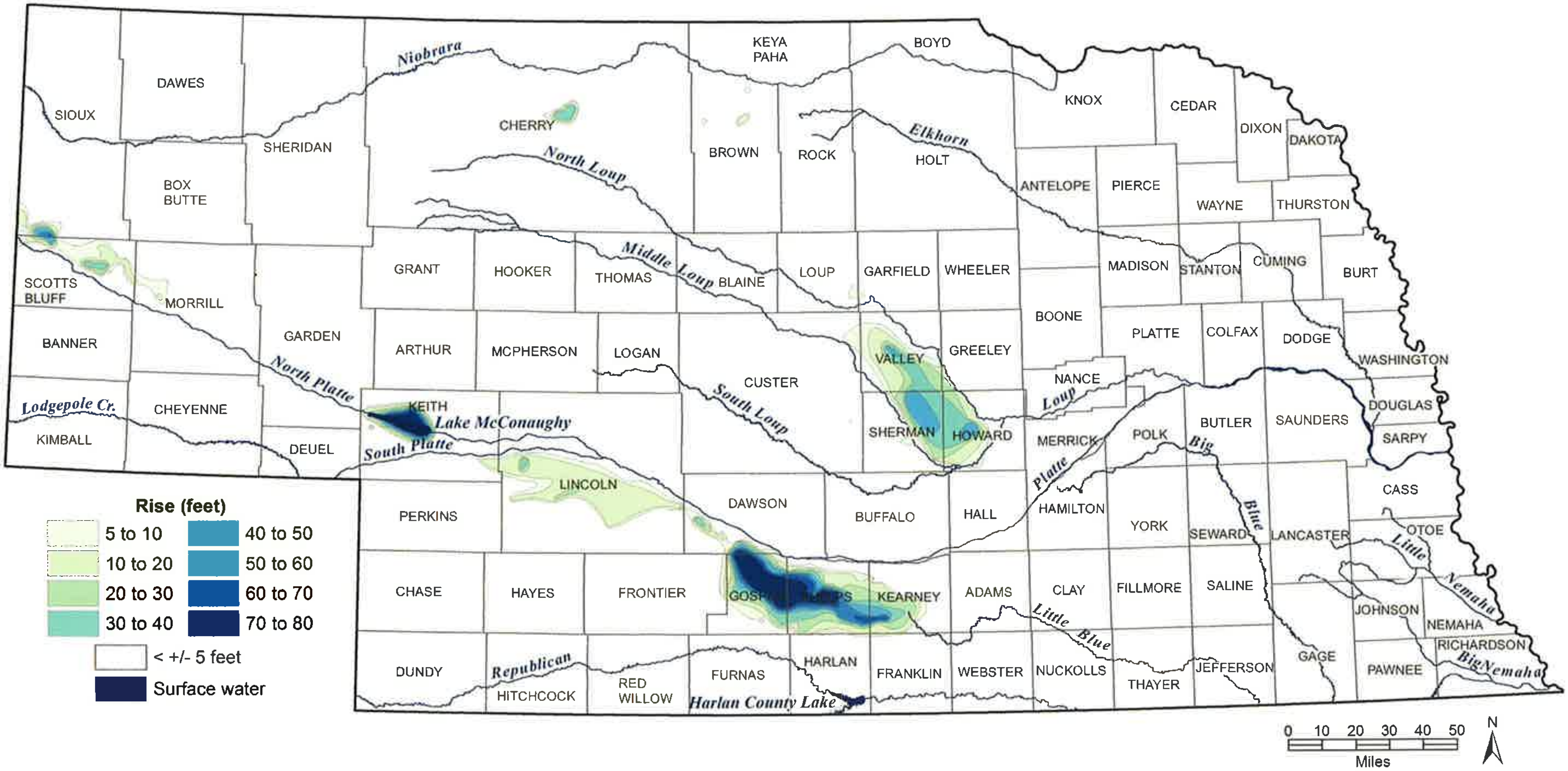


*Figure 5. Rises in groundwater levels as a result of seepage from surface water canals and reservoirs, from predevelopment to Spring, 2012.*

## GROUNDWATER BASICS

### *The Water Cycle*

Water is constantly moving within and between different components of the Earth. This movement, known as the water cycle, involves the atmosphere, oceans, glaciers, streams, groundwater, lakes, soils, and living organisms. The distances and rates at which water moves through these components vary tremendously. Water may travel hundreds of miles in the atmosphere over a few days, but it may take ice hundreds or thousands of years to travel only several miles in a glacier. Similarly, water may remain in a groundwater system for just a few days or as much as thousands of years. A key aspect of the water cycle is that these components are connected to one another via precipitation, evaporation, evapotranspiration, and surface and underground flows (Fig. 6).

Precipitation is the ultimate source of *recharge* to groundwater. Much of the precipitation that falls on the land surface may either run off the soil and into lakes and streams or *infiltrate* into the soil. Some of this water may be taken up by plants, but if it infiltrates to a depth below the root zone, that water will eventually become groundwater. In certain hydrologic settings, some of the water along the beds of streams, canals, and lakes may also recharge the

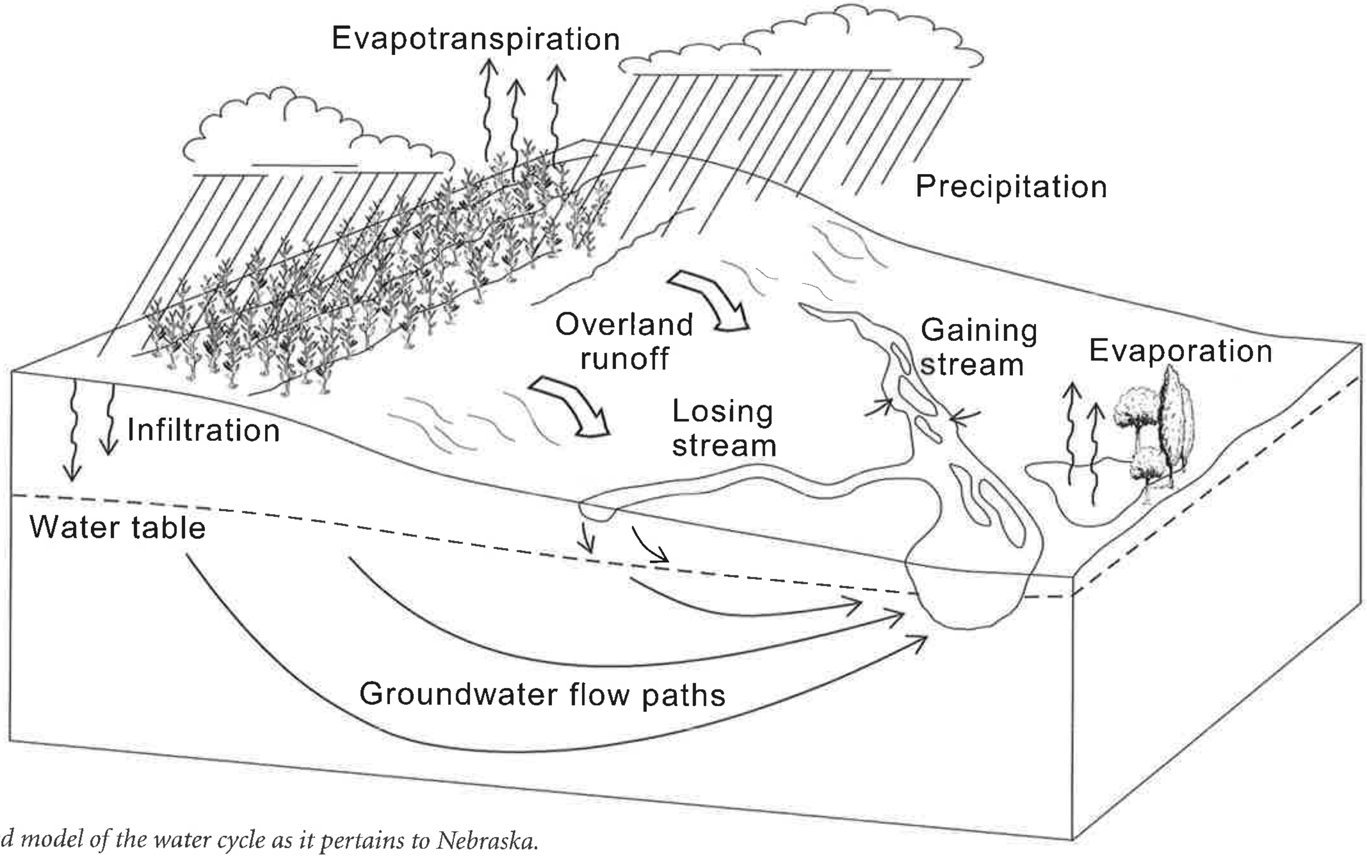


*Figure 6. Conceptualized model of the water cycle as it pertains to Nebraska.*

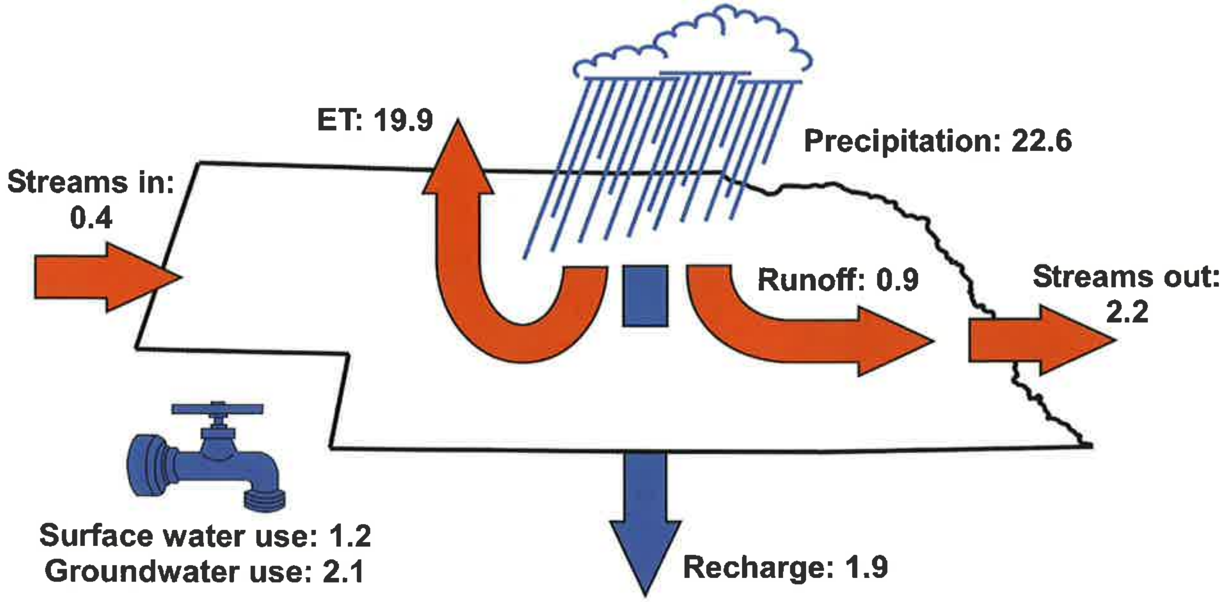


*Figure 7. Generalized water budget of Nebraska.*

groundwater system by moving downward through the underlying *sediments* under the force of gravity. Under other hydrologic conditions, wetlands, streams, and lakes are sites of *groundwater discharge* as it moves upward or outward to become surface water. Over time, the movement of groundwater through the subsurface defines a path from an area of recharge to an area of discharge (Fig. 6).

Even though the water cycle operates at a global scale, it is sometimes useful to study the part of the water cycle that operates in a particular area. The flows into and out of an area can be expressed in terms of a local *water budget*. Hydrologic boundaries are best suited to defining such areas, but for the purposes of this Atlas, we calculated a generalized water budget for the State of Nebraska (Fig. 7). The water budget of Nebraska shows that precipitation and *evapotranspiration* (ET) are by far the largest components. Furthermore, most of the precipitation that falls on the ground returns to the atmosphere via evapotranspiration. Only a small portion of that precipitation becomes runoff to streams or recharge to groundwater. Notice also that streams flowing into the state carry much less water than streams flowing out, showing the net gain to streams from groundwater discharge and precipitation runoff.

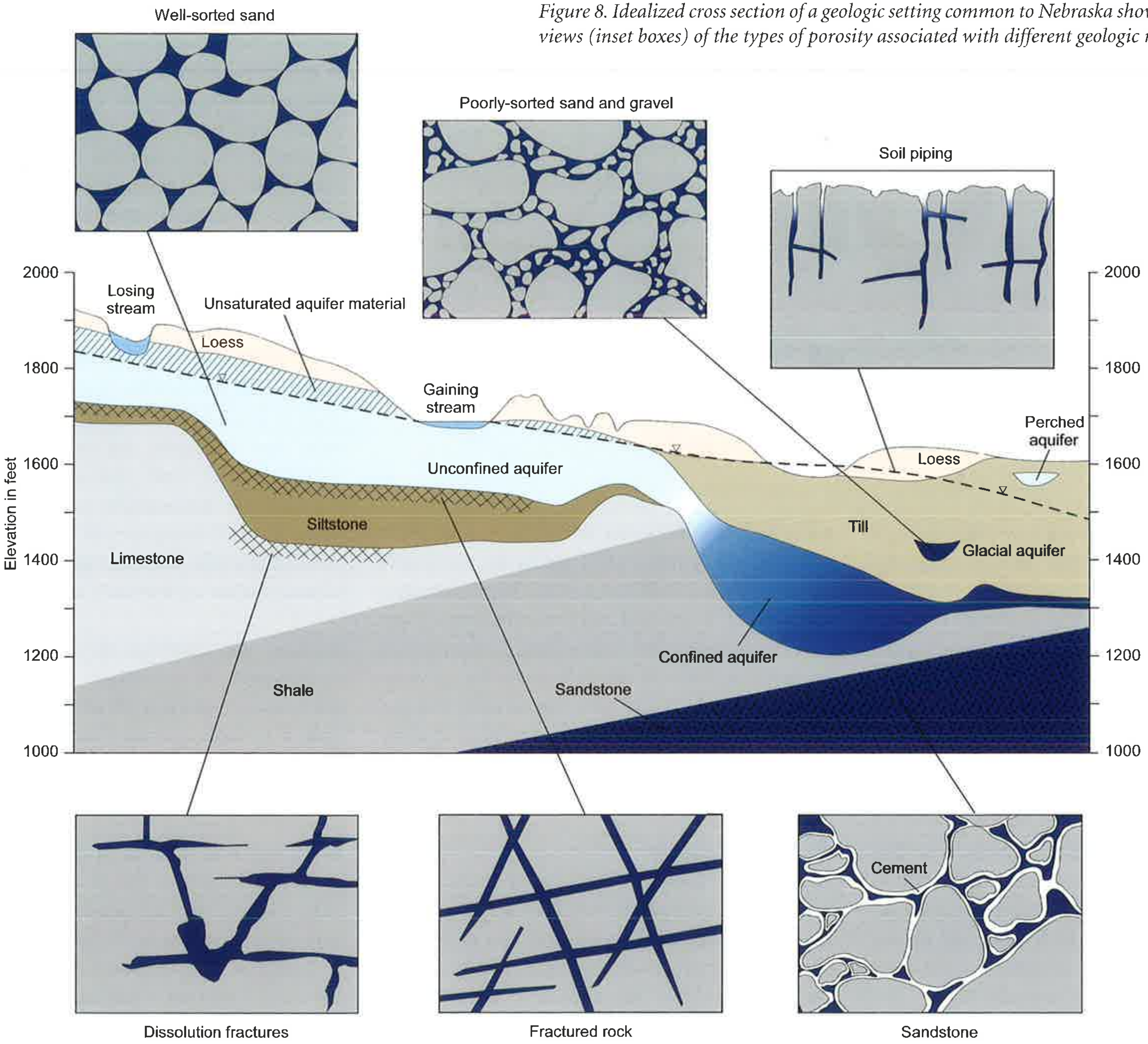
## *Basic hydrogeology*

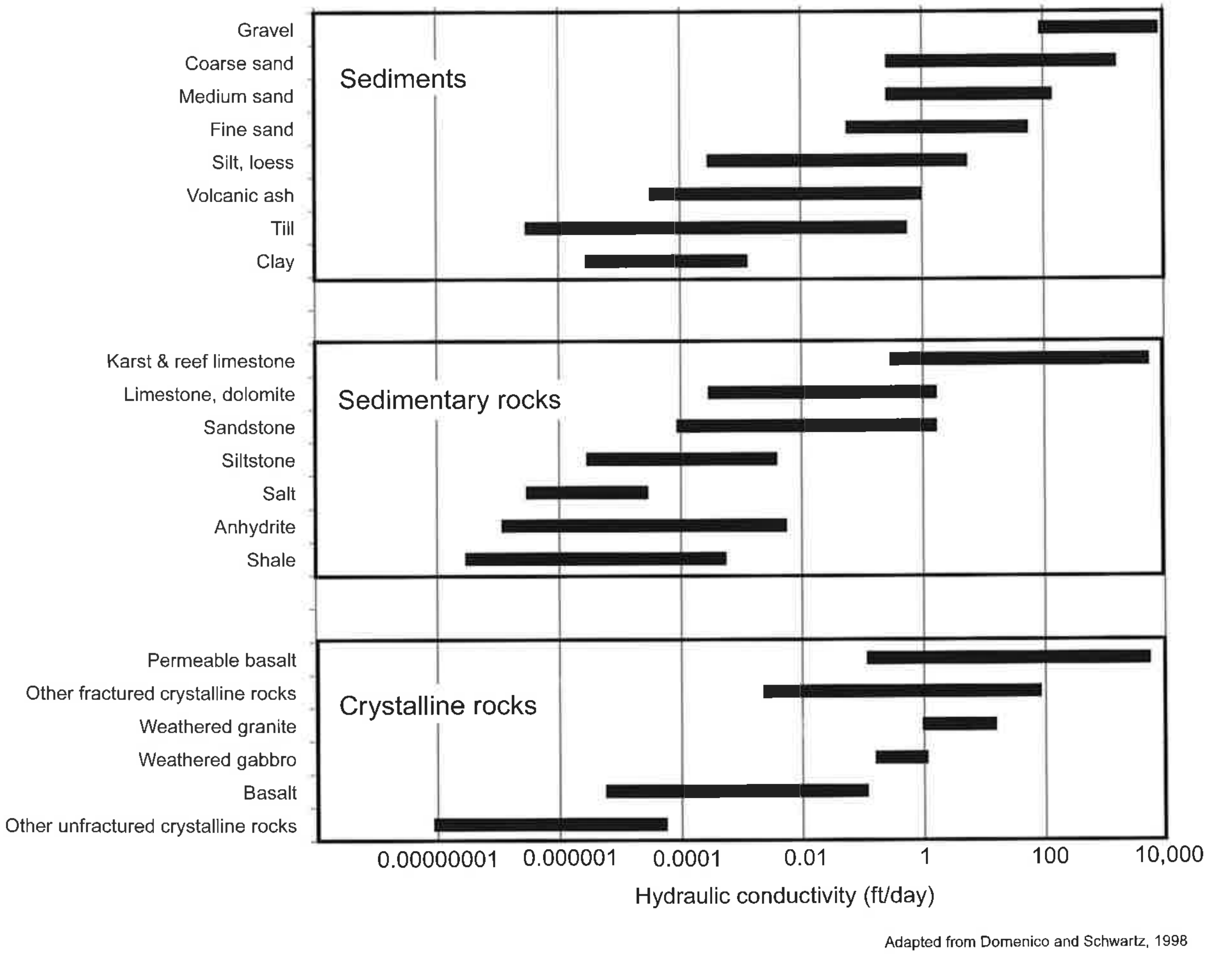
Groundwater resides in and moves through tiny voids between grains, between fractures in rocks, or in other cavities within sediments and rocks (Fig. 8). All sediments contain abundant *porosity*; usually between 20–60% of their volume consists of pores (open spaces or voids). Many rocks are porous unless they are deeply buried or unweathered. Since much of the Earth's surface is underlain by sediments or weathered rock, it follows that groundwater exists almost everywhere. Its widespread abundance, however, does not mean that groundwater is useful everywhere as a resource. Some water-bearing materials are aquifers, others are not.

An *aquifer* is an underground body of saturated sediment or rock that yields water to a well at a rate that is sufficient for its intended use. Thus, the ease with which water flows through sediment or rock, known as its *permeability*, is of chief concern in the study of groundwater (Fig. 9). In high permeability rocks and sediments, the void spaces are well-connected and water can move more quickly than in low permeability rocks and sediments where the void spaces are not well-connected. Low permeability geologic materials that retard the flow of groundwater are known as *confining units.*

Aquifers are classified as either confined or unconfined. An *unconfined aquifer* is bounded below by a confining unit and above by the *water table*, a surface connecting water levels in shallow open wells (Fig. 10). Below the water table, the pore water pressure is greater than atmospheric pressure, so water will flow into a well until the water standing in the well is at the level of the local atmospheric pressure surface (i.e. the water table). The water table may rise and fall depending on seasonal or long-term variations in the amount of recharge to or discharge from the aquifer. Thus, the *saturated thickness* of unconfined aquifers is variable within

Figure 8. *Idealized cross section of a geologic setting common to Nebraska showing highly magnified views (inset boxes) of the types of porosity associated with different geologic materials.*





Adapted from Domenico and Schwartz, 1998

*Figure 9. Ranges of hydraulic conductivity (permeability relative to water) for different sediments and rocks. Due to extremely large range of values, horizontal scale is logarithmic so that each division from left to right marks a hundred-fold increase from the previous division.*

a certain range. Unconfined aquifers are usually close to the ground surface and therefore receive recharge from all or most of the overlying land surface relatively soon after water infiltrates below the root zone.

A *perched* aquifer is a special type of unconfined aquifer. A perched aquifer forms where a small, relatively shallow body of impermeable material hinders the flow of water as it moves downward through the unsaturated zone, creating a small pocket of saturated material above the regional water table.

A *confined* aquifer is bounded below and above by confining units. Water recharges a confined aquifer where it intersects an unconfined aquifer. As the water enters the confined aquifer, it moves to a lower elevation and becomes pressurized by the weight of the water and the seal provided by the overlying confining unit. A well drilled into a confined aquifer is an *artesian well*. Water will flow into the well until the water standing in the well is above the top of the aquifer. In some artesian wells, the water may continue rising until it flows out at the ground surface, in which case the well is called a *flowing artesian well*. An imaginary line drawn between water levels in artesian wells forms a *potentiometric surface*, which defines the height to which water has the potential to rise in wells drilled into that aquifer. Confined aquifers are usually, but not always, deeper below the ground surface than unconfined aquifers.

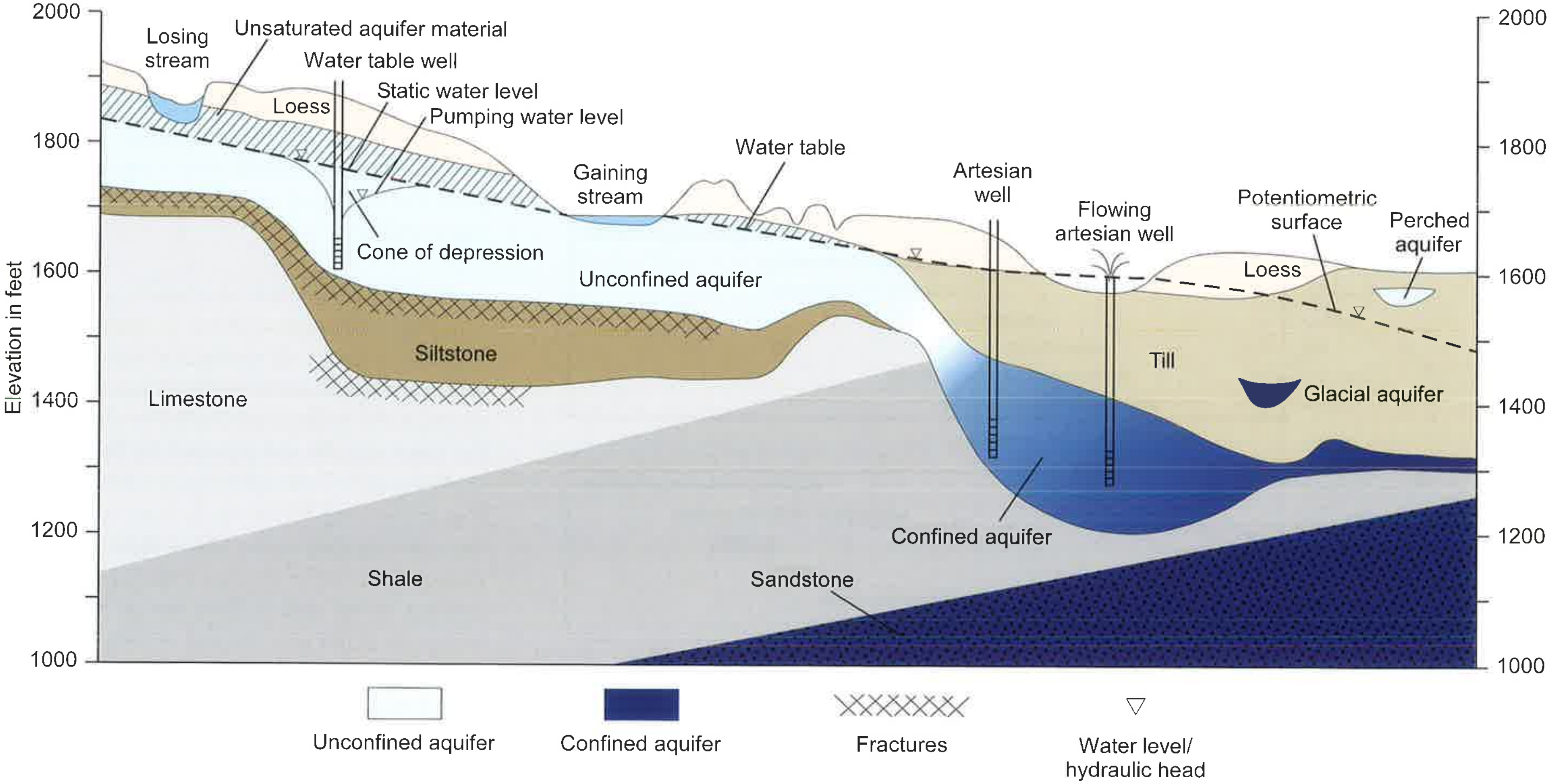


*Figure 10. Idealized cross section of a geologic setting common to Nebraska showing basic hydrogeologic concepts.*

### *Response of an aquifer to pumping*

Under average natural conditions, a groundwater flow system is in balance. The average amount of water recharged to the aquifer equals the average amount of water discharged. The volume of groundwater in the aquifer, known as storage, generally does not change (Fig. 11). When groundwater is pumped from a well, however, this balance is disrupted, the natural flow paths around the well change, and the water table declines. Water is initially supplied to the well from a reduction in aquifer storage. This period of rapid drawdown of the water table is known as the aquifer mining phase (Fig. 11). The mining phase may last from a few hours to tens of years, depending on the local hydrogeology. If the well continues to pump at the same rate, the water table around the well will eventually stabilize, and there will be no further reductions to aquifer storage. The water supplying the well must come from another source, either an increase in recharge (e.g. increased seepage into the aquifer from a stream), or a decrease in discharge (e.g. reduced discharge of groundwater into a wetland). This period of time is known as the surface water depletion phase (Fig. 11). Wells in shallow, unconfined aquifers near streams reach this phase quickly, whereas wells in deep, confined aquifers located far away from streams reach this phase only after many years of pumping. Though highly simplified, this concept of *hydrologic balance* can be applied at the scale of an individual well or the scale of an entire aquifer with many wells.

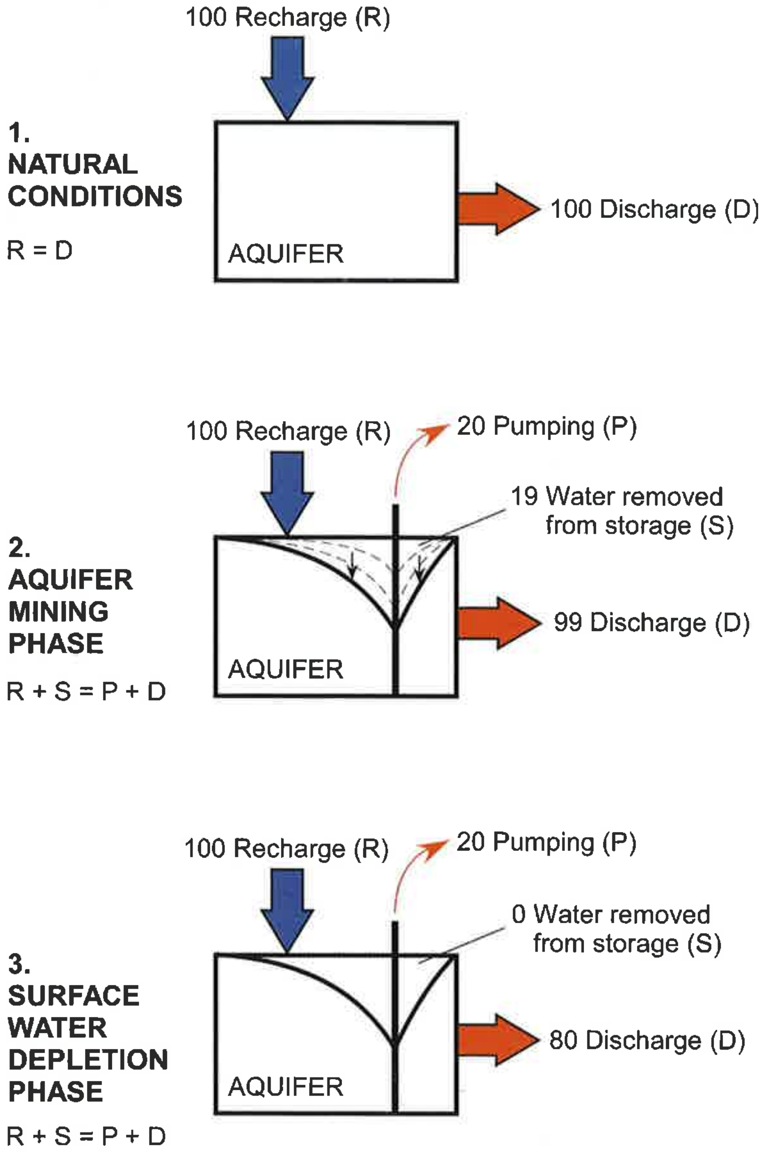
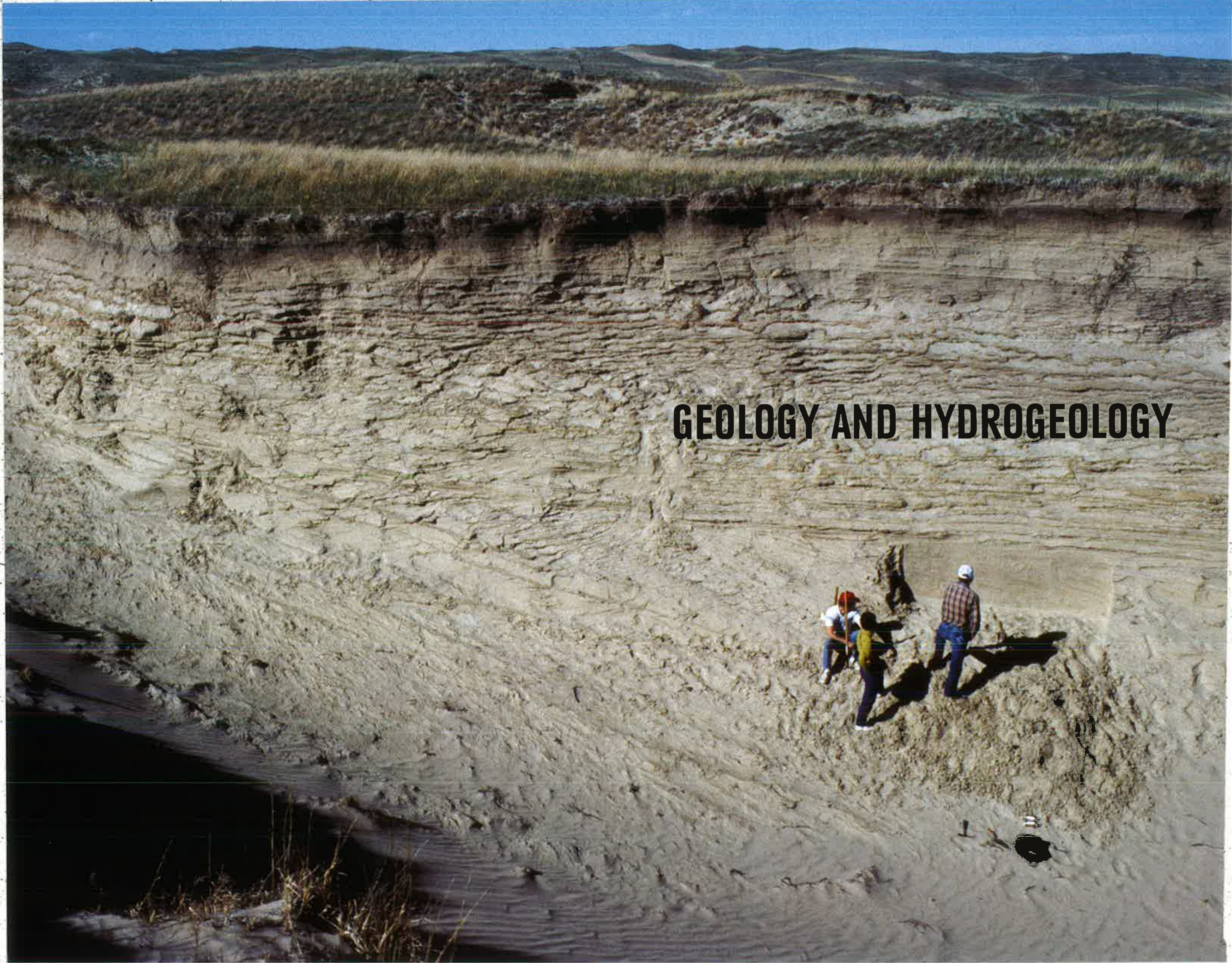


*Figure 11. Conceptualization of hydrologic balance as it pertains to groundwater pumping. Numbers show arbitrary values of recharge (blue) and discharge (red). During each phase, discharge plus pumping always equals recharge plus water removed from storage. 1) Natural conditions prior to any pumping. 2) Aquifer mining phase begins immediately upon pumping and lasts until reductions in discharge become significant. 3) Surface water depletion phase begins when new water removed from storage approaches zero and lasts until pumping stops.*



# GEOLOGY AND HYDROGEOLOGY

## SURFICIAL GEOLOGY AND TOPOGRAPHY

Nebraska's topography and surficial geology vary greatly from flat plains with lush soils to rugged, rocky escarpments. This variety resulted from erosion and deposition caused by wind, water, glacial ice and, to a small extent, human modification to the landscape. Each of these geologic processes and their associated deposits has created eight distinct topographic regions in Nebraska with different landforms, soils, and hydrogeologic properties (Fig. 12).

### *The Nebraska Sand Hills and smaller dune fields*

Perhaps the most widely known topographic region of Nebraska is the Sand Hills. The Sand Hills are the largest continuous area of sand dunes in North America. The sand dunes are currently mostly vegetated and stable, but were active during drier times through much of the Quaternary Period, and as recently as about 700 years ago (Miao et. al. 2007). Smaller areas of dunes occur discontinuously throughout the state as far east as Stanton County. Sand dunes overlie primarily sandstones and siltstones of Oligocene and Miocene age, as well as Pliocene and Pleistocene sands and silts. Areas of dunes in Nebraska have high rates of *infiltration*, and in some locations water that seeps through the dunes directly *recharges* the High Plains aquifer.

### *Plains*

Plains are uplands with relatively low relief. Generally, plains are developed upon older sandstones, sands, and gravely sands that have been blanketed by a thick layer of *loess* (wind-blown silt) or by *eolian* sand. In Nebraska, loess is sourced primarily from dust created by impacting sand grains in the Sand Hills, and from dust deflated from rivers at times of low flow. Soils formed in loess are generally very fertile, and allow moderate infiltration of precipitation.

### *Dissected plains*

Dissected plains have *sediments* and soils similar to the plains. These regions are dissected by smaller tributaries of the major river systems, creating comparatively higher topographic relief, with sharp ridge crests and occasional large, flat-topped mesas and buttes. Generally, the soils of the dissected plains east of the Panhandle are formed in loess and are moderately fertile. Dissected plains in the Panhandle are eroded into Oligocene and Miocene sandstones. Although infiltration can be moderate in loess soils, runoff is high due to the steep slopes and fine grained sediments.

### *Rolling hills*

The region of rolling hills in eastern Nebraska was glaciated from about 2.6 million to no later than 300,000 years ago. When the glaciers melted, they deposited a poorly sorted mixture of gravel, sand, silt, and clay known as *till*. The region was subsequently shaped by flowing meltwater and by more recent stream erosion creating a landscape of rounded, rolling hills and valleys. During the Quaternary Period, the region was blanketed by layers of loess of variable thicknesses. Due to the fine nature of sediments in this region, runoff is extremely high with little or no infiltration of surface water. Rolling hills in unglaciated northwestern Nebraska consist of deeply eroded Cretaceous bedrock hills with compact and clayey soils with low infiltration.


Steve Ress, Water Center, UNL

*Retired UNL hydrogeologist Jim Goeke discusses test hole cuttings with crew members.*

### *Major stream valleys*

Valleys of the major river systems in Nebraska are areas of relatively low relief having surface soils that are dominated by fine to coarse sands with moderate soil fertility. Many of the major stream valleys have large quantities of groundwater within a few feet to a few tens of feet beneath the surface, making these places prime for irrigated farmland. As a result areas along the Platte River have the highest density of irrigation wells in the state. However, the coarse sediments and shallow *water tables* allow for rapid infiltration, putting these areas at high risk for contamination from nitrates, farm runoff, and chemical spills. Areas near the Platte River where the water table is near the surface

*Geologists studying internal architecture of a sand dune in the central Sand Hills. Photo credit: Jim Swinehart, Conservation and Survey Division, UNL.*

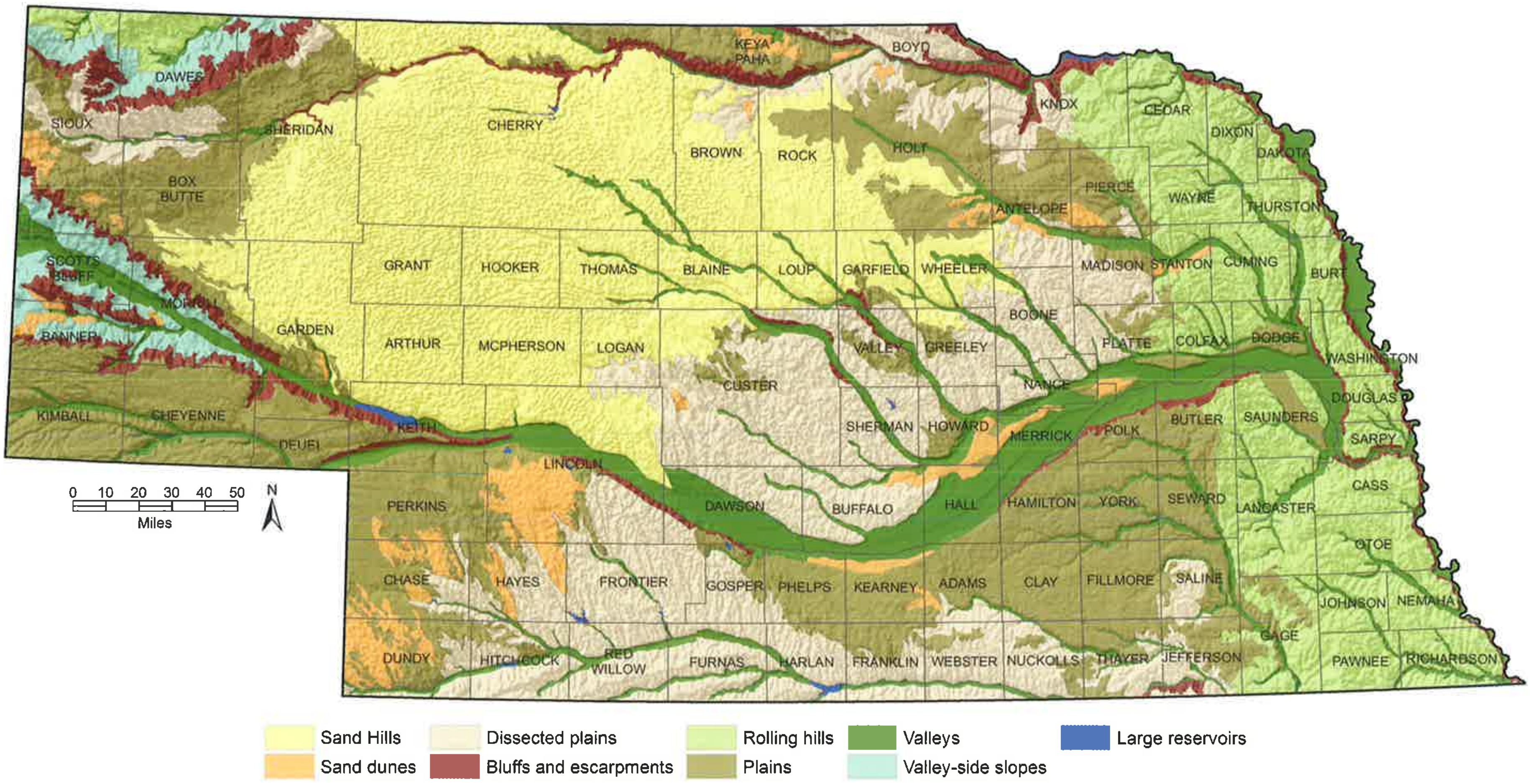


*Figure 12. Topographic regions of Nebraska.*

and *evapotranspiration* is high have significant evaporative salt concentrations in the surface soils.

### *Bluffs and escarpments*

Bluffs and escarpments include the extremely steep slopes adjoining the major river valleys throughout the state. Bluffs and escarpments in western and northern Nebraska are generally formed in sandstone, shale or limestone bedrock. Bluffs elsewhere in the state are eroded into loess or till. Runoff in these areas is extremely high with little or no infiltration. Some areas are used for livestock grazing; however agricultural use is generally limited due to the steep slopes.

### *Valley side slopes*

Valley side slopes are areas of moderate to steep slopes between the bluffs and escarpments and the low relief valleys. Valley side slopes are present along river valleys in the Panhandle. These regions are eroded bedrock and abandoned stream terraces that have in some places been blanketed by loess. Runoff in these regions is extremely high, and agricultural use is limited.

### *Large reservoirs*

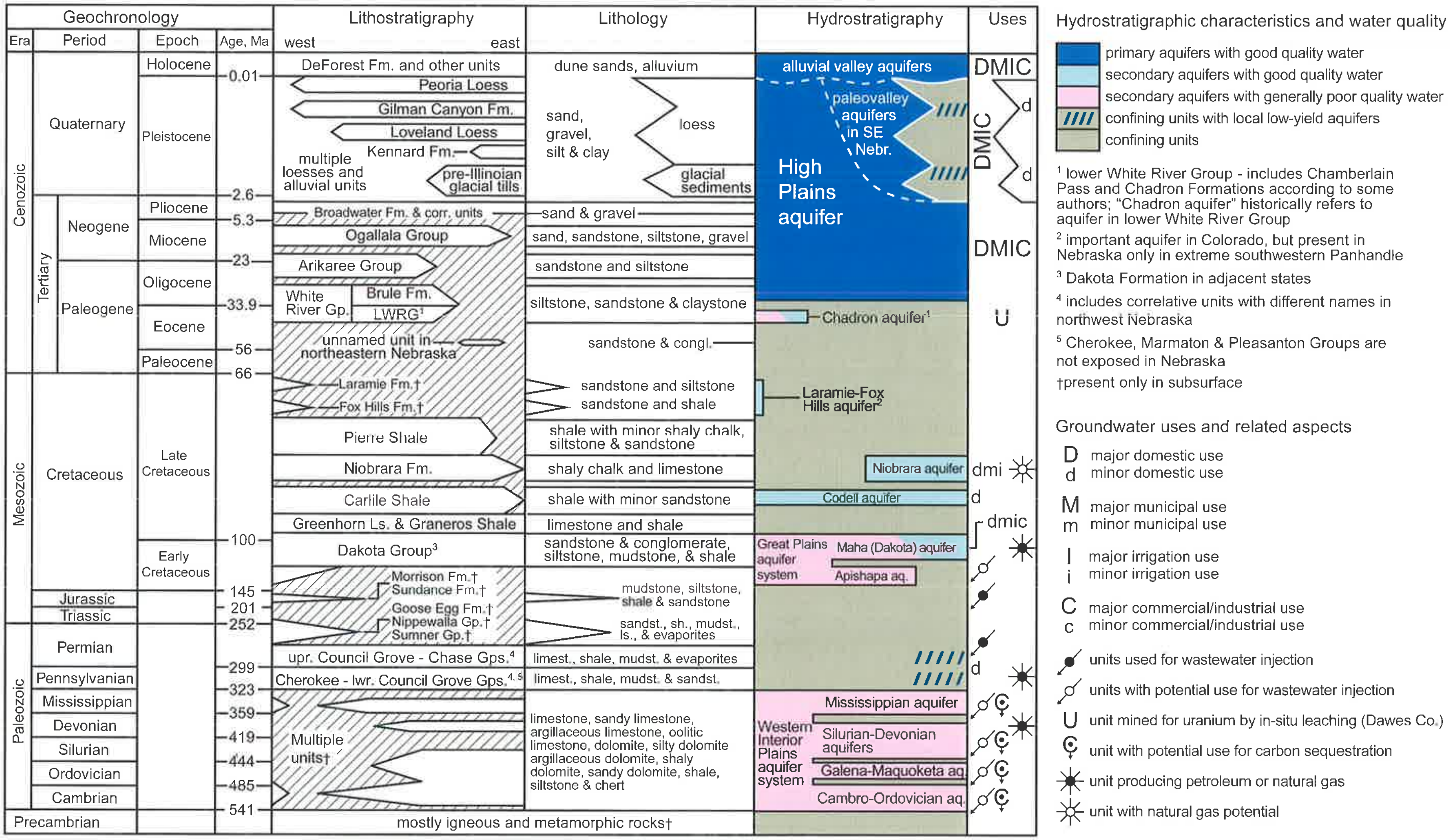
Throughout Nebraska there are a number of large reservoirs, and to a lesser extent canal systems that were built for flood control, irrigation, power generation and recreation. Although they cover only a small fraction of the state's area, reservoirs and canals have a large impact on regional groundwater levels. Water seeping out of them has artificially raised the water table by as much as 70 feet in some areas (Fig. 5).

## GEOLOGY AND AQUIFERS

Nebraska's groundwater wealth is a product of its unique geological history. Over the past 541 million years, layer upon layer of sediment was deposited by the repeated advances and retreats of shallow seas, the flows of rivers and streams, and the actions of glaciers and wind. Periods of deposition were separated by millions of years of non-deposition or erosion, resulting in gaps in the geologic record known as *unconformities*. The layers, therefore, are separated in time but not by vertical distance (Fig. 13). Built upon a basement of older, dense, crystalline *igneous* and *metamorphic* rocks, these *sedimentary* strata range in thickness from 10,000 feet in the southwestern corner of the Panhandle to about 500 feet in the southeastern corner of Nebraska. The layers exhibit a gentle downward slope toward the west such that if one could travel from eastern Nebraska to the eastern border of the Panhandle along the top of bedrock, increasingly younger bedrock units would be encountered (Figs. 14, 15). Some older rocks are interrupted by zones of faults and steeply dipping strata with as much as 2,500 feet of offset, but these features have little or no expression on the modern land surface (Fig. 14). Many of these strata are discontinuous, distributed in patches, or completely absent in some areas. The availability of groundwater in Nebraska is directly related to the variability in these strata and the hydrogeologic characteristics of different rock and sediment types (Figs. 13–15).


*Jim Swinehart, Conservation and Survey Division, UNL*

*Conservation and Survey Division's test hole drilling rig overlooking Sand Hills and bluffs above Niobrara River valley.*



[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

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

*Figure 13. Generalized geologic and hydrostratigraphic framework of Nebraska.*

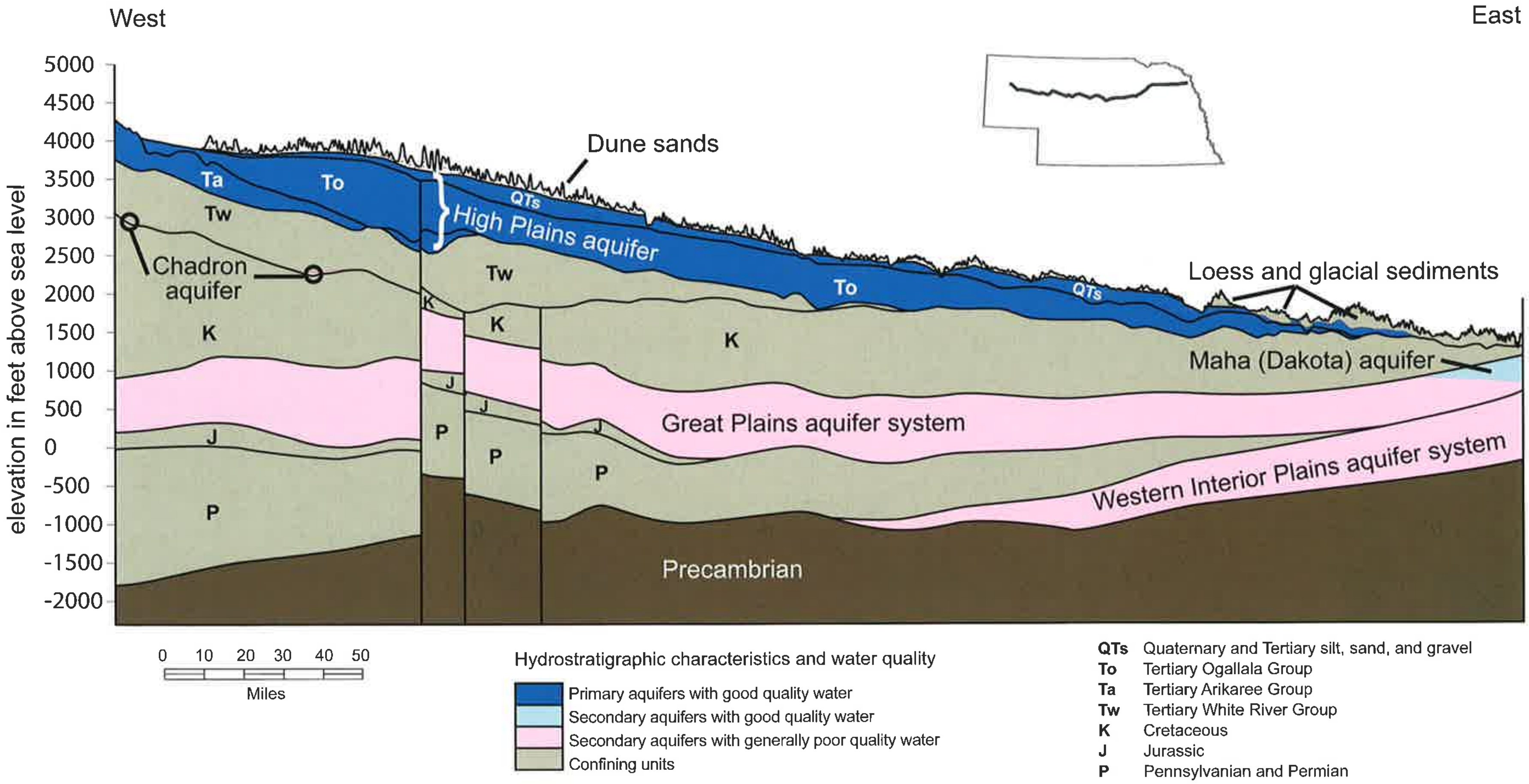


*Figure 14. West-east cross section through Nebraska showing principal aquifers and confining units. Inset map shows line of cross section. Colors correspond to hydrostratigraphic characteristics and water quality described in Figure 13.*

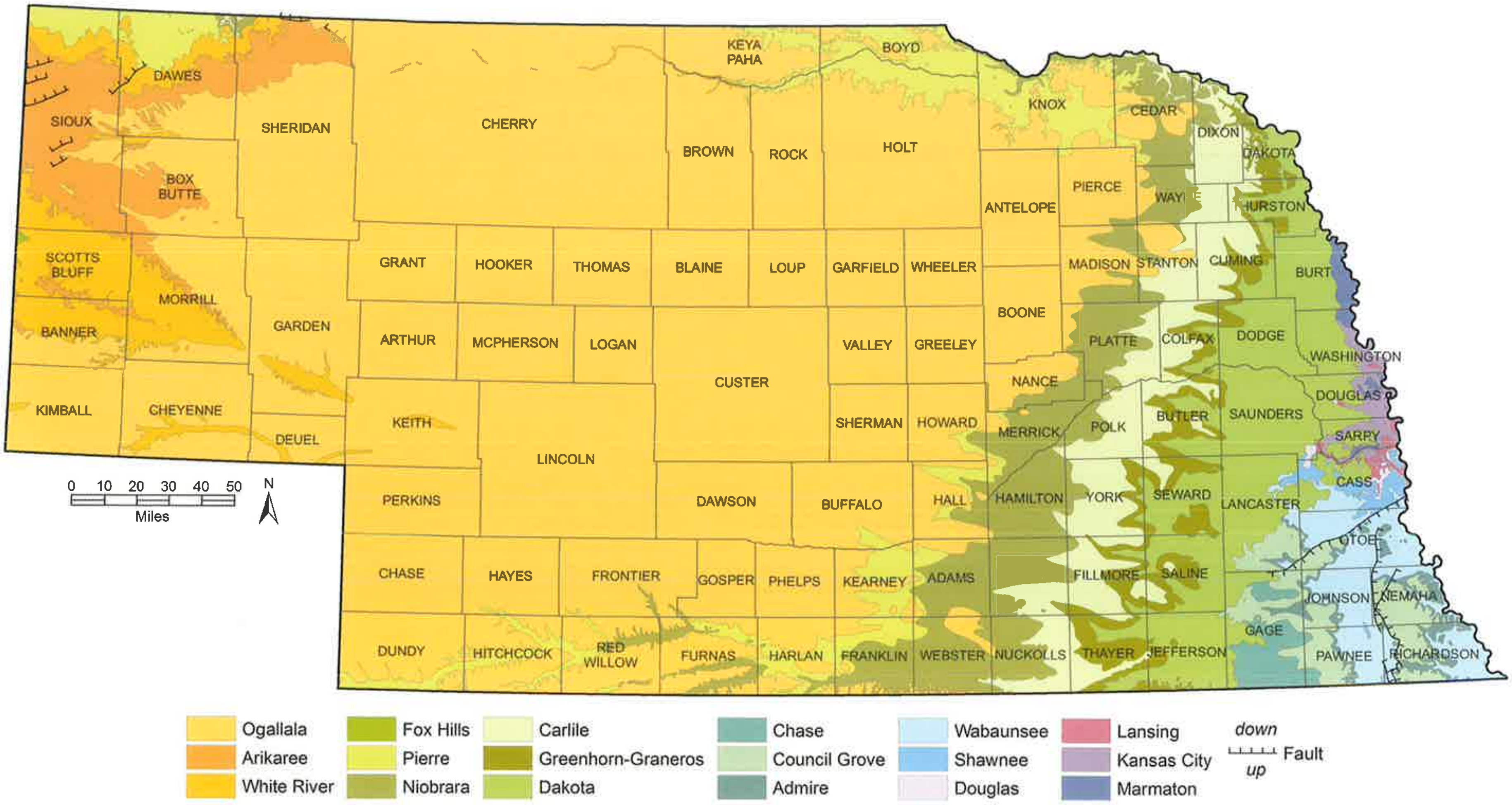


*Figure 15. Geologic bedrock map of Nebraska (modified after Burchett, 1986). Pennsylvanian System includes Marmaton, Kansas City, Lansing, Douglas, Shawnee, Wabaunsee, Admire, and lower Council Grove Groups. Permian System includes upper Council Grove and Chase Groups. Cretaceous System includes Dakota Group, Greenhorn Limestone, Graneros Shale, Carlile Shale, Niobrara Formation, Pierre Shale, and Fox Hills Formation. Tertiary System includes White River, Arikaree, and Ogallala Groups.*

### *Paleozoic aquifers*

Many different layers of rock were formed in Nebraska during the 218 million years from the beginning of the Cambrian to the end of the Mississippian. These rocks formed primarily in shallow seas and include limestones, dolomites, sandstones, siltstones, shales, and cherts. This entire package of rock is grouped into the Western Interior Plains aquifer system (Miller and Appel, 1997), which underlies much of the state (Fig. 16). This *aquifer* system is an important source of water in adjacent states to the east, where it has been subdivided into separate aquifers (Prior et al., 2003). In Nebraska, only a few water wells have been completed into it near Omaha (Carlson and Sibray, 1992). The uppermost part of this aquifer is at least 500 feet beneath the land surface and contains primarily poor quality water.

Shallow seaways waxed and waned repetitively throughout the Pennsylvanian and Permian Periods. This waxing and waning is recorded by cycles of sandstone, shale, limestone, mudstone, and lesser amounts of other sedimentary rocks. These rocks typically have low permeability and serve as *confining units.* Some low-yield wells, however, are completed into weathered, fractured limestones beneath the top of the bedrock surface in southeast Nebraska. Elsewhere in Nebraska, porous zones in these rocks may contain highly mineralized water, oil, or natural gas.

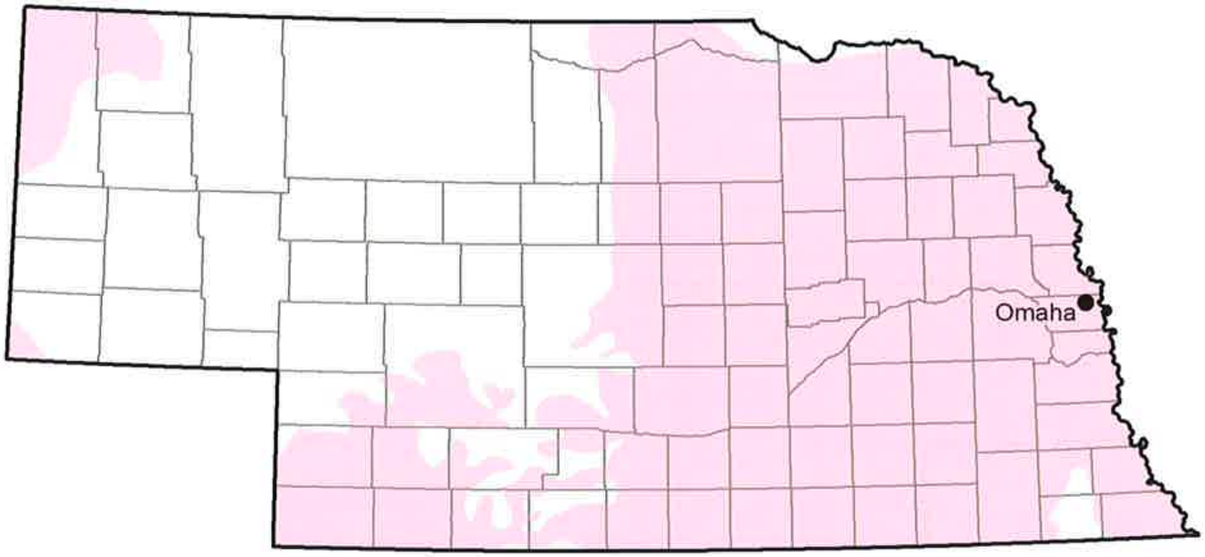


*Figure 16. Areas of Nebraska underlain by the Western Interior Plains aquifer system.*

### *Cretaceous aquifers*

The Cretaceous Period was a time of warm global conditions in which shallow seas developed across central North America. *Transgression* of the seas into Nebraska during the Early Cretaceous brought widespread deposition of sands, silts, and clays on the coastal plain and in river valleys and near-shore environments. These deposits, now part of the Dakota Group, include sandstones that are important secondary aquifers in Nebraska. These aquifers, part of the Great Plains aquifer system (GPAS), exist under most of Nebraska except for the southeast and extreme east (Fig. 17). The GPAS consists of two main aquifers separated by a confining unit. The Apishapa aquifer is the lowermost aquifer unit. It occurs only in west-central and western Nebraska and contains mostly poor quality water or oil and gas (Miller and Appel, 1997). The Maha aquifer, commonly known as the Dakota aquifer in Nebraska, is the upper aquifer unit. Water quality in the Dakota aquifer is highly variable, but fresh water exists locally in eastern Nebraska where precipitation *recharges* the aquifer in the shallow subsurface (Lawton et al., 1984). The Dakota aquifer is an important secondary aquifer for municipal, domestic, and irrigation uses in parts of eastern Nebraska. This aquifer is also an important source of water for irrigation wells in parts of northeast Nebraska, even though it is confined by as much as 1000 feet of overlying strata. The Dakota aquifer is not widely used as a source of water in central and western Nebraska because it is deeply buried by overlying strata, including units of the High Plains aquifer, and because the waters are generally too salty for most uses (Miller and Appel, 1997).

Shallow marine environments existed across Nebraska for the remainder of the Cretaceous, leading to the development of a thick succession of shales, limestones, and chalks. These rocks are primarily confining units, but they include secondary aquifers in some locations (Fig. 18). The Niobrara aquifer of northeast Nebraska is developed in areas where the chalks are weathered, fractured, and occur near the surface. The Codell aquifer comprises isolated sandstones within the Carlile Shale and is a secondary aquifer in parts of northeast Nebraska where the High Plains aquifer is absent (Souders, 1976). The Laramie-Fox Hills aquifer is an important aquifer in Colorado, but it underlies only the extreme southwestern Panhandle and it is not known to be a source for any wells in Nebraska.

### *Chadron aquifer*

Underlying the modern landscape of the Nebraska Panhandle is a buried former landscape of rolling uplands and valleys developed by erosion of Cretaceous strata. It was into the valleys of this landscape that sands, gravels, and muds were deposited in streams, lakes, and wetlands during the Eocene Epoch. These deposits form the lower White River Group (Fig. 19). Water-bearing sandstones and conglomerates within the *paleovalleys* are known historically as the Chadron aquifer. This aquifer is buried by as much as 400 feet of overlying confining strata, and reportedly supplies several flowing *artesian* wells (Wenzel et al., 1946). Due to its rather poor water quality,

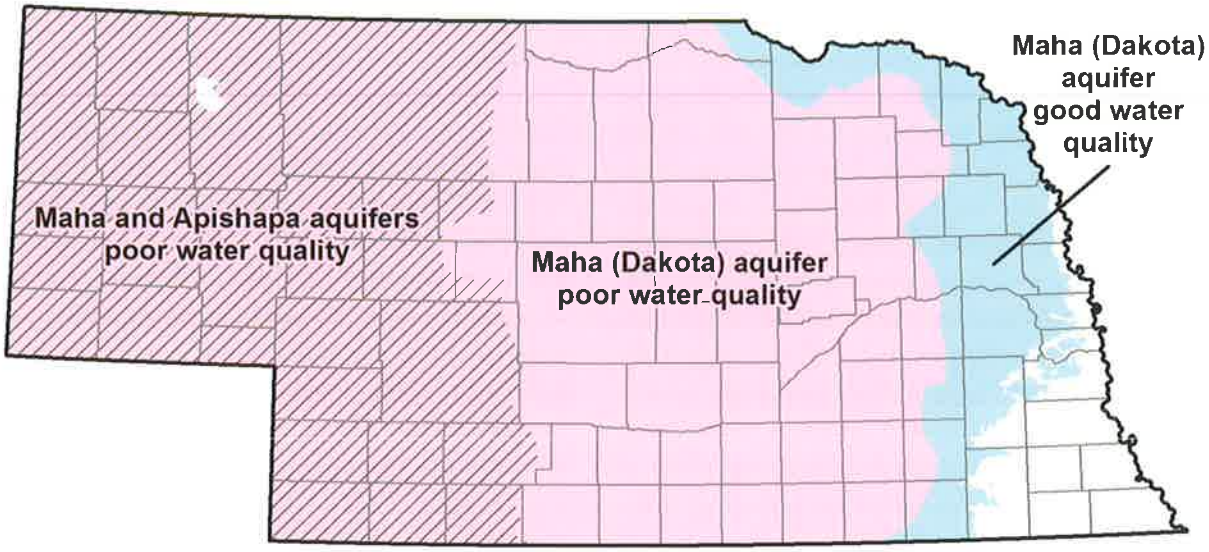


*Figure 17. Areas of Nebraska underlain by the Great Plains aquifer system, showing sub-units and generalized water quality. See also Figure 13.*

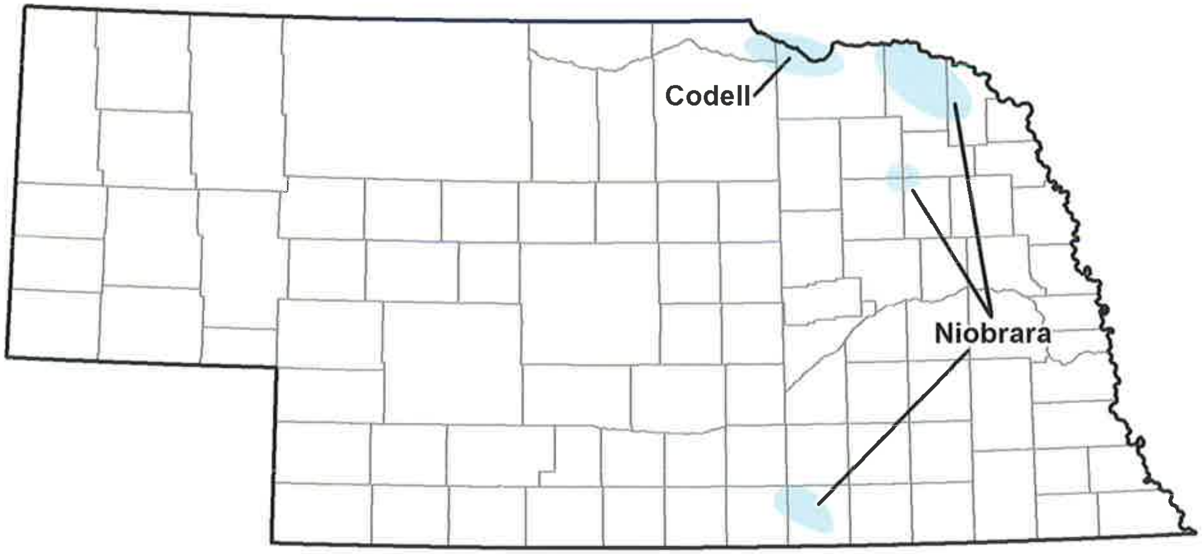
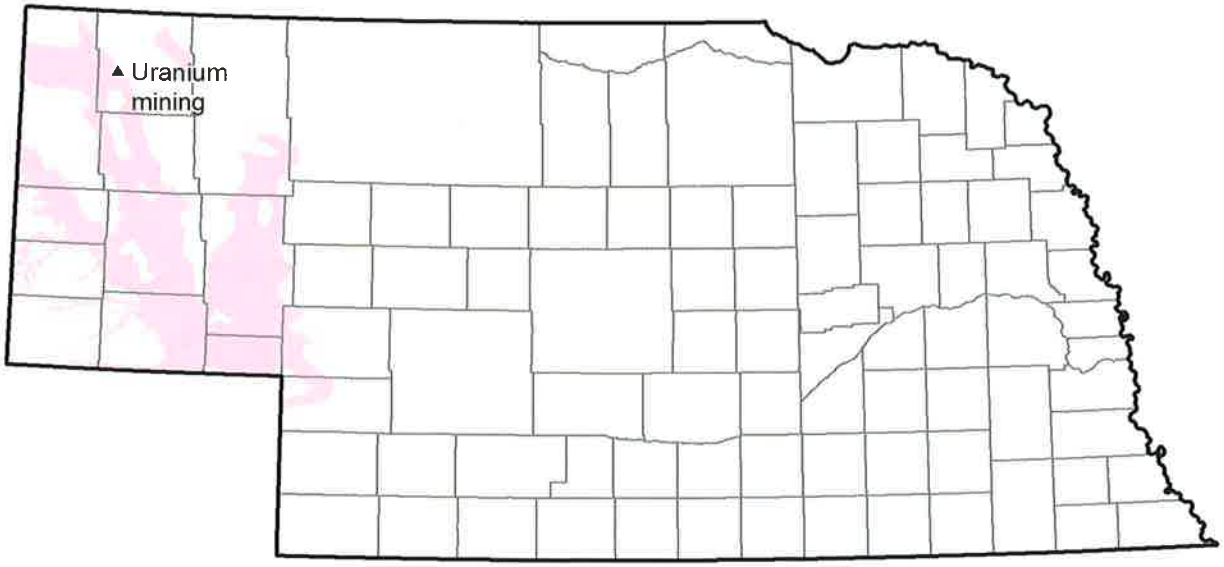


*Figure 18. Generalized areas where Niobrara and Codell aquifers are used for irrigation and municipal water supplies.*



*Figures 19. Areas of Nebraska underlain by the Chadron aquifer.*

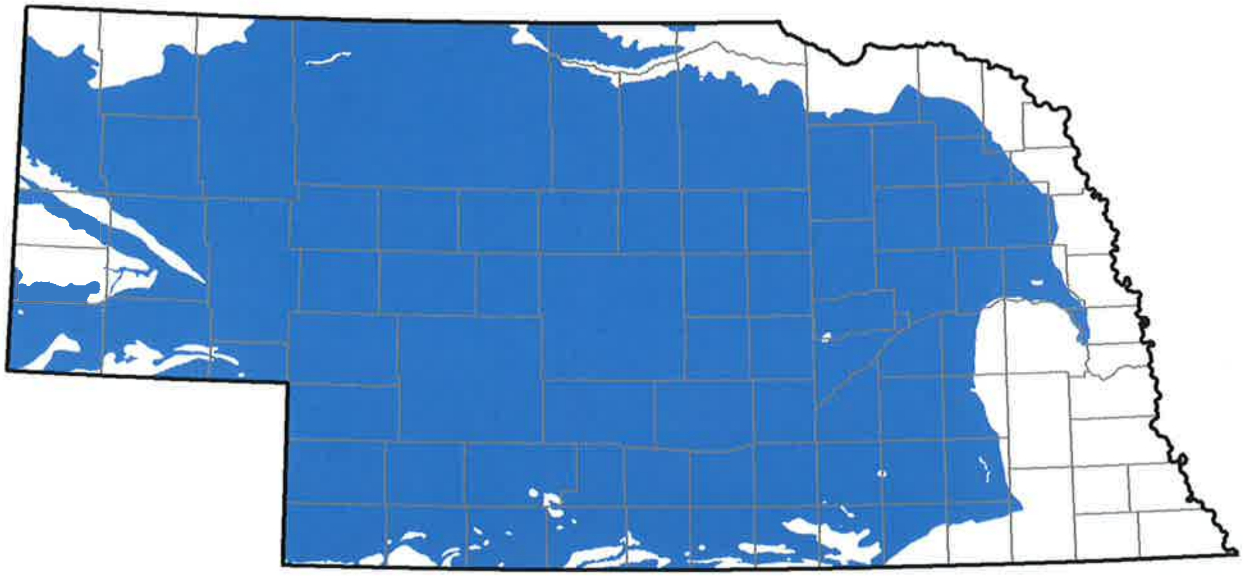


*Figure 20. Areas of Nebraska underlain by the High Plains aquifer.*

the Chadron aquifer serves only as a secondary aquifer where the High Plains aquifer is thin or absent (DeGraw, 1969). Uranium is mined from the Chadron aquifer in western Dawes County.

### *High Plains aquifer*

The most widely used and best-known aquifer in Nebraska is the High Plains aquifer (HPA). It underlies roughly 84 percent of the state (Fig. 20). Although it is often referred to as the "Ogallala aquifer", the HPA actually includes a group of aquifers of different ages stacked into one vertically continuous regional aquifer system (Figs. 13, 15). It consists of multiple layers of sand, gravel, and sandstone and lesser amounts of silt, siltstone, and clay. The units of the HPA are, from oldest to youngest, the upper parts of the Brule Formation, the Arikaree Group, Ogallala Group, Broadwater Formation, and multiple younger, unconsolidated sand and gravel units ranging in age from 2.6 million to 10,000 years old (Quaternary). The Brule Formation and Arikaree Group consist largely of air fall volcanic debris carried to Nebraska by westward winds from eruptions in the Rocky Mountains and farther west. The Brule Formation is included in the HPA only where it is present in the shallow subsurface and is fractured and weathered, or where isolated sandstone bodies exist within it. The Arikaree Group includes numerous beds of sandstone and it is an important part of the HPA in western Nebraska. The Ogallala Group is the principal unit of the HPA under most of Nebraska. It consists primarily of sand, sandstone, siltstone, and gravel that were deposited by rivers in ancient valleys and broad alluvial plains. The Broadwater

Formation and unconsolidated sands and gravels compose the uppermost portion of the HPA in central and eastern Nebraska.

The HPA averages about 600 feet in thickness under the Sand Hills, but can be as much as 1000 feet thick. Outside of the Sand Hills the HPA is generally between 100 and 400 feet thick. Its thickness and *permeability* make it one of the largest aquifers in the U.S., providing water to more than 130,000 high capacity wells.

### *Paleovalley aquifers*

Broad alluvial valleys, similar to those on the modern landscape, formed and filled with *alluvium* during the Pliocene and early Pleistocene Epochs. These valleys were in different places than the valleys on the landscape today, but they were filled with abundant sand and gravel deposits with excellent aquifer properties. The ancient valleys, or *paleovalleys*, were later buried by younger deposits. Those buried by *till* are now completely hidden from view below a hilly, dissected landscape. We know of their existence only because of the numerous wells and test holes that have penetrated them. The so-called Todd Valley, a former course of the Platte River (Condra, 1903; Lueninghoener, 1947), can still be seen on the modern landscape because it is younger than the other paleovalleys and was blanketed not by till, but by a thin cover of *loess* that preserved the ancient valley morphology. Paleovalley aquifers are the primary sources of water in parts of eastern Nebraska. At least seven eastward- and southeastward-trending paleovalley aquifers have been found (Fig. 21).

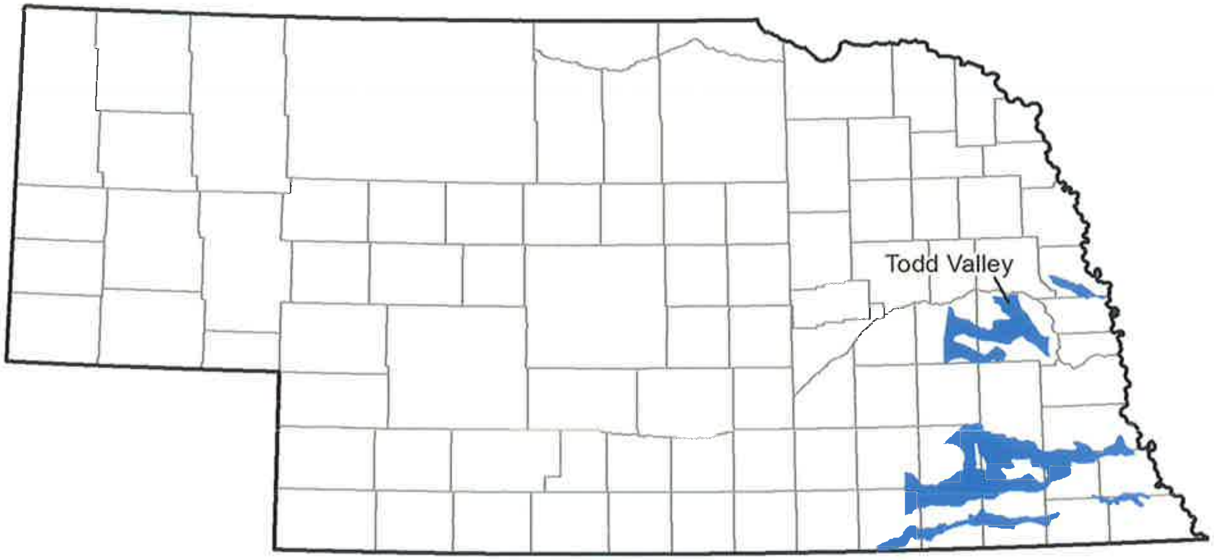


*Figure 21. Areas of Nebraska underlain by paleovalley aquifers.*

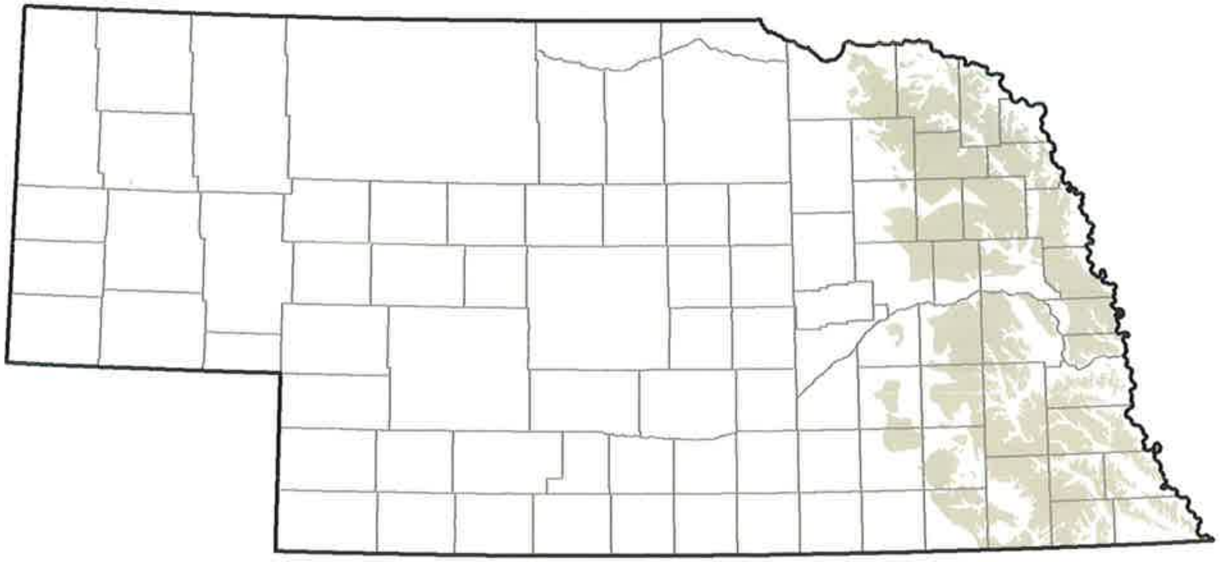


*Figure 22. Areas of Nebraska underlain by glacial deposits. Localized aquifers are contained within these deposits, but are not shown because they have not been mapped in detail.*


Conservation and Survey Division, UNL

*Geologist studying an exposure of the Ogallala Group on the shores of Lake McConaughy.*

Most are only a few miles wide, but they can be as much as 70 miles long. Most are *confined* aquifers, but some may be unconfined or partially confined where the overlying sedimentary cover is thin (Souders, 1967).

### Glacial aquifers

Glaciers repeatedly advanced and retreated across the eastern one-fifth of Nebraska during the early and middle parts of the Pleistocene Epoch (Fig. 22). The glaciers left behind a poorly sorted mixture of clay, silt, sand, and gravel known as *till.* Tills typically have low permeabilities and therefore are not usually suitable as aquifers. In many areas underlain by till, groundwater is difficult to access. It may be impossible to install a suitable water well in areas where till directly overlies a low-permeability bedrock unit. Nonetheless, some sand and gravel was deposited by flowing water within, beneath, or in front of the glaciers, forming widely separated and discontinuous local aquifers. Typically these aquifers support only small-scale withdrawals for domestic and livestock uses. Some are *perched aquifers* that lie above the regional water table and may, therefore, be more susceptible to contamination or drought. Only a few of these aquifers are productive enough to support high-capacity municipal and irrigation wells.

### Alluvial valley aquifers

The valleys of many modern streams in Nebraska contain unconsolidated sediments, or alluvium, deposited during the Quaternary Period. Multiple episodes of activation and abandonment of stream channels resulted in broad deposits of sand and gravel underneath most of the state's major river valleys (Fig. 23). The high permeability of these deposits makes them excellent aquifers. Most alluvial valley aquifers are *unconfined* and have shallow water tables, which make them some of the most accessible aquifers in the state. Unfortunately, they also make the aquifers highly vulnerable to contamination.

In most of Nebraska, alluvial valley aquifers are included by researchers as parts of the High Plains aquifer. In eastern Nebraska and in some river valleys along the boundaries of the state, such as the Niobrara and Republican, the alluvial valley aquifers are considered separate and distinct from the High Plains aquifer because the two are not physically connected.

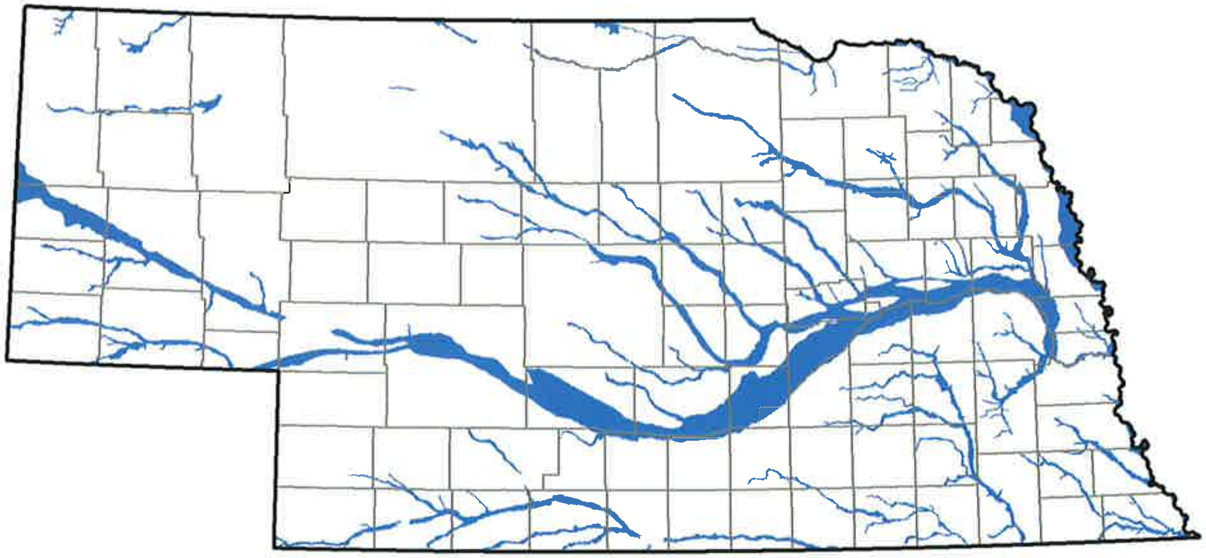
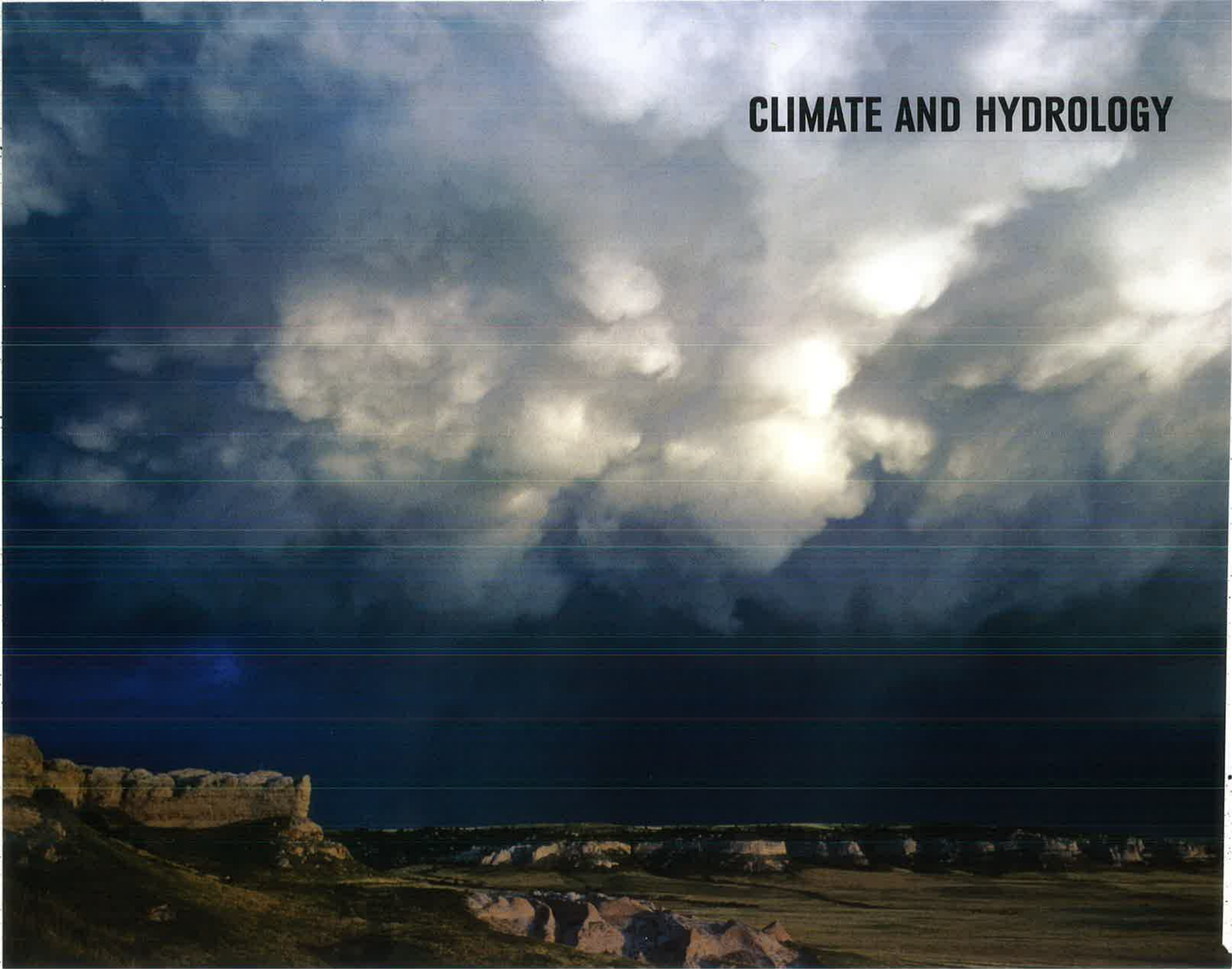


*Figure 23. Areas of Nebraska underlain by alluvial aquifers.*

# CLIMATE AND HYDROLOGY



## PRECIPITATION

Whether it is rain, snow, sleet, or hail, precipitation is perhaps the most evident aspect of the water cycle in Nebraska. It is the ultimate source of water in our streams and *aquifers*, so its variability from place to place and over time is of chief concern. Average annual precipitation ranges from more than 30 inches in the southeast to less than 12 inches in the Panhandle (Fig. 24). The lack of abundant precipitation across most of the state significantly influences the need for irrigation in agriculture. In the sub-humid east precipitation is often sufficient to account for most of the water needs of crops during the growing season, and irrigation is used to supplement precipitation especially during dry years. In the semi-arid west, however, crops such as corn and soybeans require irrigation nearly every year.

Precipitation is also highly variable over time. Figure 25 shows the average annual precipitation in Nebraska from 1960 to 2010. Nebraska has experienced multiple wet and dry periods over the years. Indeed, there are very few years during which the state receives average precipitation, which was 23.5 inches for the five decades shown.

We must also keep in mind that river basins and aquifers don't correspond to state boundaries. Not all of the surface water and groundwater in Nebraska, therefore, originates within the state. Some of this water starts as precipitation that falls in the upstream reaches of the Platte, Niobrara, and Republican basins in parts of Wyoming, Colorado, South Dakota, and Kansas. The variability of precipitation in these areas affects the flow of water into Nebraska.

*Conservation and Survey Division, UNL*

*The Platte River in eastern Nebraska during a drought, July, 2012.*

*Thunderstorm looms over bluffs in western Nebraska.*
*Photo credit: Jim Swinehart, Conservation and Survey Division, UNL*

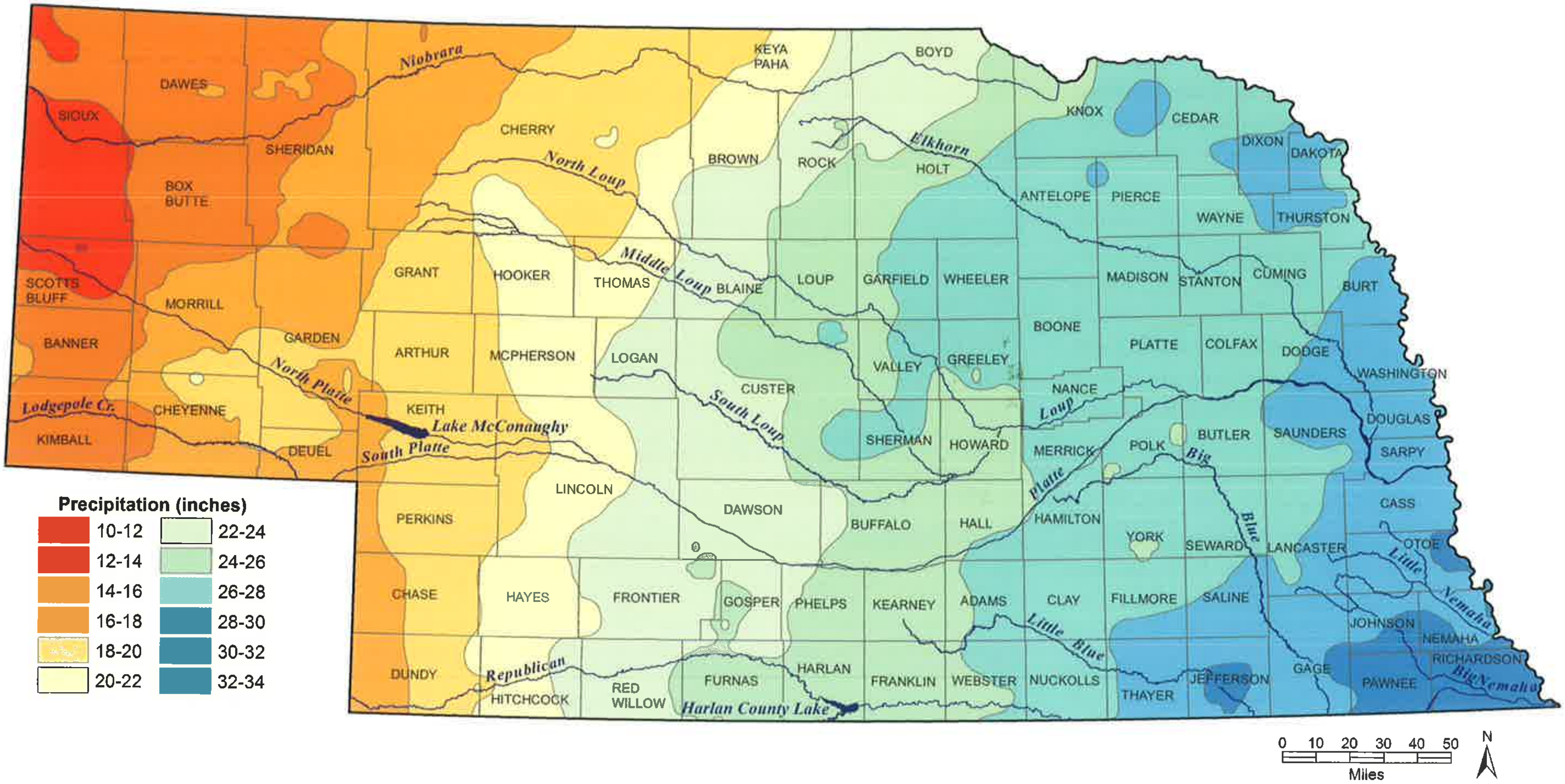


*Figure 24. Average annual precipitation based on data from 2000 to 2009 (modified from Szilagyi and Jozsa, 2012).*

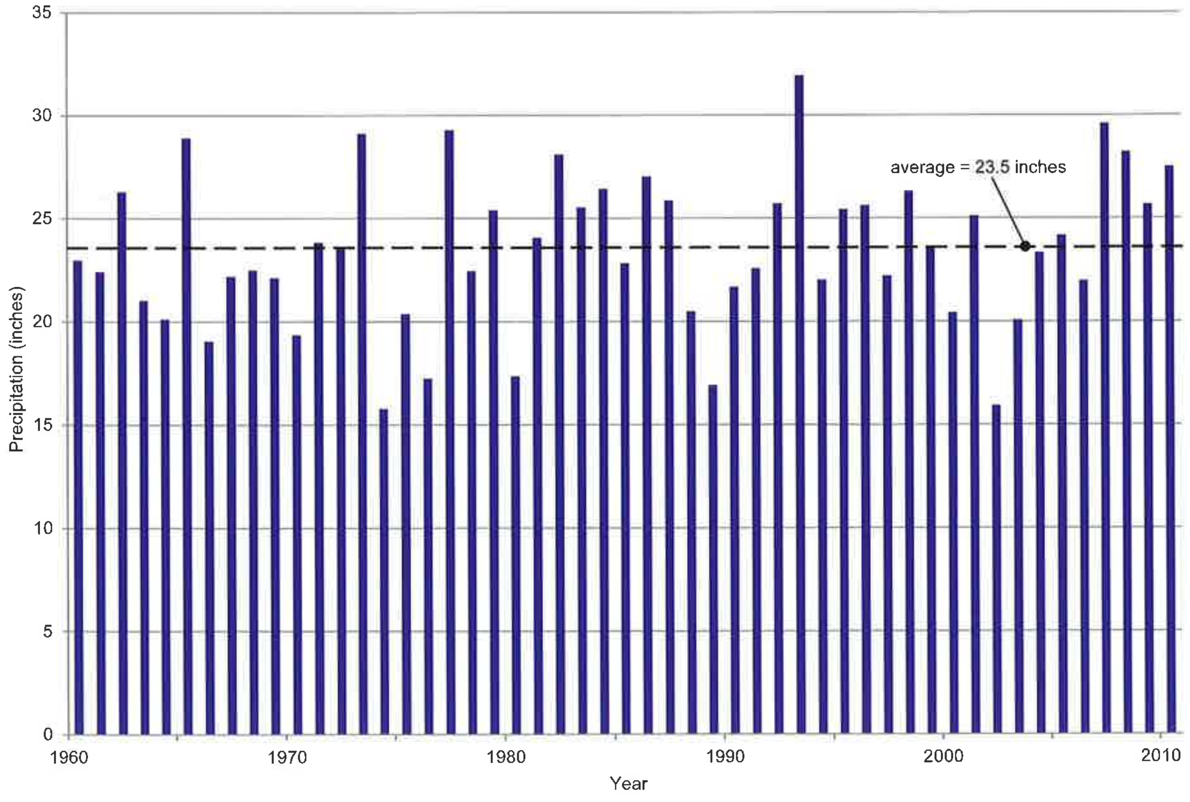


*Figure 25. Average annual statewide precipitation from 1960 to 2010.*

## EVAPOTRANSPIRATION

While precipitation is a visible component of the hydrologic cycle, *evapotranspiration* (ET) goes mostly unnoticed to the casual observer. Scientists, however, can monitor ET using a variety of advanced techniques. ET is dependent on temperature, humidity, wind, and soil moisture. As humidity exhibits a generally uniform, declining east-to-west gradient in Nebraska, so too does ET (Fig. 26).

ET in Nebraska from 2000–2009 ranged from more than 25 inches in the east to between 10 and 20 inches in the Panhandle (Szilagyi and Josza, 2012). Locally, however, there are large differences due to land use and cover. Large water bodies display the largest ET rates, around 40 inches annually. The open water surfaces of wide rivers such as the Platte, Loups, Elkhorn, and Republican, and the shallow *water tables* in their valleys, result in ET rates of more than 30 inches per year. Areas of intensive irrigation also have ET values near 30 inches per year. The smallest rates of ET are in the driest regions of Nebraska and in urban areas, where large impervious concrete and asphalt surfaces enhance surface runoff. The eastern outline of the Sand Hills is clearly visible in Figure 26, as well as the sandy areas between the Loup and the Platte rivers. Due to their high porosities, sandy soils favor deep *infiltration* of the water, often out of reach of the vegetation, thereby resulting in lower ET.

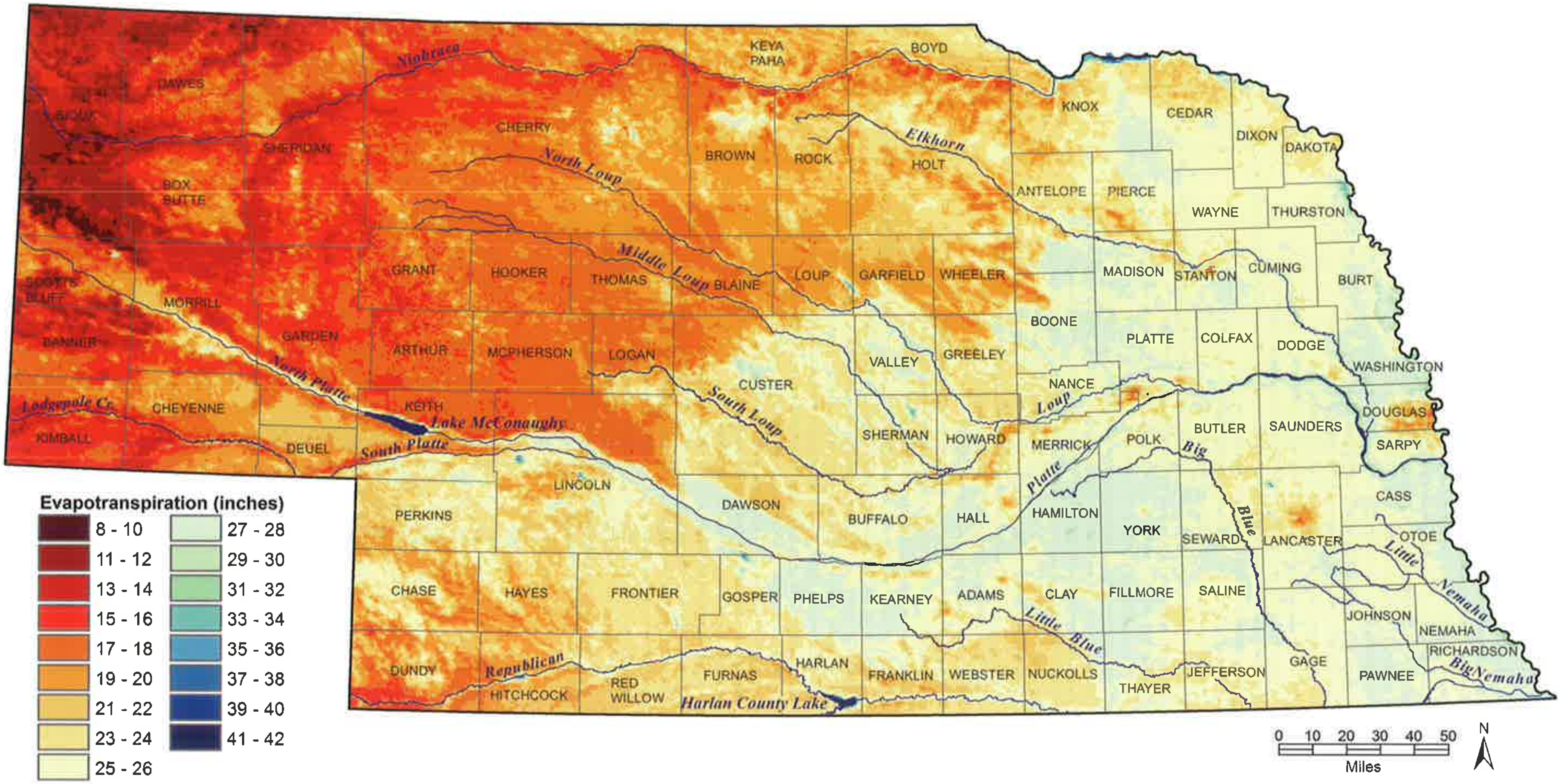


*Figure 26. Average annual evapotranspiration (ET) rates based on data from 2000 to 2009 (modified from Szilagyi and Jozsa, 2012).*

## RECHARGE

*Recharge* to groundwater in Nebraska also goes generally unnoticed, but its effects are readily evident in other parts of the hydrologic cycle. The water that is recharged to aquifers underlying the Sand Hills, for example, eventually *discharges* to steadily flowing, groundwater-fed rivers such as the North, Middle, and South Loups. Recharge, like precipitation, is variable in time and space. Average annual recharge rates are greater than 4 inches in parts of the central and east (Fig. 27). Recharge rates are negative in some areas such as the southwest and the Panhandle, indicating that evapotranspiration exceeds precipitation in those areas (Szilagyi and Jozsa. 2012). Locally, however, groundwater recharge tends to be highly influenced by variations in soil type and topography.

In addition to groundwater quantity, recharge is also an important factor in groundwater quality. Areas with high recharge rates are more susceptible to contamination because contaminants may be transmitted to the aquifer with little chance to degrade or be absorbed in the soils. Generally speaking, the faster the recharge rate of an aquifer, the more susceptible the aquifer is to contamination. Knowing the recharge rate at a specific location allows water managers to make informed decisions on how to manage water quality on a local level.


*Jim Swinehart, Conservation and Survey Division, UNL*

*"Old Growler", a vigorous spring near the headwater of a Sand Hills stream.*

## STREAM FLOW

Stream flow is a visually evident part of the hydrologic cycle. The rate and amount of precipitation has a substantial effect on stream flow, but since aquifers and streams exchange water in many areas of Nebraska, changes in groundwater levels can also have a direct effect on stream flow.

The rivers of Nebraska generally flow west to east. The major rivers within Nebraska are the Platte, Loup, Niobrara, Elkhorn, Big Blue, Little Blue, Republican, Big Nemaha, and Little Nemaha. Figure 28 compares the average stream flow in these rivers during the decades of 1960–1970 and 2000–2010. Of the twelve rivers compared, five show increased flows and seven show decreased flows. The greatest increases occurred in the Elkhorn River (~40%) and the Niobrara River (~10%). The greatest decreases occurred in the Republican River (~70%), the Little Blue River (~40%), and the North Platte River (~30%). Average precipitation over these decades was 22.8 inches in 1960–1970 and 23.4 inches in 2000–2010.

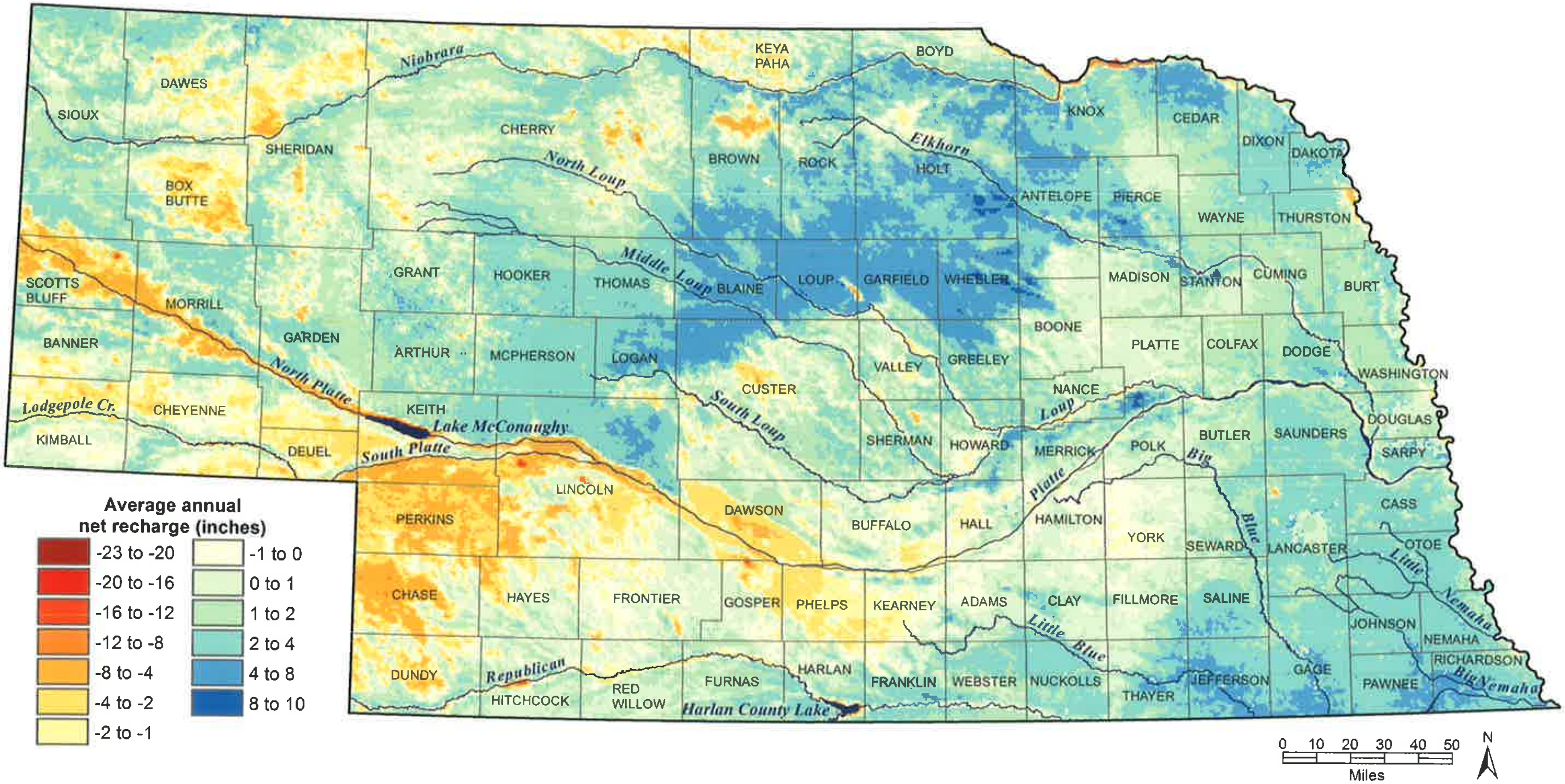


*Figure 27. Average annual net recharge to groundwater based on data from 2000 to 2009 (modified from Szilagyi and Jozsa, 2012). Negative values indicate that evapotranspiration is greater than precipitation.*

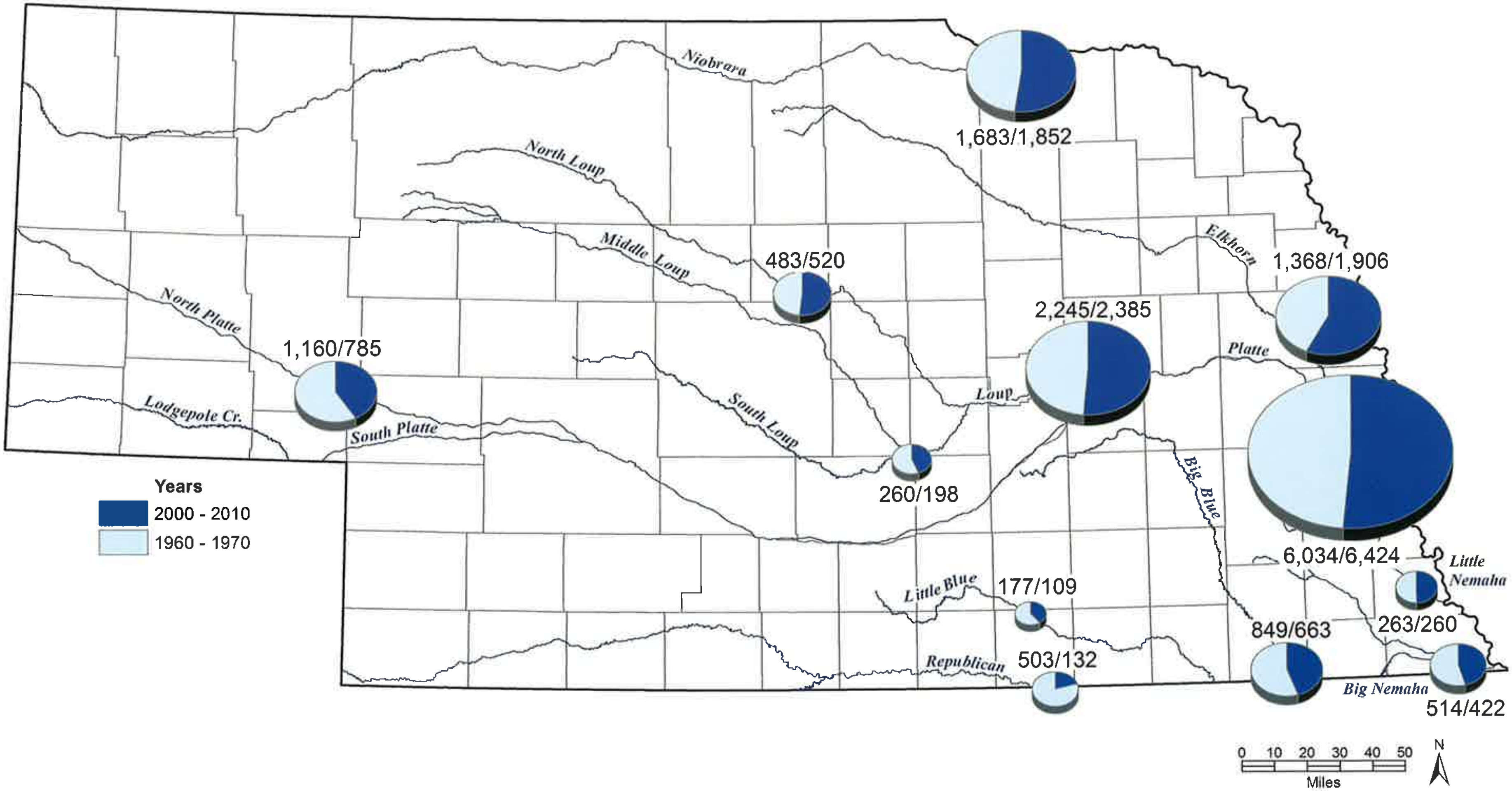


*Figure 28. Comparisons of average stream flows from 1960–1970 to stream flows from 2000–2010 for U.S.G.S. stream gauge sites where data exists for both periods. Sizes of circles and areas within circles are proportional to stream flow values, which are given as cubic feet per second (cfs).*

# GROUNDWATER QUANTITY

## ELEVATION OF THE WATER TABLE

The *water table* is not at all like the surface of a table. Rather, it is an undulating surface much like the land surface above it. It consists of highs, lows, and divides, and it intersects the land surface along the banks of streams, lakes, and in wetlands. Since groundwater is hidden from view below the land surface, the elevation of the water table must be measured from wells that have their screens placed near the upper part of the *aquifer*. Using a large number of these measurements from a single aquifer, hydrogeologists can draw lines connecting points of equal elevation, giving an approximation of the water table. Groundwater moves from high elevation to low elevation in three dimensions (both horizontally and vertically) creating a *hydraulic gradient*. A map of the water table (or *poteniometric surface*) is a two-dimensional representation of the horizontal hydraulic gradient that indicates the direction of flow.

The maps in this section were drawn and edited originally at a scale of roughly 1:500,000 and are not intended to be used to determine groundwater conditions at a local scale.

### *High Plains aquifer*

The map in Figure 29 shows the elevation of the water table in the High Plains aquifer. Generally, the elevation of the regional water table is a subdued expression of the overall surface elevation. Elevations of both the water table and the land surface are higher in the west, and lower in the east, thus in general both surface and groundwater flows from west to east. In some areas such as the Panhandle, the southwest, and in part of the Blue River basin, the High Plains aquifer exists mostly under *confined* conditions. The contours in these areas represent the elevation of the potentiometric surface.

In the northeastern part of the state (hatched area of Fig. 29) wells are screened in various geologic units depending on local conditions. The variable nature of wells in this area makes it difficult to produce a meaningful map of the water table or potentiometric surface, so this area was omitted. Similarly, wells in some river valleys are screened in deep, confined aquifers with potentiometric surfaces that are significantly different than the local water tables. These areas were also omitted from the map.

The water level contours on this map were drawn using data obtained from irrigation wells and monitoring wells measured in the spring of each year by researchers from the University of Nebraska–Lincoln, the Nebraska Natural Resource Districts, and the U.S. Geological Survey. The most recent measurement obtained over the last ten years was used for each well, with most wells having been measured within the last two years. Water level measurements for wells registered with the Nebraska Department of Natural Resources were taken by drillers at the time of installation. Only those measurements taken between March and June from 2000–2012 were used. In total over 25,000 data points were used to create this map.

*Conservation and Survey Division, UNL*

*Retired UNL technician Jerry Leach installs digital water level monitoring equipment in a monitoring well.*

*Center pivot irrigation.*
*Photo credit: Steve Ress, Nebraska Water Center, UNL*

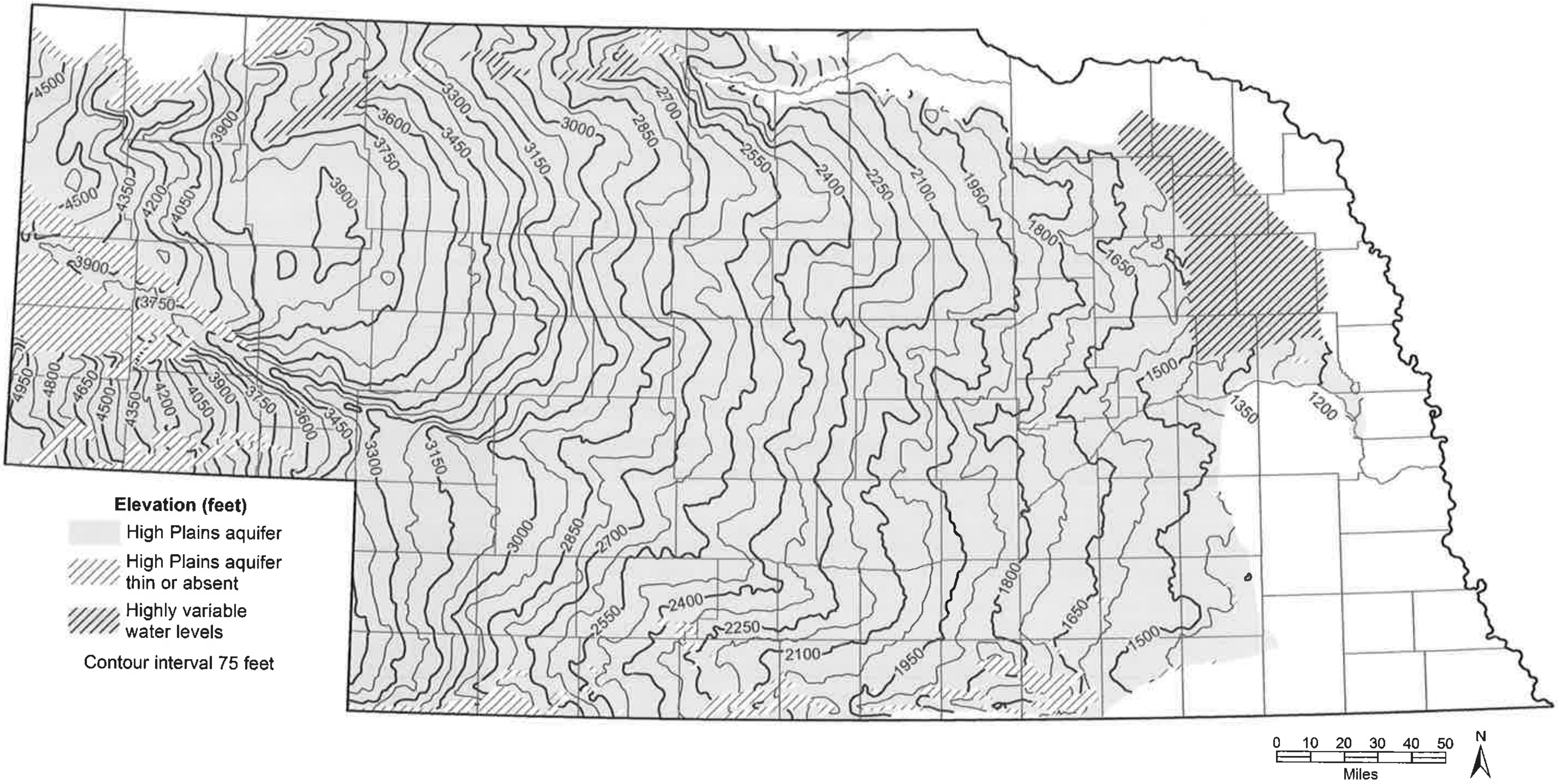


*Figure 29. Elevation of the water table or potentiometric surface for the High Plains aquifer. The High Plains aquifer exists under confined conditions in some areas of the Panhandle as well as southwest and south-central Nebraska. The contours in these areas represent the potentiometric surface. The eastern part (hatched) could not be contoured because data are insufficient.*

### *Dakota aquifer*

The map in Figure 30 shows the elevation of the water table or potentiometric surface in the Dakota aquifer in eastern Nebraska. Water level elevations are generally highest in Knox County and the western areas where the Dakota aquifer is confined and the water levels represent a potentiometric surface. In the eastern portions of the state, the aquifer is mostly *unconfined* and the water levels are more likely to represent a water table.

The water level contours were drawn using measurements primarily from registered wells that were recorded by the well driller when the well was completed. Only wells that were completed in 1990 or later and in October through May were used. Wells completed in the summer (June–September) were not used because the water levels recorded at that time are more likely to reflect pumping conditions rather than the static water level. The water levels in some wells used to construct this map were recorded annually or semiannually. In these wells, the average water level was used. Due to the wide date ranges of the water level data, the contours depicted on this map should be considered average static conditions over the last thirty years.

While some of the wells used to construct this map are completed into only the Dakota aquifer, most of the wells are connected to both the Dakota aquifer and parts of younger, overlying aquifers. The water levels in these wells are an amalgam of the levels in the Dakota aquifer and overlying aquifers. Since the younger aquifers are generally thin, it is possible to assume that the water level contours are influenced primarily by conditions in the Dakota aquifer. Some areas of the map, however, could reflect a component of water levels from the overlying aquifers.

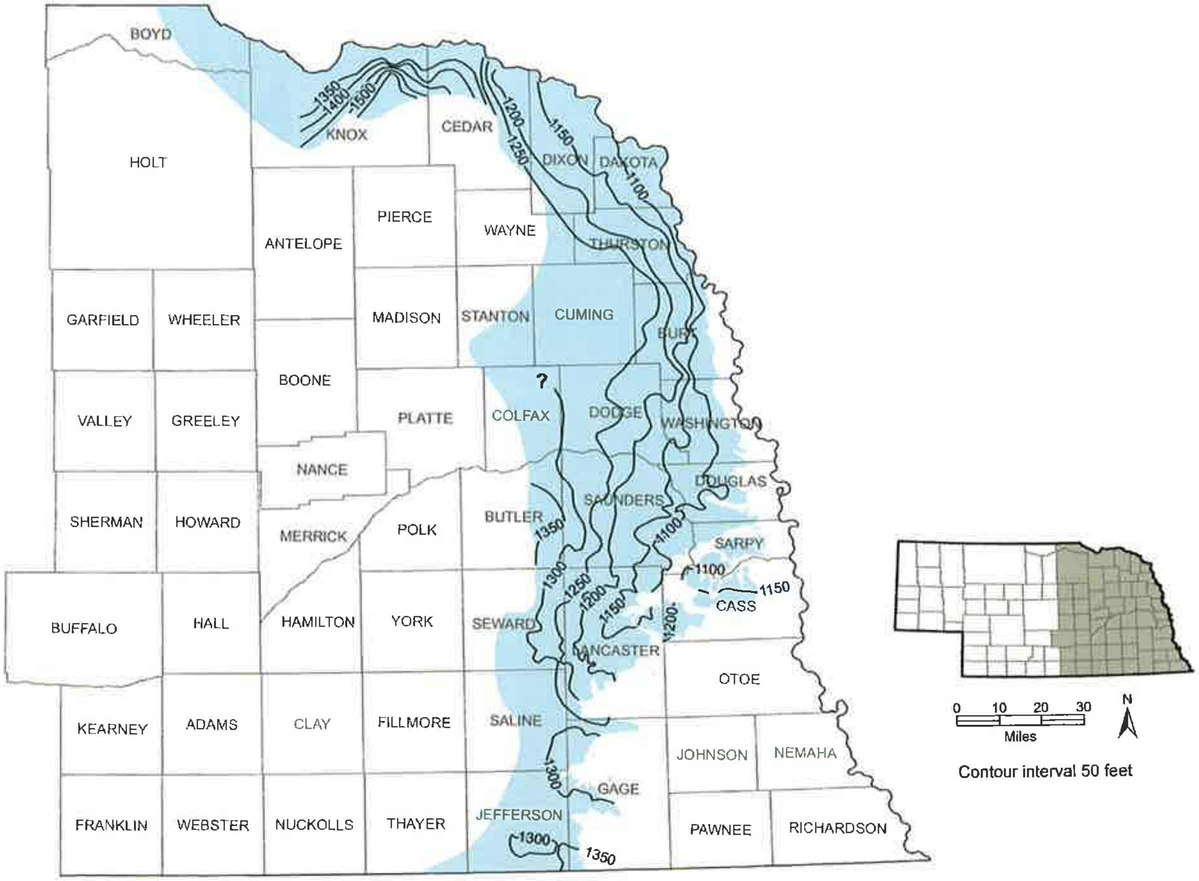


*Figure 30. Elevation of the water table or potentiometric surface of the Maha (Dakota) aquifer.*

### *Paleovalley aquifers*

The map in Figure 31 shows the elevation of the potentiometric surface in the *paleovalley aquifers* of southeast Nebraska. Water level elevations are generally highest in the west and decrease to the east, similar to the general groundwater flow direction across the state. The complex layering of sand and silt units in the paleovalley aquifers means that the aquifers are a mix of unconfined and confined. The authors attempted to omit water levels from wells in unconfined units, so the contours primarily represent a potentiometric surface.

The water level contours were drawn using measurements mainly from registered wells that were recorded by the well driller when the well was completed. Only wells that were completed in 1990 or later and in October through May were used. Wells completed in the summer (June–September) were not used. Some wells used to construct this map were recorded annually or semiannually. In these wells, the most recent water level measurement was used. If the most recent water level measurement in a well was taken before 1990, that data was not used. Due to the wide date ranges of the water level data, the contours depicted on this map should be considered average static conditions over the last thirty years.

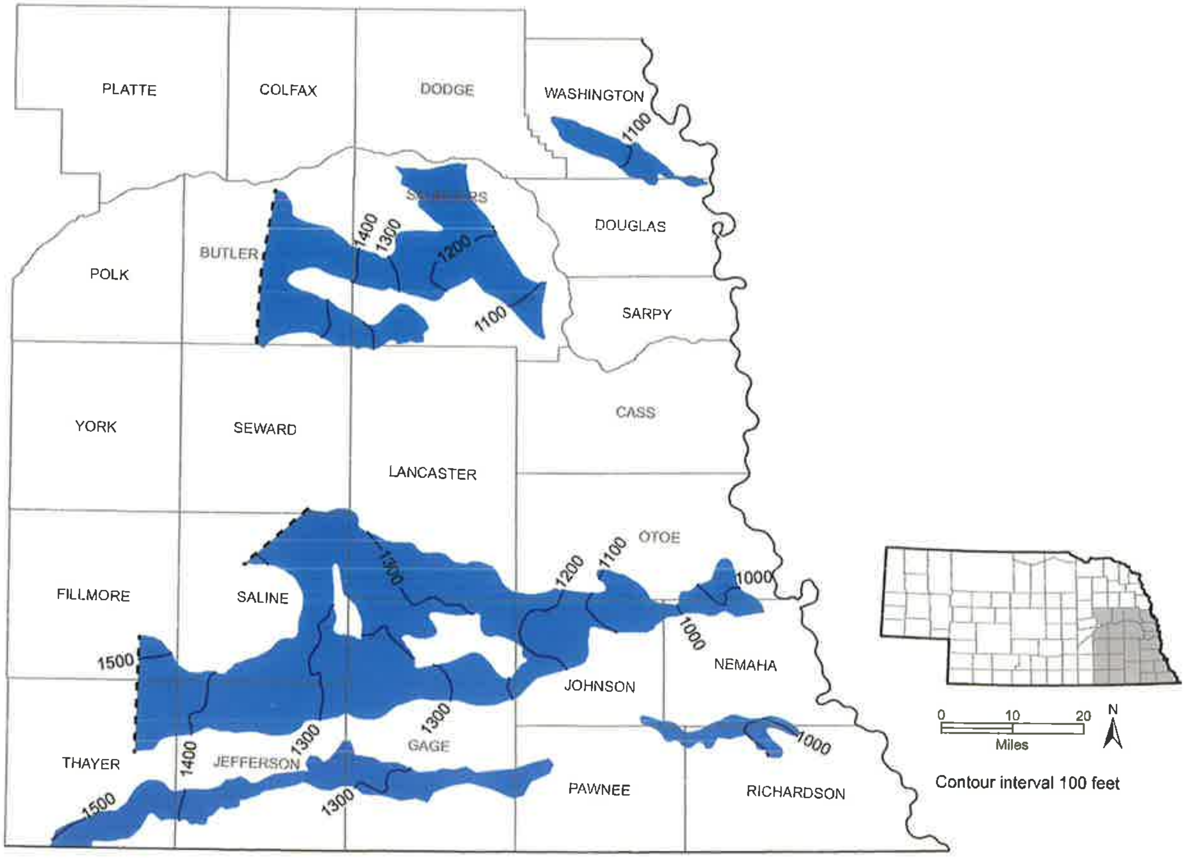


*Figure 31. Elevation of the potentiometric surface in the paleovalley aquifers of eastern Nebraska.*

## DEPTH TO THE WATER TABLE

Commercial agriculture in much of Nebraska is dependent on irrigation from the High Plains aquifer as a supplement to precipitation. The cost of pumping groundwater increases substantially with the depth from which it must be pumped. Furthermore, it costs more to drill a deep well than a shallow well. These costs affect each farmer's profit margin. All other factors being equal, it costs an irrigator much less to install a well and pump groundwater in southern Holt County, where groundwater is within 50 feet of the surface, than it does for an irrigator in southwest Custer County, where groundwater may have to be pumped in excess of 300 feet (Fig. 32).

The map in Figure 32 represents the depth to groundwater for unconfined portions of the High Plains aquifer. This map shows only the portion of the High Plains aquifer to the north of the Platte River, where the aquifer is mostly unconfined over a large region. The depth to water in this area represents the distance from the land surface to the water table. In other areas, the water levels in wells reflect a mixture of unconfined and confined aquifers. The water level in a monitoring well installed in a confined aquifer does not reflect the depth to saturated sediments. This map highlights the need for additional investigations to better understand the distribution of confined and unconfined conditions in the High Plains aquifer.

Depth to water in the mapped area varies greatly (Fig. 32). Depth to water may be less than 25 feet in river valleys. Similarly, in parts of Holt and Rock counties, groundwater can be at or near the surface, creating wetlands in low lying areas. However, in parts of Custer County, where there is a thick layer of *loess* and *alluvial* sediments blanketing the surface, depth to groundwater may be 400 feet or more. In the Nebraska Sand Hills, depth to groundwater can vary from a few hundred feet to ten feet or less depending on whether the depth to water is measured from the top of a dune or from the bottom of a meadow between the dunes.

The map in Figure 32 was derived by subtracting the elevation of the regional water table (Fig. 28) from a digital elevation map of the state. This map is not intended to be used on a local level for locating or installing wells because of the scale at which it was drawn and the large variability of the landscape at a regional level.

*Conservation and Survey Division, UNL*

*Researcher measures the depth to water in an irrigation well, circa 1950s.*

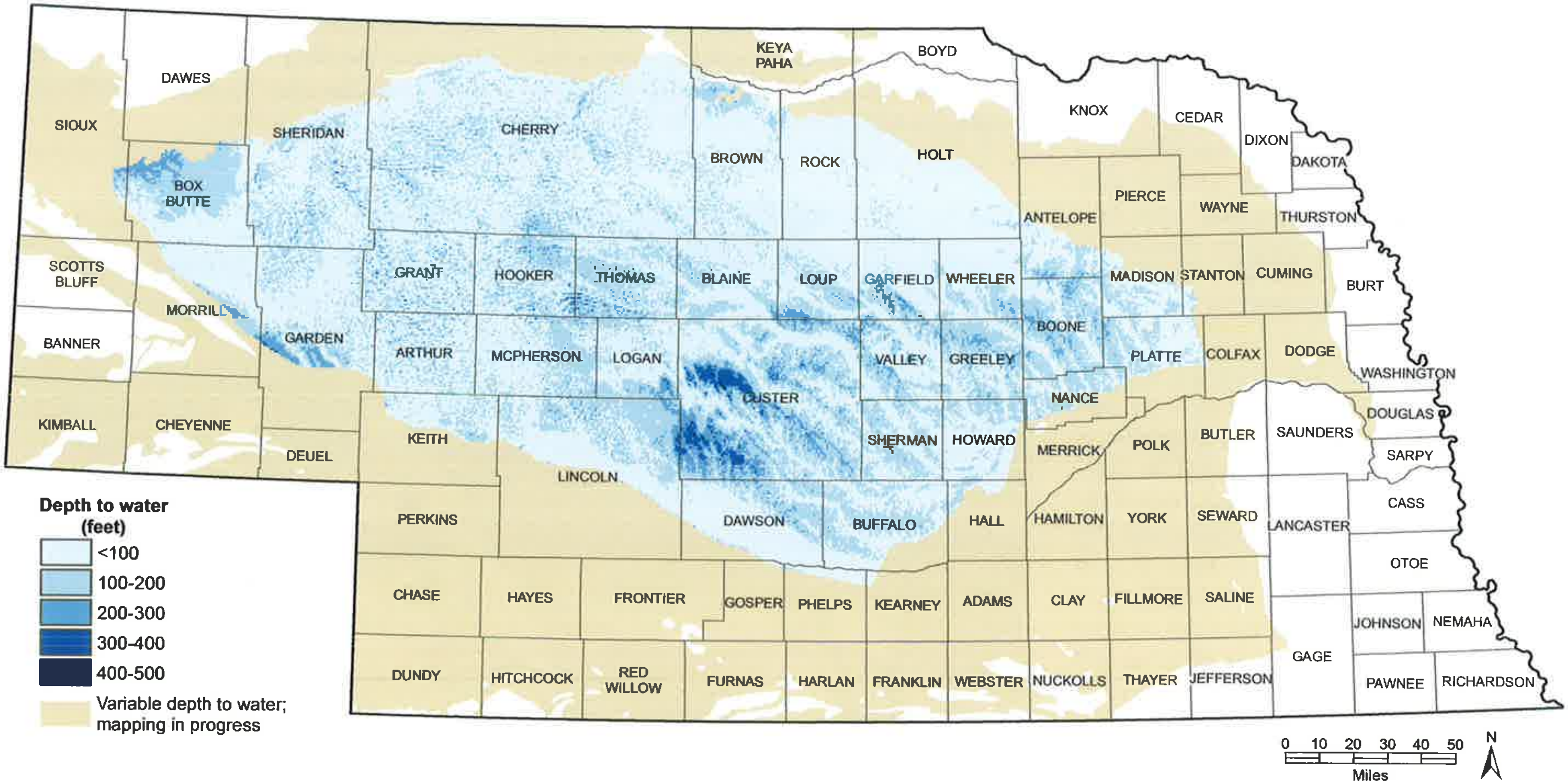


*Figure 32. Depth to the water table for unconfined portions of the High Plains aquifer. In other areas of the High Plains aquifer, the depth to the top of the water-bearing unit is highly variable and has not been mapped in detail.*

## SATURATED THICKNESS OF THE HIGH PLAINS AQUIFER

*Saturated thickness* is the thickness of an aquifer material that is completely saturated with water. In an unconfined aquifer, it is the thickness from the base of the aquifer to the water table. The map in Figure 33 was created by subtracting the elevation of the base of the principal aquifer (CSD, 1979) from the elevation of the water table (Fig. 29). This map, however, does not represent the total thickness of water in storage. To estimate water in storage, the saturated thickness must be multiplied by the *specific yield*, which is a measure of the amount of water that can drain from a material under the influence of gravity. The average specific yield of the High Plains aquifer (HPA) in Nebraska is approximately 15.2% (McGuire et al., 2003). If an aquifer has a saturated thickness of 100 feet, for example, the aquifer can only yield 15.2 feet of groundwater.

In a confined aquifer, the saturated thickness is the thickness of the aquifer between the two primary *confining units*. Confining units have yet to be mapped in detail in Nebraska, so only those areas under which the aquifer exists in regionally extensive, unconfined conditions are shown in Figure 33.


Steve Ress, Nebraska Water Center, UNL

*Gravity flood irrigation.*

Nebraska contains more than 60% of the volume of water in the entire High Plains aquifer (McGuire et al, 2003). The greatest saturated thicknesses anywhere in the HPA underlie Nebraska's Sand Hills, where as much as 1,100 feet of saturated sand, gravel, and sandstone exist (Fig. 33). Other areas with significant saturated thickness in Nebraska are along the border of southern Holt and northern Garfield counties, and parts of northern Lincoln County. The saturated thickness is relatively thin north of the Platte River in east-central part of the state, in parts of northern Box Butte and Garden counties, as well as northwestern Lincoln County.

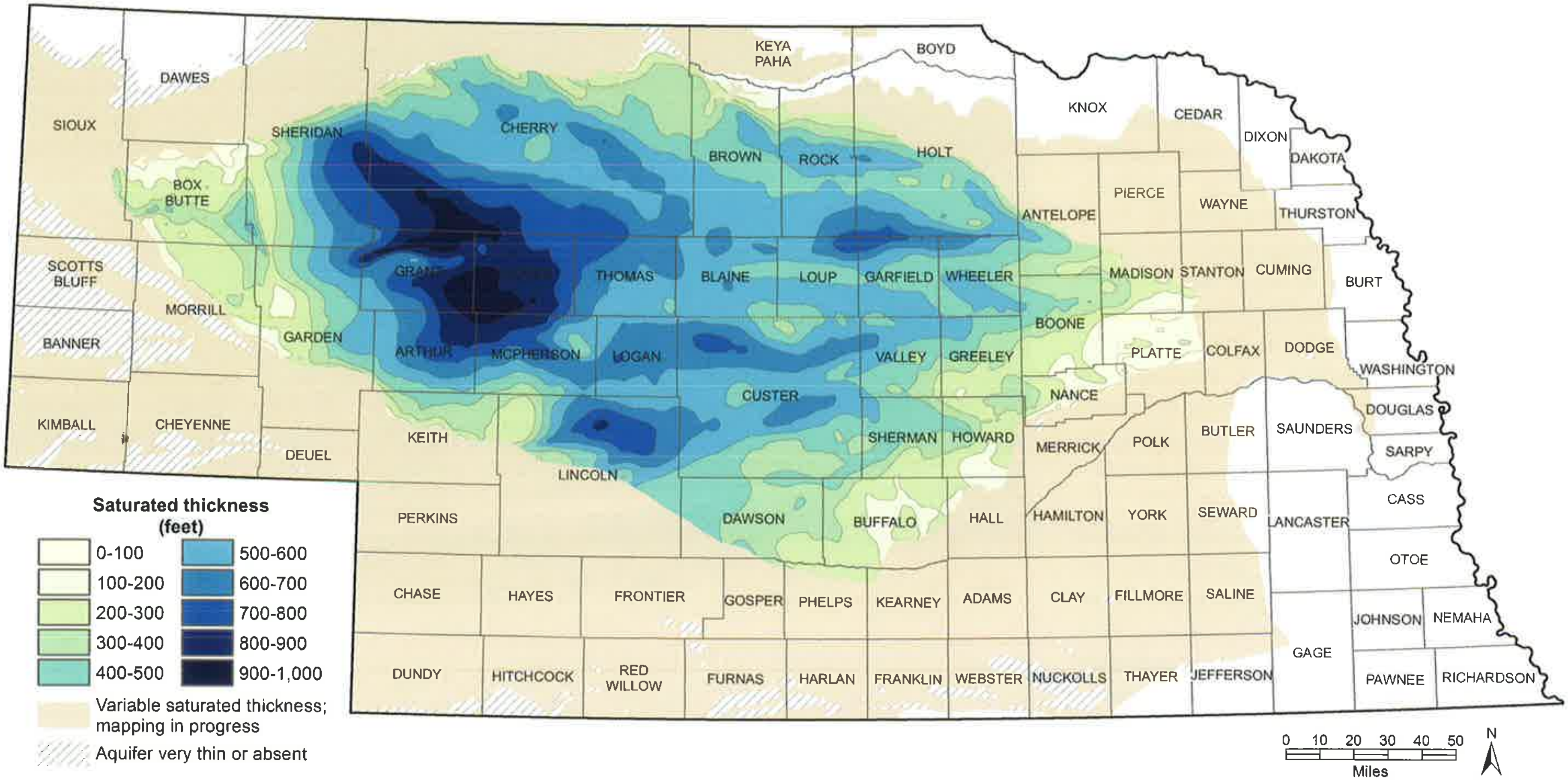


*Figure 33. Saturated thickness of the unconfined portions of the High Plains aquifer. In other areas of the High Plains aquifer, the saturated thickness is highly variable and has not been mapped in detail.*

## TRANSMISSIVITY

All aquifers differ. Some aquifers transmit water to wells at rates that are plentiful enough for almost any use; irrigation, municipal, industrial, commercial, etc. Other aquifers may transmit water at rates that are only useful for household or livestock supplies. Thus, well drillers, hydrogeologists, and groundwater users are interested in an aquifer's *transmissivity*, or its ability to supply water to wells. Transmissivity is dependent on a combination of the saturated thickness and the *permeability* of the aquifer. A thick aquifer composed of highly permeable material will have a much higher transmissivity than a thin aquifer composed of moderately permeable material.

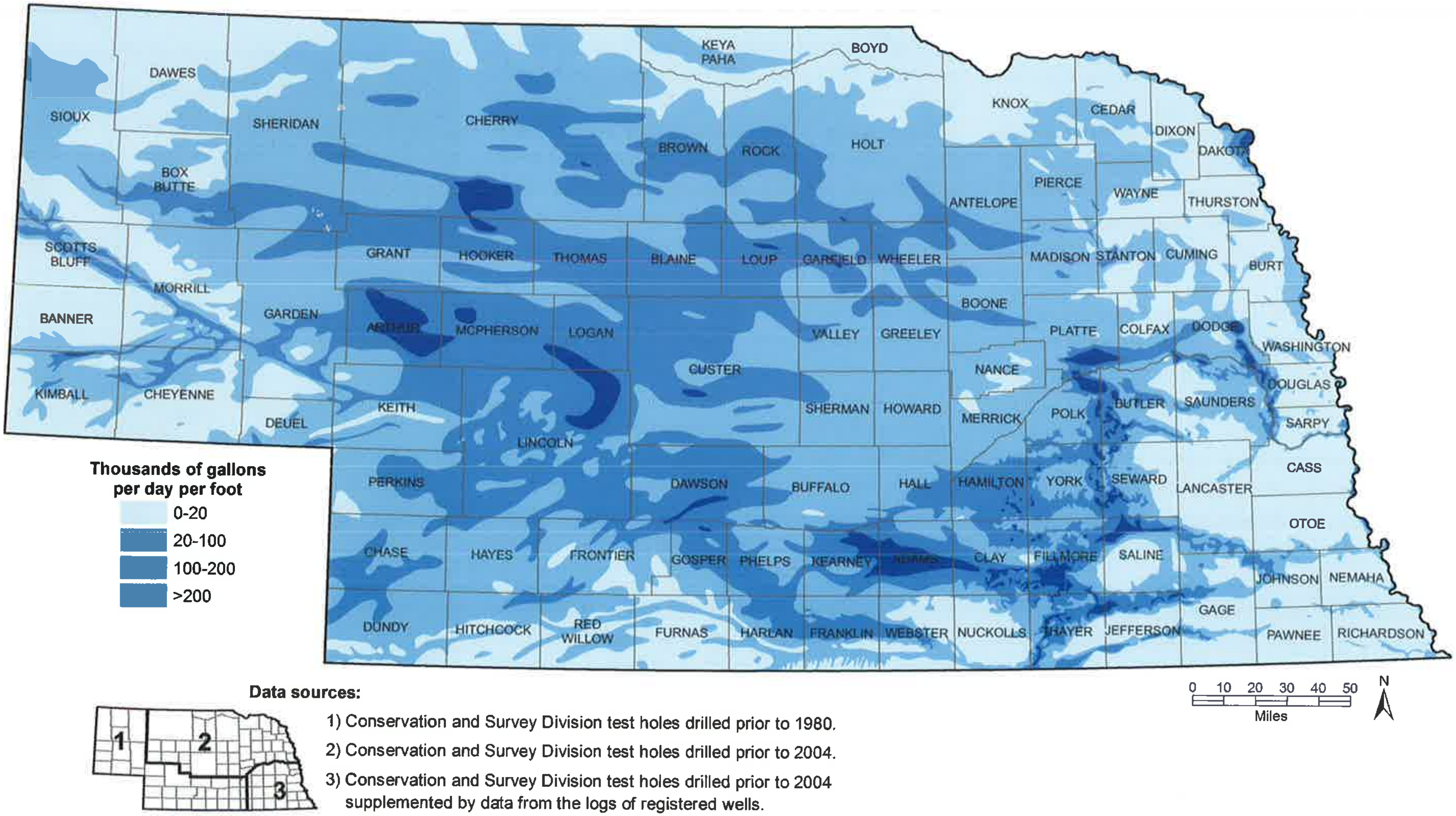
Though transmissivity is useful as a guide, one cannot directly predict *well yield* based only upon it. The yield, or pumping rate, of a well depends also on the type of construction and development of the well, the amount of drawdown during pumping, and whether the aquifer is confined or unconfined. Generally, however, aquifers with transmissivity of about 20,000 gallons per day per foot can support wells for some types of irrigation, such as low-pressure or subsurface drip systems. Aquifers with transmissivity in excess of 100,000 gallons per day per foot may support high-capacity wells of more than 1,000 gallons per minute, which can be developed for nearly any type of irrigation, industrial, or municipal use.

Figure 34 shows the transmissivity of the principal aquifers of Nebraska, which are the High Plains aquifer, paleovalley aquifers, glacial aquifers, and alluvial aquifers. Bedrock aquifers are not included due to a lack of information on their permeability and thickness. Large areas of Nebraska, such as the Sand Hills, are underlain by highly transmissive aquifers composed of coarse-grained sand, sandstone, and sandy gravel. Not only are these aquifers highly permeable, but they are also very thick, exceeding 500 feet under most of the Sand Hills. Transmissivity is also high in the North Platte River and South Platte River valleys, the Platte River valley, and in much of the Big Blue River basin. Aquifers of high transmissivity also occur where thick layers of sand and gravel fill bedrock paleovalleys, such as in southern Thayer, Jefferson, and Gage counties.

Aquifers with low transmissivity are characterized either by fine-grained deposits or by thin deposits of coarse-grained sediments. In some areas, the transmissivity is low primarily because bedrock is shallow and aquifers are thin, such as along Nebraska's southern border (Fig. 34). An area of shallow bedrock also exists within the High Plains aquifer of east-central Nebraska in Buffalo, Sherman, Howard, and Nance counties. Transmissivity is lower in this area compared to surrounding areas. Low transmissivity in the Panhandle primarily relates to the fine-grained nature of rocks in the Arikaree and White River Groups. In the eastern part of the state, transmissivity values are highly variable because of the great changes over short distances in the thickness of sand and gravel deposits.


*Conservation and Survey Division, UNL*

*Geologists inspect a core taken from sediments underlying a Sand Hills lake.*



**Data sources:**

1) Conservation and Survey Division test holes drilled prior to 1980.
2) Conservation and Survey Division test holes drilled prior to 2004.
3) Conservation and Survey Division test holes drilled prior to 2004 supplemented by data from the logs of registered wells.

*Figure 34. Transmissivity of the primary aquifers of Nebraska, including the High Plains aquifer, alluvial aquifers, glacial aquifers, and paleovalley aquifers. Sources of data vary by area, shown in inset map: 1) modified from an unpublished CSD map; 2) modified from Summerside et al., 2005; and 3) modified from Summerside et al., 2005, in which test hole data were supplemented by data from the logs of registered wells.*

## CHANGES IN GROUNDWATER LEVELS

Although Nebraska's water resources are vast, they are not infinite. Depletion of groundwater in certain parts of Nebraska would have huge economic and social impacts; therefore, groundwater must be conserved to ensure supplies are available for future generations. The Conservation and Survey Division, later with the U.S. Geological Survey, Natural Resources Districts, Central Nebraska Public Power and Irrigation District, and the U.S. Bureau of Reclamation have been monitoring groundwater level changes in Nebraska since the 1930s. To monitor long-term groundwater-level changes, we obtained baseline predevelopment values for select wells throughout the state with long-term records. These baseline measurements represent a close approximation of the depth to water in the well prior to the extensive development of irrigation in a region. Most of these values were obtained before the mid-1950s.

Prior to 1981 groundwater levels were declining in almost all parts of Nebraska (Fig. 35). By 1981, parts of Box Butte, Chase, Fillmore and Clay counties had water level declines in excess of thirty feet, with many surrounding counties experiencing significant declines of more than 20 feet since widespread irrigation use began in these areas. Groundwater-level increases during this period were limited to areas surrounding large surface water projects. Water seeping from surface water reservoirs and canal systems spanning the distance from Lake McConaughy to western Kearney County resulted in groundwater-level rises of 50 feet or more in some locations. Similarly, water seeping from the Sherman reservoir and associated irrigation canals led to groundwater rises of more than 30 feet in parts of Sherman and Howard counties. Rises in groundwater levels also occurred along canals in southern Sioux and northern Scotts Bluff counties.

However, in the period from 1981–2012, water-level changes in the eastern part of Nebraska were markedly different (Fig. 36). Groundwater-level declines in the eastern part of the state had reached a maximum by 1981, with water levels remaining steady or increasing through the spring of 2012. Water levels along the central Platte River continued to rise due to seepage from the Tri-County canal system. However, rises not resulting from canal seepage are likely the result of a number of factors including (1) reduced groundwater withdrawals during several long periods of above-average precipitation, (2) increased irrigation efficiencies that resulted in reduced pumping rates and volumes, and (3) stabilization of groundwater levels as the aquifer equilibrated to the new hydrological conditions imposed on it by irrigation development decades earlier (Korus et al., 2011). Over application of irrigation water may be a fourth means of producing groundwater-level rises. Before the widespread use of center pivot irrigation, row crops were primarily irrigated using flood irrigation, which applied excess water to the land surface. Decades-worth of excess water applied to the surface may be slowly recharging the aquifer resulting in groundwater-level rises in some areas. In the drier, western part of the state, where large quantities of irrigation water are required to supplement natural precipitation for crop production, groundwater levels continued to decline. Between 1981 and 2012, water levels in parts of Box Butte, Perkins, Chase, and Dundy counties declined an additional 40–60 feet.

The net result of groundwater-level rises and declines in Nebraska since the widespread use of groundwater for irrigation began is represented in the map showing changes from predevelopment to Spring 2012 (Fig. 37). As of the spring of 2012, water levels in parts of Box Butte, Perkins, Chase, and Dundy counties have declined by more than 70 feet in some locations. Numerous water use policies have been enacted in these areas to slow the rate of water level decline. However, water levels in these areas will likely continue to decline, although at a slower rate than in the past, unless the use of water for irrigation is further curtailed (Korus et al., 2011). Water levels in central Nebraska, however, have in many areas returned close to predevelopment levels, with some areas having groundwater-level rises of 20 feet or more. Water levels in Fillmore and surrounding counties continue to have declines of 30 feet or more from predevelopment levels, but water levels have been steadily rising, particularly in York, Polk, and Hamilton counties. If these trends continue for the eastern and central portions of the state, water levels in the coming decades may return close to predevelopment levels.

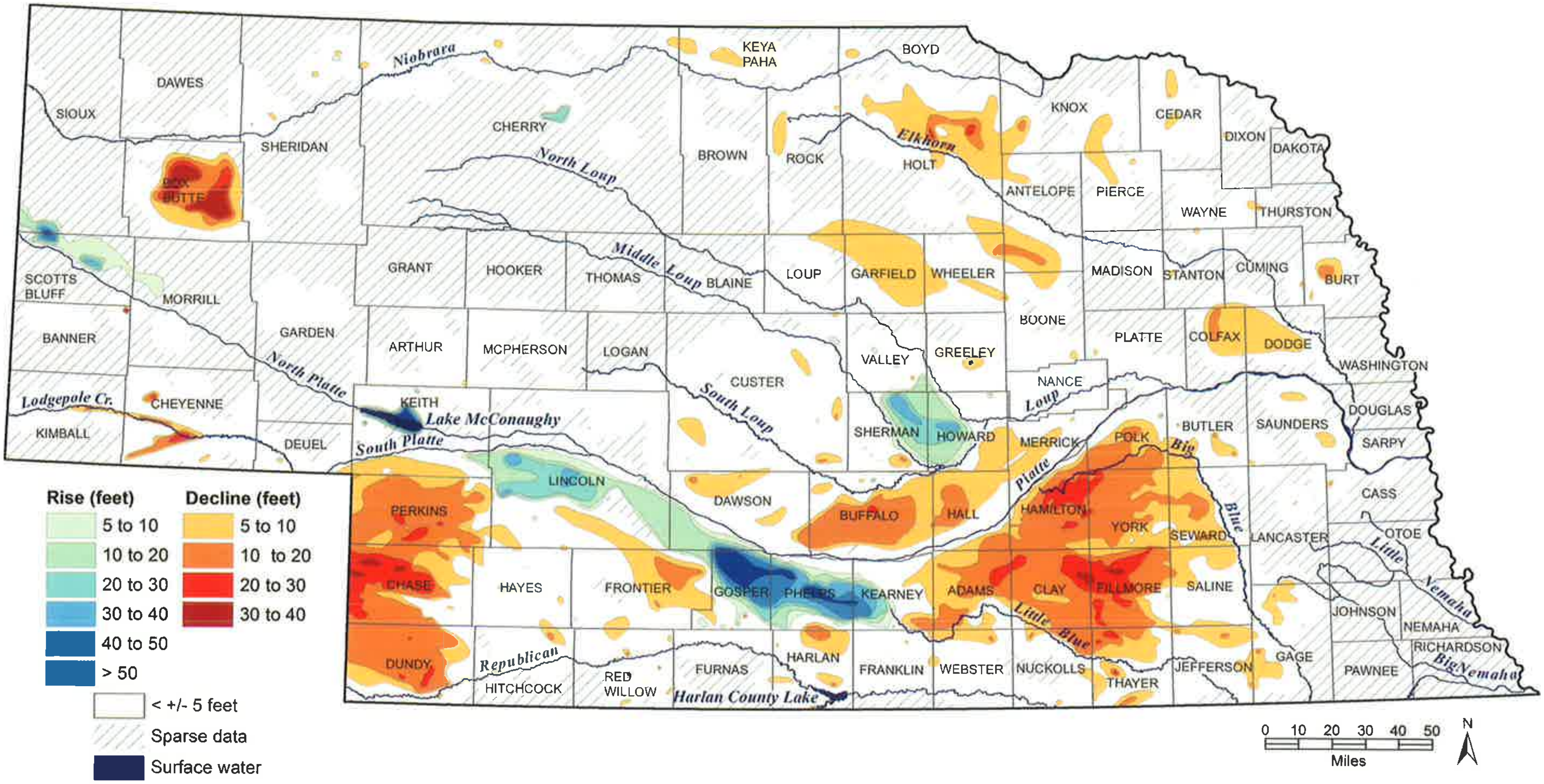


*Figure 35. Changes in groundwater levels from predevelopment to Spring 1981.*

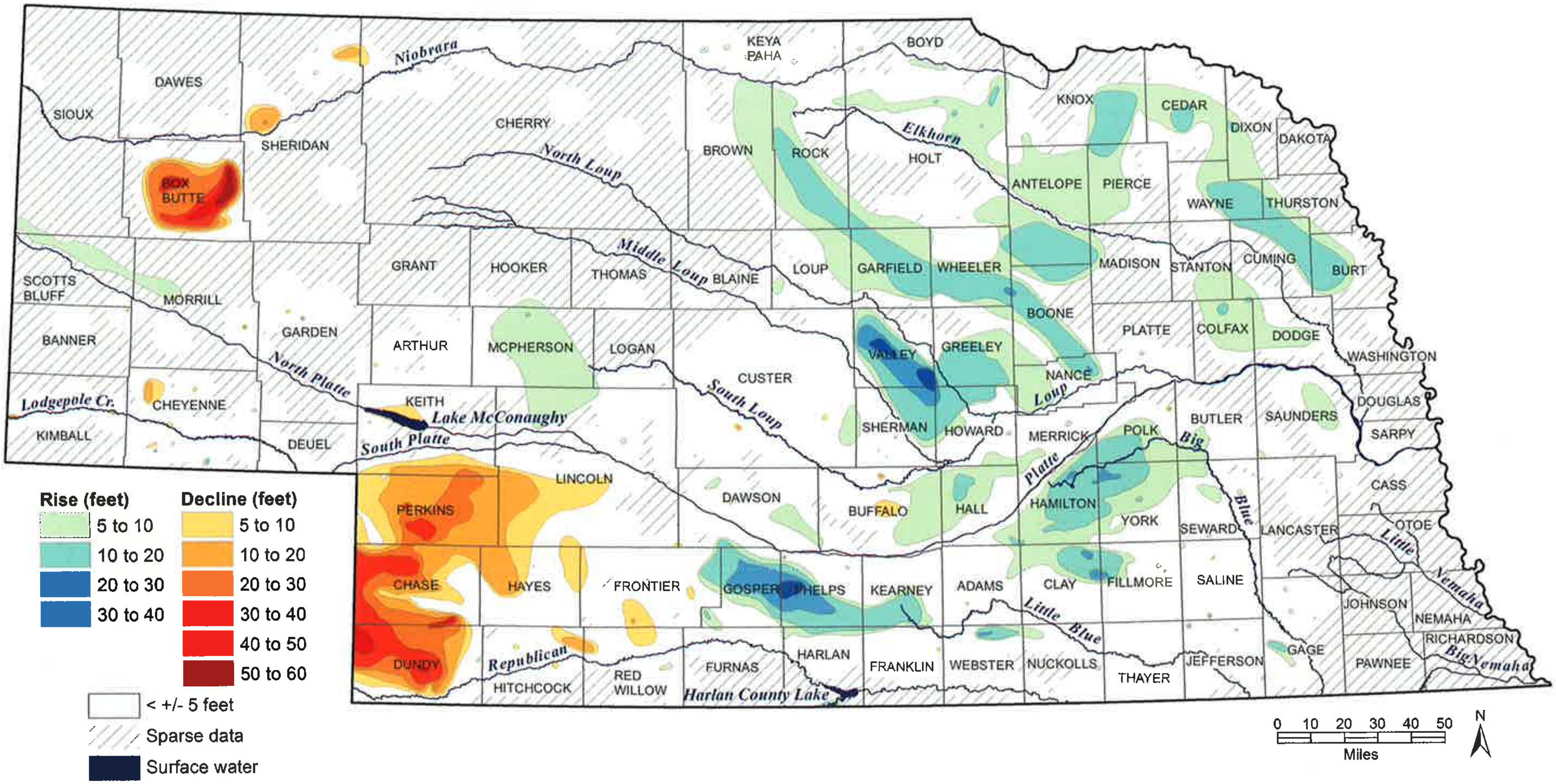


*Figure 36. Changes in groundwater levels from Spring 1981 to Spring 2012.*

North Platte River stream gauge as a regular, uniform curve in the hydrograph, peaking at approximately 1,000 cubic feet per second (cfs) at the end of each September (Fig. 39). The curve slowly declines through the winter months. Other peaks in the hydrographs are due to releases from dams further upstream and are unrelated to the groundwater mound.

It is often necessary to manage groundwater and surface water as a single, integrated resource because of their interconnections. Through the 1900s and into the 2000s, conflicts among water users led to the development of integrated management laws in Nebraska, which designated certain areas of the state as overappropriated and provided a framework for developing integrated management plans. As a result, the Nebraska Department of Natural Resources has designated certain areas of the state as fully appropriated, based upon the expected long-term availability of what it terms "hydrologically connected" groundwater and surface water (Fig. 40). Within these areas, the Natural Resources Districts and Department of Natural Resources are required to design and implement plans to achieve a balance between water demand and supply of the interconnected resource in both the near term and long term.

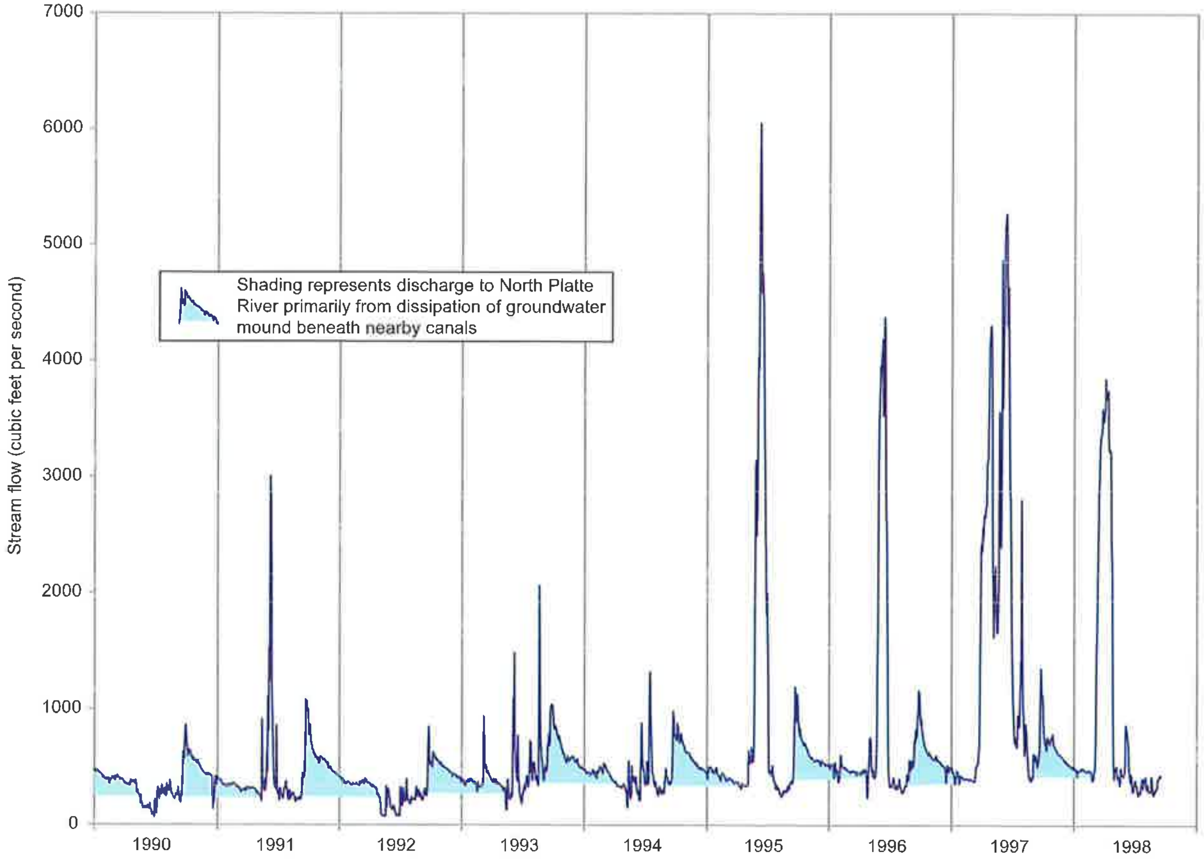


*Figure 39. Stream flow hydrograph from North Platte River near Mitchell in western Scotts Bluff County. Large peaks are from releases of water from dams upstream. Small peaks in September each year (shaded) reflect increased groundwater discharge to the stream from dissipation of the irrigation-induced groundwater mound nearby.*

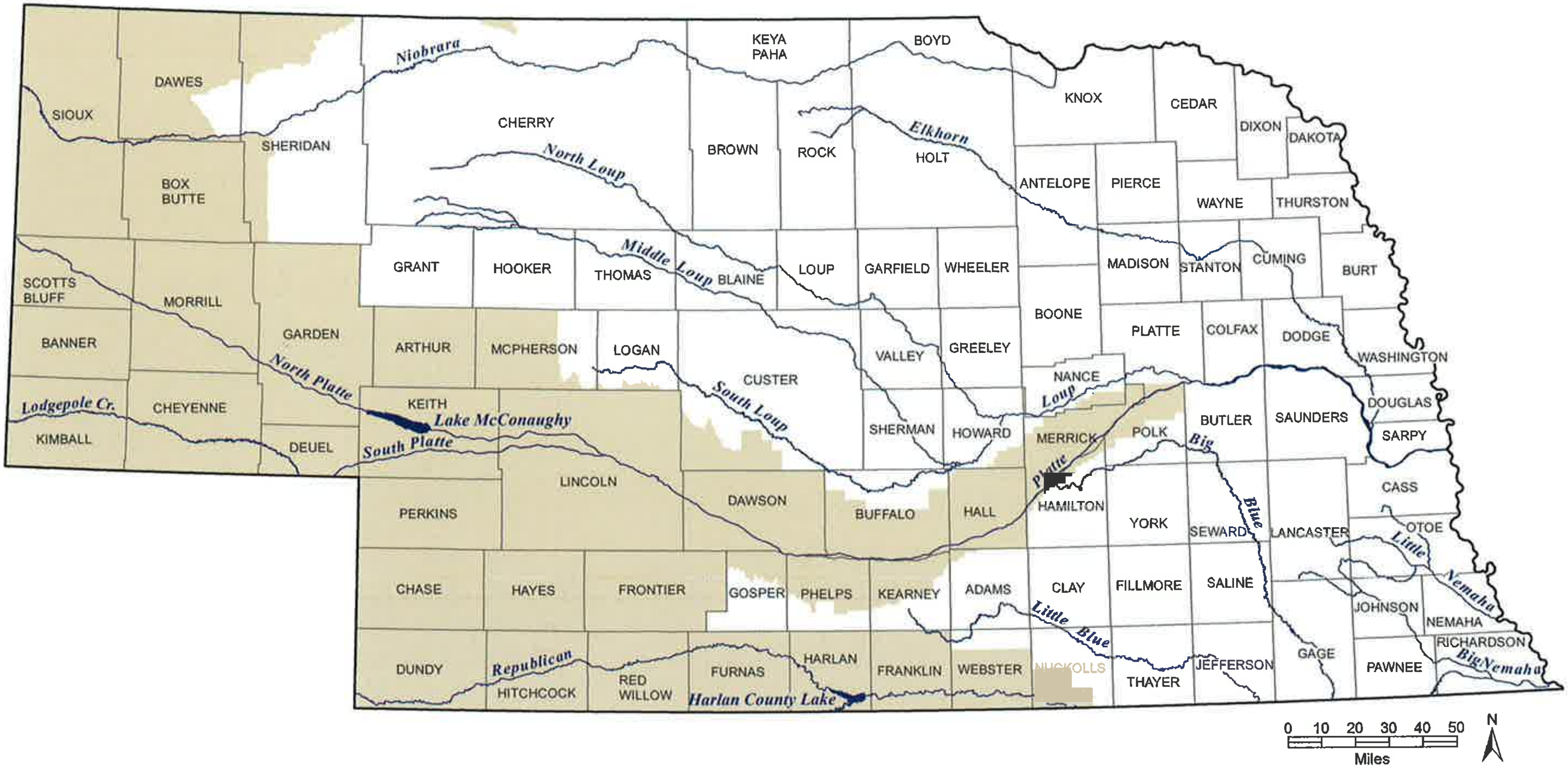


Figure 40. Fully and over-appropriated groundwater and surface water in Nebraska (Nebraska Department of Natural Resources, 2013).

# GROUNDWATER QUALITY

## NATURAL WATER QUALITY

Natural water quality can vary widely and is primarily impacted by the age of the water and the geologic composition of the *aquifer*. Older groundwater and groundwater that flows through aquifers rich in leachable minerals tend to be of poorer quality than young groundwater or groundwater that flows through aquifers rich in stable minerals. A general measure of the quality of groundwater is *total dissolved solids* (TDS), which is a summation of the concentration of each major ion: calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate. Drinking water standards specify maximum concentrations of 500 parts per million (ppm) for TDS.

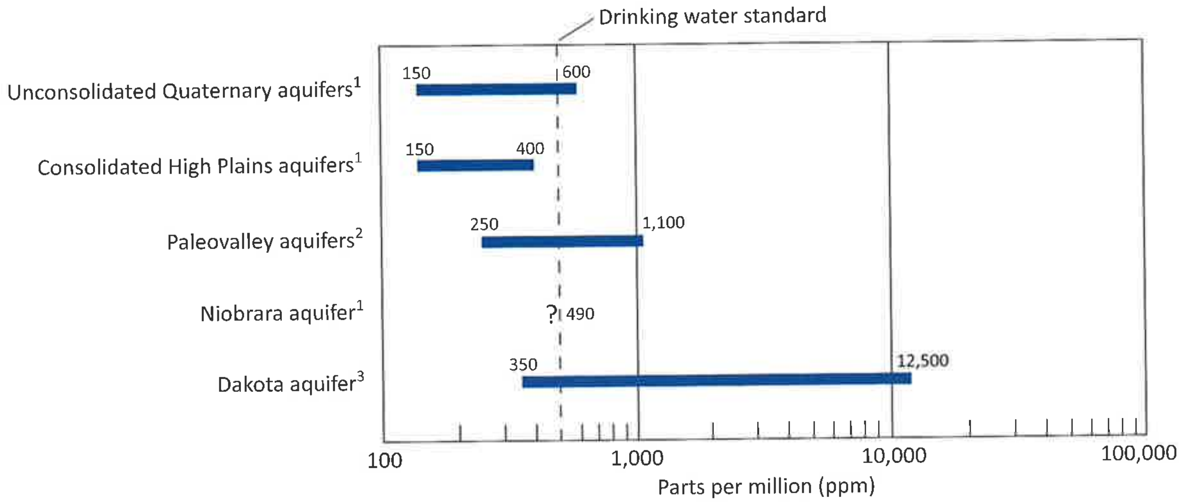


*Figure 41. Total dissolved solids in parts per million (ppm) in selected aquifers of Nebraska. Superscript denotes source of data: 1) Engberg and Druliner, 1987, 2) Lower Platte South Natural Resources District (2013), 3) Gosselin et al., 2001.*

Figure 41 shows the range of TDS concentrations in the major aquifers of Nebraska. The scale for TDS is logarithmic, so very large values are compressed relative to smaller values. The consolidated bedrock units of the High Plains aquifer (Ogallala, Arikaree, and Brule) have fairly consistent TDS and generally range from 150–400 ppm (Engberg and Spalding, 1978). The unconsolidated Quaternary *sediments* that cover much of the state have water with TDS concentrations that range from approximately 150–600 ppm (Engberg and Spalding, 1978). The higher concentrations tend to occur in areas where agriculture is an important land use and the aquifer is *unconfined* (McMahon et al., 2007).

The TDS concentrations in paleovalley aquifers can vary widely depending on localized conditions. The data presented in Figure 41 are taken from three different paleovalley aquifers in southeast Nebraska. The TDS concentrations in these aquifers vary from approximately 250–1,100 ppm. The high TDS concentrations tend to occur in high-capacity wells that are screened at the bottoms of the aquifers near bedrock.

The Niobrara aquifer is composed of shaly chalk and limestone and serves as a primary aquifer only where fractures or solution cavities have formed. Limited data make characterization of the water quality difficult, though Engberg and Druliner (1987) estimate a median TDS concentration of 490 ppm.

The Dakota aquifer has a wider range of TDS concentrations than any other aquifer in Nebraska. It varies from approximately 350 ppm to as much as 12,500 ppm (Fig. 41). Water having low TDS concentrations typically occurs where the aquifer is unconfined and the water has been recently *recharged* by precipitation (Gosselin et al., 2003). In areas where the Dakota is a *confined* aquifer, the water is likely much older and the TDS tends to be in the range of 1,100–1,400 ppm

*A Sand Hills lake surrounded by wildflowers.*
*Photo credit: Jim Swinehart, Conservation and Survey Division, UNL*

(Gosselin et al., 2003). The very high 12,500 ppm concentrations occur where sodium chloride brines are present in the Dakota. These salty waters emerge as springs in Lancaster County and form saline wetlands.

Naturally occurring compounds present at lower concentrations than TDS can also affect water quality. One of the most common of these trace compounds in Nebraska is arsenic (Engberg and Spalding, 1978). Arsenic is a carcinogen regulated at 10 parts per billion (ppb) by the U.S. Environmental Protection Agency (EPA). The primary source of arsenic in Nebraska is probably the iron-sulfide mineral pyrite, which is found in the sediments that compose many aquifers (Gosselin et al., 2004).

Arsenic concentrations greater than 5 ppb are fairly common in the High Plains aquifer, especially in the Panhandle. Average concentrations in the Quaternary and Ogallala are fairly similar (4.47 and 4.27 ppb, respectively), but the Arikaree is somewhat higher (6.4 ppb) (Gosselin et al., 2004). Though TDS concentration is variable and often high in the Dakota aquifer, arsenic concentrations are fairly low. Data reported by Gosselin et al. (2004) indicate that the average arsenic concentration in the Dakota aquifer is approximately 0.75 ppb. Arsenic concentrations in three paleovalley aquifers of southeast Nebraska are near to or below the laboratory detection limit of 0.001 ppb. No arsenic data has been published for the Niobrara aquifer.


Steve Ress, Nebraska Water Center, UNL

*UNL hydrogeologist Dave Gosselin inspects a water sample being prepared for analysis.*

## ANTHROPOGENIC IMPACTS TO WATER QUALITY

Contamination of groundwater by human activity can result from leaks and spills that emanate from a specific location (*point source*) or from more general land use activities (*non-point source*). Leaking storage tanks are an example of a point source and pose a direct threat to groundwater because they are often located underground and may be filled with toxic substances. Other potential point sources include landfills, feedlots, and industrial facilities. The Nebraska

Department of Environmental Quality (NDEQ) is responsible for regulating these point sources.

Contamination resulting from the application of agricultural pesticides and fertilizers is known as non-point source because it comes from broad areas rather than a specific location. Although most of Nebraska's groundwater is of good quality, elevated levels of nitrate have been detected, especially in areas of intensive agriculture, porous soils, and shallow *water tables* (Fig. 42). Several state agencies have a role in monitoring non-point source pollution. Nebraska's Natural Resources Districts (NRDs) are responsible for regulating non-point source contamination and collectively sample thousands of wells each year to measure nitrate concentrations. Many NRDs also monitor groundwater for pesticides. This data is publically available through the Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater (http://dnrdata.dnr.ne.gov/clearinghouse/) and through an annual report produced by NDEQ.

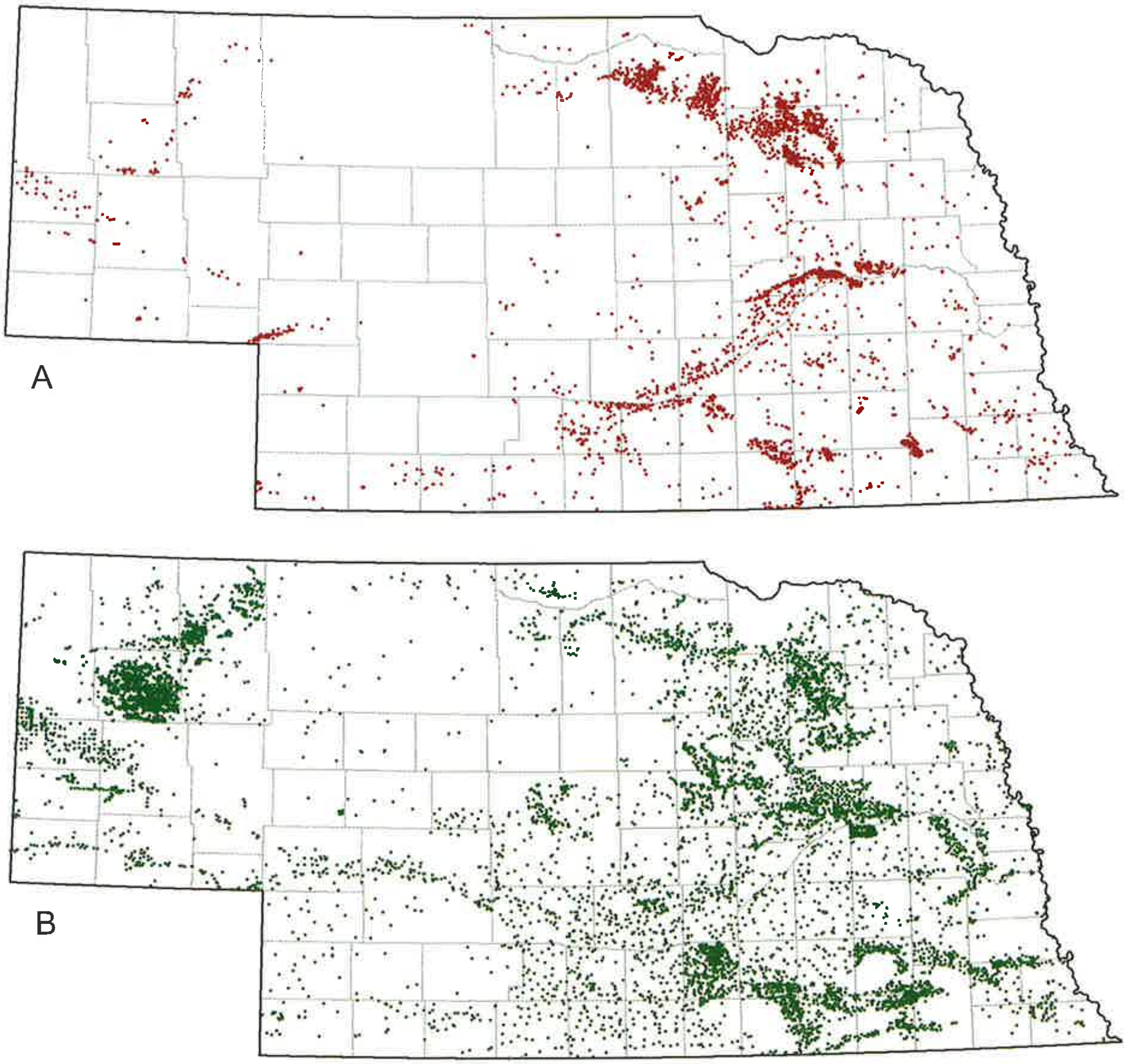


*Figure 42. Most recent nitrate concentrations in wells sampled between January 2001 and December 2011. A) Wells with most recent nitrate concentration greater than 10 parts per million (ppm). B) Wells with most recent nitrate concentration less than 10 ppm. Source: Quality-Assessed Agrichemical Contaminant Database for Nebraska Groundwater (UNL, 2013).*

## VULNERABILITY OF GROUNDWATER TO CONTAMINATION

The likelihood that the natural water quality of an aquifer will be impacted by contamination depends on several factors, but the most important is whether or not the aquifer is unconfined or confined. Unconfined aquifers are overlain by relatively permeable material all the way to the ground surface. They receive recharge from all (or most) of the overlying land surface relatively quickly. In these situations, the recharge water may be contaminated by land use activities over the entire surface area of the aquifer. For confined aquifers, a relatively impermeable layer of material exists between the ground surface and the top of the aquifer. This fine-grained *confining unit* may divert, degrade, absorb, or simply slow movements of contaminants that are introduced above the layer. Confined aquifers may also have very localized recharge areas. Instead of the entire surface area of the aquifer acting to recharge it, one or a few small areas may recharge a relatively large volume of confined aquifer. Under these conditions, the land use in the recharge area may be comparatively easier to monitor and control.


*Conservation and Survey Division, UNL*

*UNL hydrogeologist Sue Lackey collects a water sample from a monitoring well in northeast Nebraska.*

Once contaminated water reaches the aquifer, it moves both vertically and horizontally through it. Hydrogeologists speak of the direction of groundwater movement in terms of the *hydraulic gradient*. Groundwater moves down-gradient. Thus, water up-gradient of the source will not be contaminated by that source. Water down-gradient of the source is vulnerable to contamination. The more direct path recharge water takes from its source to the aquifer, the more likely groundwater contamination will occur.

Groundwater recharge from surface water irrigation (predominantly from canal seepage) can result in lower mineralization and an improvement in groundwater quality (as well as a rise in the water table). However, recharge enriched with agricultural chemicals and nitrate can degrade the groundwater quality (Engberg and Druliner, 1987). All of the aquifers discussed in the preceding sections are at least somewhat vulnerable to contamination. In the High Plains aquifer, units closest to the surface are the most likely to become contaminated. The Dakota aquifer is most vulnerable in Washington, Sarpy, Cass, and Lancaster counties where it is a shallow unconfined aquifer. Paleovalleys are geologically complex and may contain both shallow unconfined and deep confined aquifers separated by low *permeability* units. In these cases, the unconfined unit may become contaminated while the confined unit does not. The Niobrara aquifer is typically confined and has a lower likelihood for groundwater contamination than does an unconfined aquifer.

# AFTERWORD

Groundwater is a beautiful and seemingly magical thing. From the sacred springs at the base of the Athenian Acropolis, which were a focus of human activity from the Neolithic onward through Classical times, to the modern-day dowser plying his trade in Nebraska, groundwater has borne both mystique and misunderstanding for millennia. The transit of precious rain from the sky to the land surface and its passage as percolating groundwater into the subsurface realm goes on largely unheard and unnoticed. In most settings groundwater seeps through the outer skin of our planet at rates slow enough to be characterized as dilatory, yet over spans of time unfathomable to most humans it can accumulate as a vast and treasured resource. We humans plumb geologic depths, of which we have only indirect and incomplete knowledge, to tap that resource, sometimes at great expense. When groundwater reappears from the depths suddenly in the exuberance of boiling springs or when it leaps unaided in silvery arcs from artesian wells it inspires great wonder. But groundwater's most salient image in the human mind is one of availability accepted as a matter of faith. This image is dangerously in error.

Nebraska has been called "the groundwater state" and, indeed, the greater part of the volume of the High Plains aquifer underlies it. Although Nebraskans have always been tied in some way to the underground waters beneath their feet, the connection between human endeavor and groundwater supply has become ever more binding since the mid-20th century, with the widespread use of center-pivot irrigation and the growth of our urban areas. During drought periods, when Nebraskans become acquainted once again with the vagaries of their subhumid to semiarid continental climate, that linkage seems almost inexorable in its magnitude and it cries out for public discourse. When the rains return, however, the public generally loses interest in the proposition and is lulled back into the complacency of day-to-day thinking. But all Nebraskans will need to consider groundwater in the longer run as the events of the 21st-century exert unprecedented pressures on our resource base.

The key to an expanded awareness of groundwater resource issues will be a greatly improved scientific understanding of groundwater among the members of the public. What will this improved understanding of groundwater entail? First, it will require an understanding of the intimacy of relationships between the component parts of the hydrologic cycle. Specifically the unavoidable linkage between surface water and groundwater is vital. Nebraskans must come to know that the water that flows through their rivers also flows into and out of the ground, that when we impact one of these, we likewise impact the other. Second, it will require an appreciation that the behavior of water in the porous medium of an aquifer differs significantly from the behavior of water at Earth's surface. Nebraskans must grasp the notion that deposits of recharge into the groundwater "bank" are slow and incremental, whereas our withdrawals are profligate. Hand-in-hand with these facts comes the revelation that sustainable yield relative to recharge is a fallacy. Moreover, we may come to question what constitutes even a "safe" yield of groundwater. Third, it will require an acceptance of the fact that groundwater is a renewable resource only on a time scale that vastly exceeds human lifespans and our own Industrial Age. In other words, we are using and abusing far more groundwater than the natural system could replenish or refurbish.

All of us must recognize now the pressing need to manage wisely all of our water resources. In Nebraska, that recognition includes, of necessity, a renewed commitment to scientific study, public understanding, wise management, and preservation for future generations. In most of us, there is a very fond hope that Nebraska will evermore be famed for its abundant, clean groundwater.

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# GLOSSARY

**Alluvium or Alluvial** – general term for unconsolidated sediment deposited during comparatively recent geologic time by stream or other body of running water.

**Aquifer** – a body of rock or sediment that contains sufficient saturated permeable material to conduct groundwater and to yield significant quantities of water to wells and springs.

**Artesian Well** – a well tapping a confined aquifer; water in the well rises above the level of the top of the aquifer under artesian pressure, but does not necessarily reach the land surface.

**Confined Aquifer** – an aquifer bounded both below and above by confining units and in which water exists under pressure.

**Confining Unit** – a body of relatively impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers.

**Eolian** – pertaining to the wind; especially said of such deposits as loess and dune sand.

**Evapotranspiration** – the loss of water from a land area through transpiration of plants and evaporation from the soil and surface-water bodies.

**Flowing Artesian Well** – an artesian well that taps an artesian aquifer in which the head (i.e. the height of a vertical column of water) is sufficient to raise the water in the well above the land surface.

**Groundwater Discharge** – the release of water from the saturated zone, either naturally as part of the hydrologic cycle or artificially through pumping.

**Hydraulic Gradient** – the rate of change of total head (i.e. the height of a vertical column of water) per unit of distance of flow at a given point and in a given direction in an aquifer.

**Hydrologic Balance** – a condition of a hydrologic system in which there is a balanced inflow and outflow of water.

**Igneous Rock** – a rock that solidified from molten or partly molten material.

**Infiltration** – the movement of water into soil or porous rock.

**Loess** – a widespread, homogenous, commonly nonstratified blanket deposit, consisting predominantly of silt with secondary grain sizes ranging from clay to fine sand, believed to be windblown dust of Pleistocene age.

**Metamorphic Rock** – a rock derived from preexisting rocks by mineralogical, chemical, or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the Earth's crust.

**Non-point Source Pollution** – pollution from sources that cannot be defined as discrete points, such as areas of crop production, timber, surface mining, disposal of refuse, and construction.

**Paleovalley** – a valley in an ancient land surface or in bedrock, now covered by younger deposits.

**Perched Aquifer** – an unconfined aquifer separated from an underlying main body of groundwater by an unsaturated zone.

**Permeability** – the capacity of a porous rock, sediment, or soil to transmit a fluid. Permeability relative to water is known as hydraulic conductivity.

**Point-source Pollution** – pollution resulting from any confined, discrete source, such as a pipe, ditch, tunnel, well, container, or concentrated animal-feeding operation.

**Porosity** – the percentage of the bulk volume of a rock, sediment, or soil that is occupied by interstices, or voids.

**Potentiometric Surface** – a surface representing the total head (i.e. the height of a vertical column of water) of groundwater and defined by the levels to which water will rise in tightly cased wells.

**Recharge** – the process involved in the addition of water to the saturated zone, naturally by precipitation or runoff, or artificially by spreading or injection.

**Saturated Thickness** – the thickness of saturated materials, measured in an unconfined aquifer from the basal confining unit to the water table, or in a confined aquifer from the lower confining unit to the upper confining unit.

**Sediments** – solid fragmental material that originates from weathering of rocks, is transported or deposited by air, water, or ice, and that accumulates in a loose, unconsolidated form as sand, silt, clay, and gravel.

**Sedimentary Rock** – a rock resulting from the consolidation of loose sediment or organic remains or by precipitation from solution.

**Specific Yield** – the ratio of the volume of water that a given mass of saturated rock, sediment, or soil will yield by gravity to the total volume of that mass.

**Till** – a dominantly unsorted, unstratified, heterogeneous mixture of clay, silt, sand, gravel, and boulders ranging widely in size and shape, deposited directly by and underneath a glacier.

**Total Dissolved Solids** – a term that expresses the quantity of dissolved material such as calcium, magnesium, sodium, potassium, chloride, sulfate, and bicarbonate ions in a sample of water.

**Transgression** – the spread or extension of the sea over land areas that brings offshore, typically deep-water environments to areas formerly occupied by nearshore, typically shallow-water conditions.

**Transmissivity** – the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

**Unconfined Aquifer** – an aquifer in which the upper surface is the water table.

**Unconformity** – a surface that represents a significant break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession.

**Water Budget** – an accounting of all the flows into, outflows from, and storage in an aquifer.

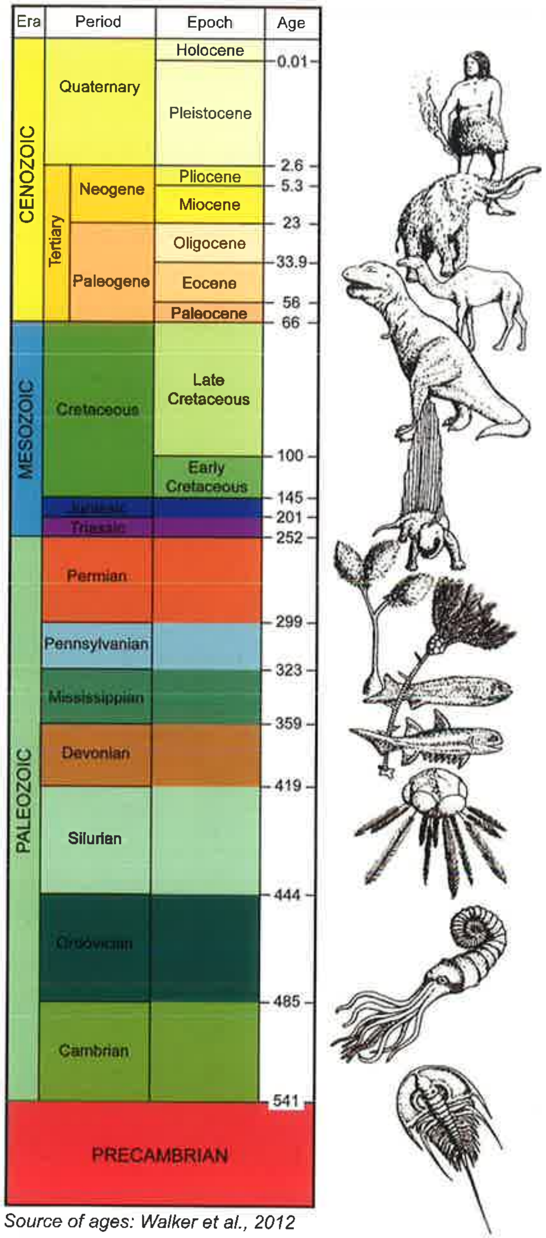
**Water Table** – that surface of a body of unconfined groundwater at which pore pressure equals atmospheric pressure and below which the pore spaces are generally saturated.

**Well Yield** – the discharge of a well at nearly steady flow.

*Conservation and Survey Division, UNL*

*Part of the archive of cuttings from thousands of test holes drilled by the Conservation and Survey Division.*

Geologic time units and
age in millions of years



*Source of ages: Walker et al., 2012*

## Factors for converting U.S. Standard units to the International System of Units (SI)

| **Multiply** | **By** | **To Obtain** |
|---|---|---|
| | **Length** | |
| inches (in) | 25.40 | millimeters (mm) |
| feet or foot (ft) | 0.3048 | meters (m) |
| miles (mi) | 1.609 | kilometers (km) |
| | **Area** | |
| acres | 4047 | square meters ($m^2$) |
| acres | 0.4047 | hectares (ha) |
| | **Volume** | |
| gallons | 3.785 | liter (l) |
| | **Flow Rate** | |
| gallons per minute (gpm) | 0.06309 | liters per second |
| cubic feet per second (cfs) | 28.32 | liters per second |
| | **Hydraulic Conductivity** | |
| feet per day | 0.3048 | meters per day |
| | **Transmissivity** | |
| gallons per day per foot | 0.01242 | square meters per day |