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The Groundwater Atlas of Nebraska

Resource Atlas No. 4

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The Groundwater Atlas of Nebraska

Resource Atlas No. 4 / 1986

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The Conservation and Survey Division of the University of Nebraska is the agency designated by statute to investigate and interpret the geologically related natural resources of the state, to make available to the public the results of these investigations and to assist in the development and conservation of these resources.

The division is authorized to enter into agreements with federal agencies to engage in cooperative surveys and investigations in the state. Publications of the division and the cooperating agencies are available from the Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska 68588-0517.

Publication and price lists are furnished upon request.

The Conservation and Survey Division provides information and services to all people without regard to race, color or national origin.

April 1986

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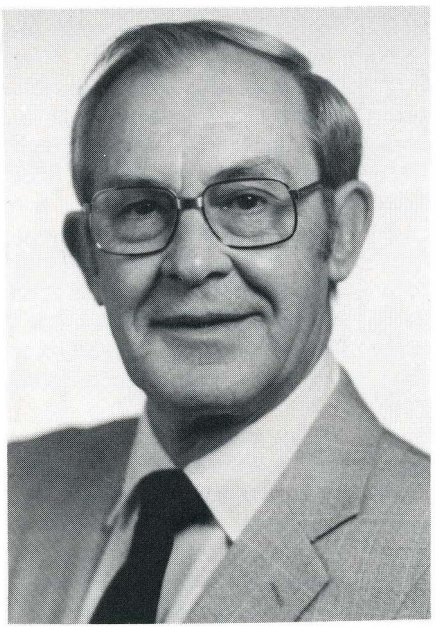
Preface

The Groundwater Atlas of Nebraska is respectfully dedicated to Vincent H. Dreeszen by the staff of the Conservation and Survey Division.

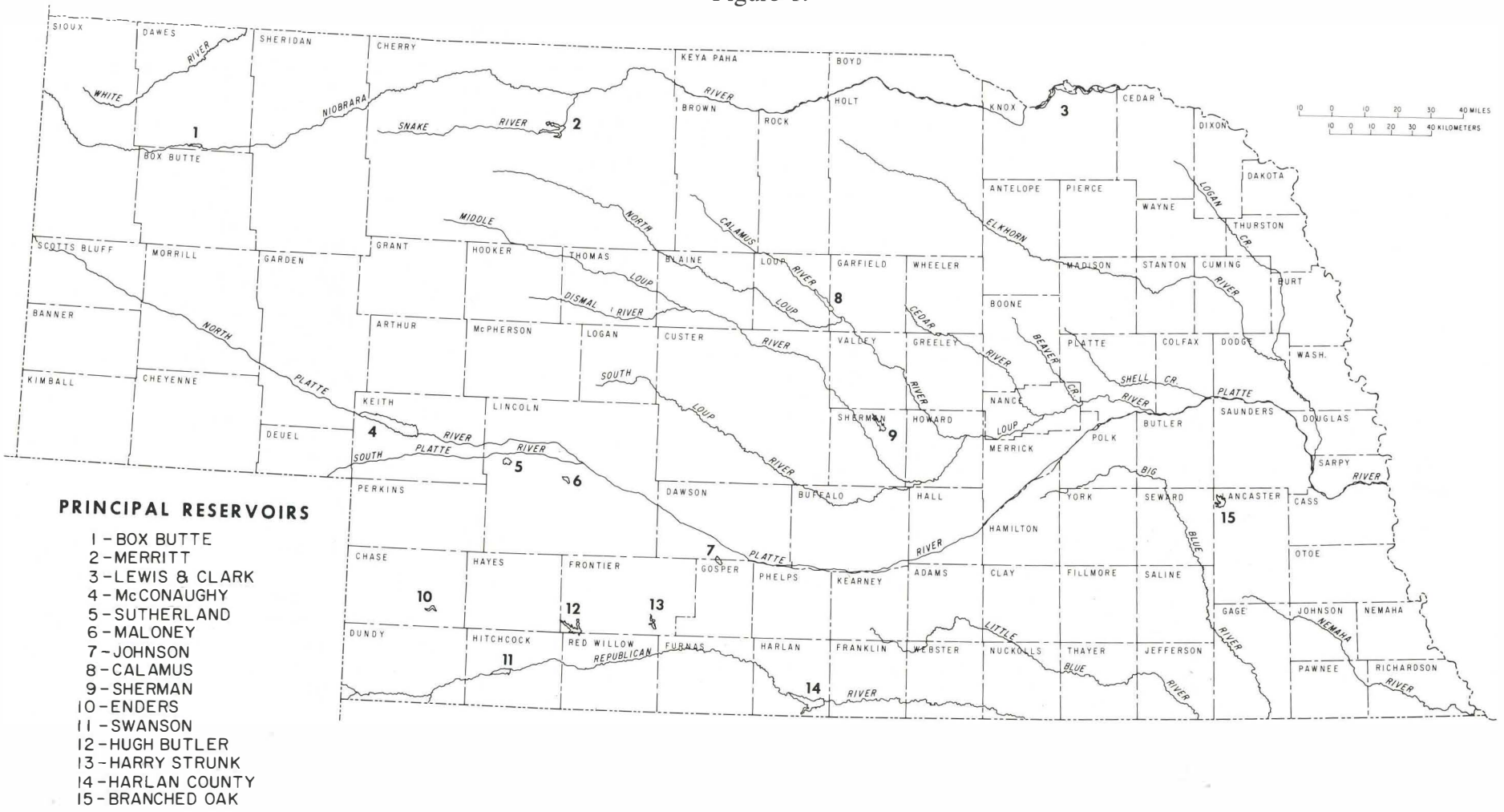


On behalf of the people of Nebraska, the staff of the Conservation and Survey Division take this opportunity to honor Vincent H. Dreeszen, our director since 1969. For nearly forty years, he has served the state and its citizens through his research and publications and in service to the division and other natural resources agencies. Under his guidance, the division has provided much basic data and counsel, particularly regarding the state's groundwater, which has contributed significantly to the appropriate use and conservation of Nebraska's natural resources.

This atlas was prepared as a cooperative project by the professional, cartographic and secretarial staff of the Conservation and Survey Division of the University of Nebraska-Lincoln. Darryll Pederson and Bob Kuzelka served as project leaders. Charles Flowerday edited the atlas.

Much of the information in the atlas is the result of cooperative projects with the U.S. Geological Survey, and the division gratefully acknowledges those contributions. Also deserving of an expression of sincere gratitude is the Nebraska Bankers Association. Its generous grant, targeted for support of printing costs at a time when groundwater is receiving considerable public attention, will help ensure the broadest possible distribution of this publication to those interested in Nebraska's groundwater resource.

Figure 1:



Base Map

Introduction

Nebraska has an abundance of water compared with most of the United States. Though some states may have greater precipitation, more water in lakes and greater streamflow, few can challenge Nebraska with respect to the amount and general availability of water stored and moving underground in porous rocks. In terms of total volume of good-quality groundwater that is available for use, Nebraska could be called "The Groundwater State."

The state's groundwater resource is a treasure underlying nearly all of its land surface. That part of this resource that is at a depth and of a quality to be usable is estimated to total about 2 billion acre-feet of water. One acre-foot is enough to cover one acre of land one foot deep with water, or is equal to 325,851 gallons. The amount of groundwater in storage is equal to about 25 years of the state's average annual precipitation, is about 250 times larger than its average annual streamflow and is about 700 times greater than the amount of water stored in its surface-water reservoirs.

Groundwater is the major source of water supply in Nebraska. It is relatively plentiful in most of the state and is used extensively as a supply for irrigation. It is also a vital and attractive resource for other uses, particularly for municipal water supplies, because it is generally constant in temperature and of good quality. Groundwater is replenished by precipitation, by some streams, by infiltration from surface water stored and/or distributed for irrigation and by planned recharge. However, the continued use of groundwater in large amounts can progressively reduce the supply in local and regional areas. Withdrawal of large amounts of groundwater reduces water in storage, natural discharge to streams and evapotranspiration.

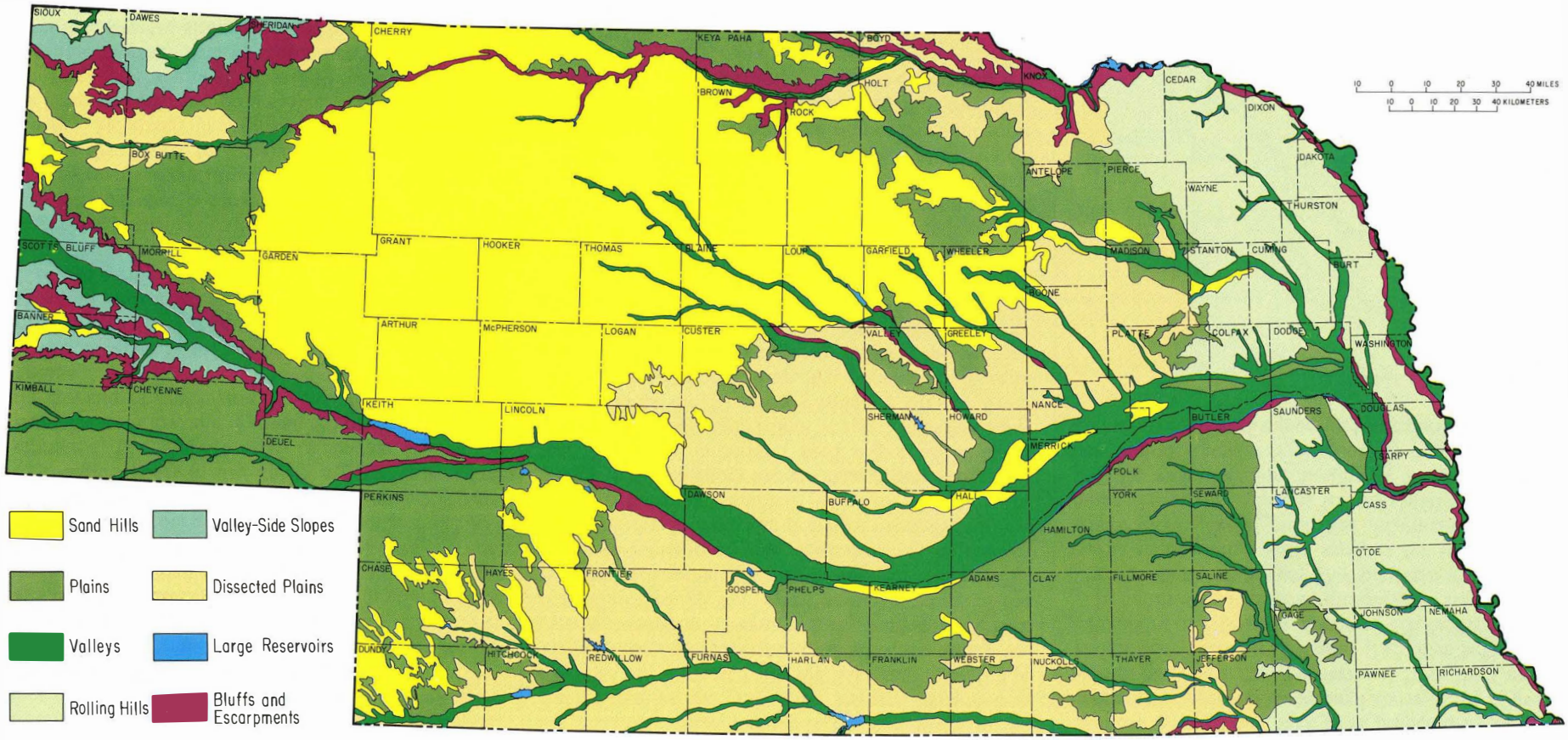
Recognizing the importance of groundwater to Nebraska and seeking to enhance the quality of knowledge about it, the Conservation and Survey Division has compiled this atlas to offer information on a range of topics related to the saturated zone under the state's land surface. The atlas contains maps and charts showing relatively current groundwater conditions in the state. Counties and geographic features illustrated in the atlas are derived from the base map (see figure 1). In the text and legends of the atlas, the term *principal groundwater reservoir* means water-bearing rock extending through the lowest permeable units of the Arikaree or Ogallala Groups or younger rocks of Pliocene or Pleistocene age, depending on the area of the state. As defined, the principal groundwater reservoir is the main source of water to wells. Not included in this category are secondary sources of water that are locally important, such as perched aquifers or rock units older than Miocene age. Secondary aquifers such as the Chadron Formation (White River Group), the Dakota Group, the Niobrara Formation and other rock units are shown only on the bedrock map and on the water-bearing properties chart (see figures 4 and 22).

In the late 1800s, the State Geological Survey, the forerunner of the Conservation and Survey Division, began studies of Nebraska's groundwater geology. An emphasis on this work has continued through several administrative reorganizations. Since 1930 the division has engaged in cooperative studies of the state's groundwater with the Water Resources Division of the U.S. Geological Survey (USGS). Much of the information in this publication is the result of this ongoing joint effort.

Since it is impossible on the scale of this atlas to show all the hydrogeologic conditions known to exist in the state, this publication includes only general maps. Local variations from the conditions shown in these illustrations and charts may occur. More detailed analyses of groundwater conditions in individual counties and regions have been prepared by the two cooperating agencies mentioned above. Lists of available publications may be obtained from the Conservation and Survey Division, 113 Nebraska Hall, University of Nebraska, Lincoln, NE 68588-0517.

In addition to its role in groundwater research, the Conservation and Survey Division also assists in locating or assessing water supplies for specific areas where more general published information is inadequate. However, requests for information should be specific as to location, preferably including a legal description, because hydrogeologic conditions differ greatly over short distances in some parts of the state.

Figure 2:



Topographic Regions

Regions of similar physical features of Nebraska's land surface are outlined on this map. It reflects the surface and subsurface geology and illustrates the effects of water, ice and wind in carving and building the present land surface. These topographic characteristics influence both the occurrence and use of groundwater in each region and were important factors in defining the groundwater regions of the state (see figure 3).

Valleys are regions of low relief along the major streams that are underlain by stream-deposited clay, silt, sand and gravel. Moisture conditions are favorable for plant growth and groundwater recharge. Evapotranspiration losses are relatively high in these shallow water-table areas, and as a result salts have concentrated in the groundwater and soils of a few areas.

Large Reservoirs were constructed to store water for irrigation, for the generation of electricity, for flood control and for recreation.

Plains are regions of relatively flat uplands generally underlain by sandstones and stream-deposited sands or gravelly sands. Soils that have formed on the mantle of wind-deposited silts (loess) are friable, fertile and allow moderate infiltration of precipitation. Runoff is low.

Dissected Plains are regions of hilly lands that have been eroded by water and wind, resulting in landforms with moderate to steep slopes, sharp ridge crests and remnants of the old plain. Generally, the soils that have formed mostly on loess are friable and fertile. They allow comparatively good infiltration of precipitation, but runoff is high because most of the land slopes.

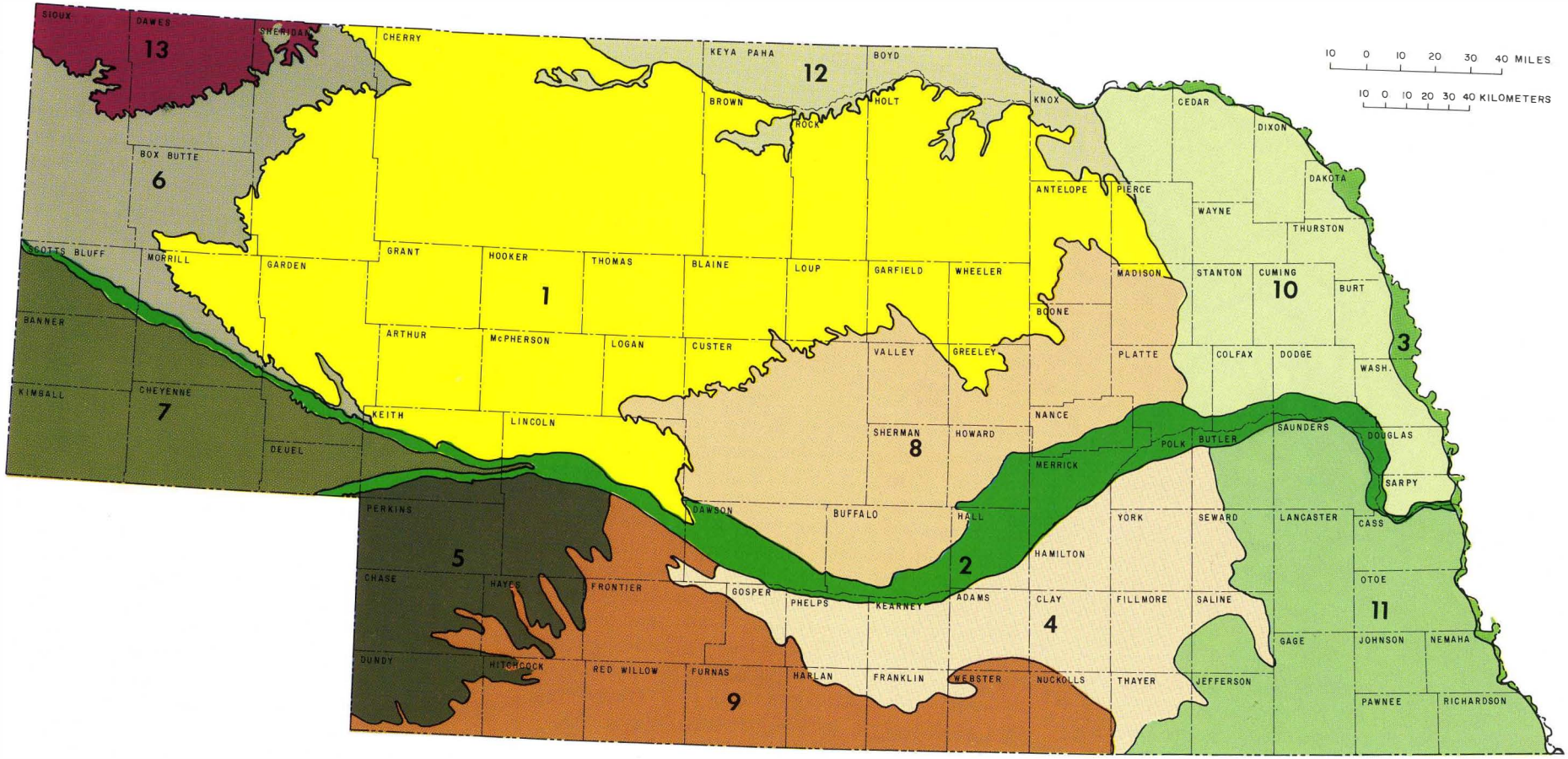
Sand Hills are regions composed of a mantle of low to high relief sand dunes that have been stabilized by vegetation. Sandstone and stream-deposited silt, sand and gravel underlie the dunes. The sandy soils permit rapid infiltration of precipitation. Streams originating in the area have a relatively constant flow due to the high rate of recharge through the sands to the groundwater reservoir. Groundwater in this region has very low concentrations of dissolved minerals.

The Rolling Hills are regions of hilly lands with moderate to steep slopes and rounded ridge crests. In eastern Nebraska they consist of a series of ridges and valleys formed by glaciers and then modified by erosion and more recent deposition. The glacial deposits consist largely of relatively impermeable boulder-clay tills. Loess in thick to thin deposits mantles the entire eastern region, permitting moderate infiltration. Perched water tables occur above the clay tills at shallow depths in much of the area. In northwestern Nebraska the region consists of eroded marine-shale hills that generally lack even small groundwater reservoirs. Because the soils are compact and clayey in this area, infiltration is low.

Bluffs and Escarpments are regions of rugged lands with very steep and irregular slopes beside some of the major valleys. The rugged terrain hinders intensive agricultural use. Runoff is high. The bluffs and escarpments generally have formed on bedrock of sandstone, siltstone, shale or limestone.

Valley-Side Slopes are regions of moderate to steep slopes between the bluffs and escarpments and the nearly level valleys in western Nebraska. These areas are mostly siltstone bedrock covered by silt, sand or gravel. Intensive agricultural use is limited, and soil-moisture conditions permit moderate plant growth.

Figure 3:



Groundwater Regions

Thirteen groundwater regions are identified on this map. Within each region groundwater occurs under similar kinds of conditions. Boundaries between regions generally represent zones of gradual change. (For more information on the water-bearing properties of the major rock units in the state, see figure 22.)

Region 1—**Sand Hills:** Large yields of good-quality water can be obtained from aquifers of Tertiary and Quaternary age. Deposits of the Ogallala Group of Tertiary age underlie the entire region but become thin toward the east. Runoff rarely occurs because precipitation readily infiltrates the sandy soils. Most groundwater either is lost by evapotranspiration from lakes between the dunes and from subirrigated meadows or is discharged by seepage into streams that are known for their uniform flow.

Region 2—**Platte River Valley:** High yields of good-quality water can be obtained from sand and gravel of Quaternary age in most parts of the region. The Ogallala Group underlies the alluvium in parts of the North Platte River and South Platte River valleys and the Platte River valley as far east as Grand Island. It is also a source of water supply. Concentrations of dissolved solids in groundwater range from 500 to more than 1,000 milligrams per liter in the alluvium throughout most of the western two-thirds of the region. The highest concentrations occur in the South Platte River valley. The water quality there is affected primarily by dissolved minerals carried from soils by infiltrating precipitation and irrigation water. In some of the Platte River valley, fertilizer applications are affecting groundwater quality.

Region 3—**Missouri River Lowlands:** Large-yield wells can be developed in sand and gravel of Quaternary age. Groundwater is more mineralized than that in the Platte River valley but is still of usable quality.

Region 4—**South Central Plains:** Abundant groundwater can be found in this region. Sand and gravel of Pliocene and Pleistocene age and the Ogallala Group of Miocene age in the west yield large amounts of good-quality water. Water-quality problems are developing in specific areas. Groundwater levels have risen in the west where water diverted from the Platte River is used for irrigation.

Region 5—**Southwestern Tablelands:** Sandstone, sand and gravel deposits of the Ogallala Group have been developed extensively for irrigation. Pumping lifts of 200 feet or more are common. Groundwater levels have declined progressively since development began.

Regions 6 and 7—**Panhandle Tablelands:** Although thick sequences of moderately permeable sediments of Tertiary age underlie the tablelands, wells are usually several hundred feet deep, and those of large capacity are restricted generally to areas underlain by the Ogallala or Arikaree Groups. Rocks beside major drainage courses usually are not saturated. In Region 7, wells also derive water from Brule Formation fractures in the valleys of Pumpkin and Lodgepole Creeks and in Sidney Draw.

Region 8—**East Central Dissected Plains:** Ogallala Group deposits underlie the western two-thirds of the region, becoming thinner toward the east. In the central and eastern parts of the region, Pliocene and Pleistocene deposits of sand and gravel, mantled by loess, are thickest within buried paleovalleys. Water quality is generally good.

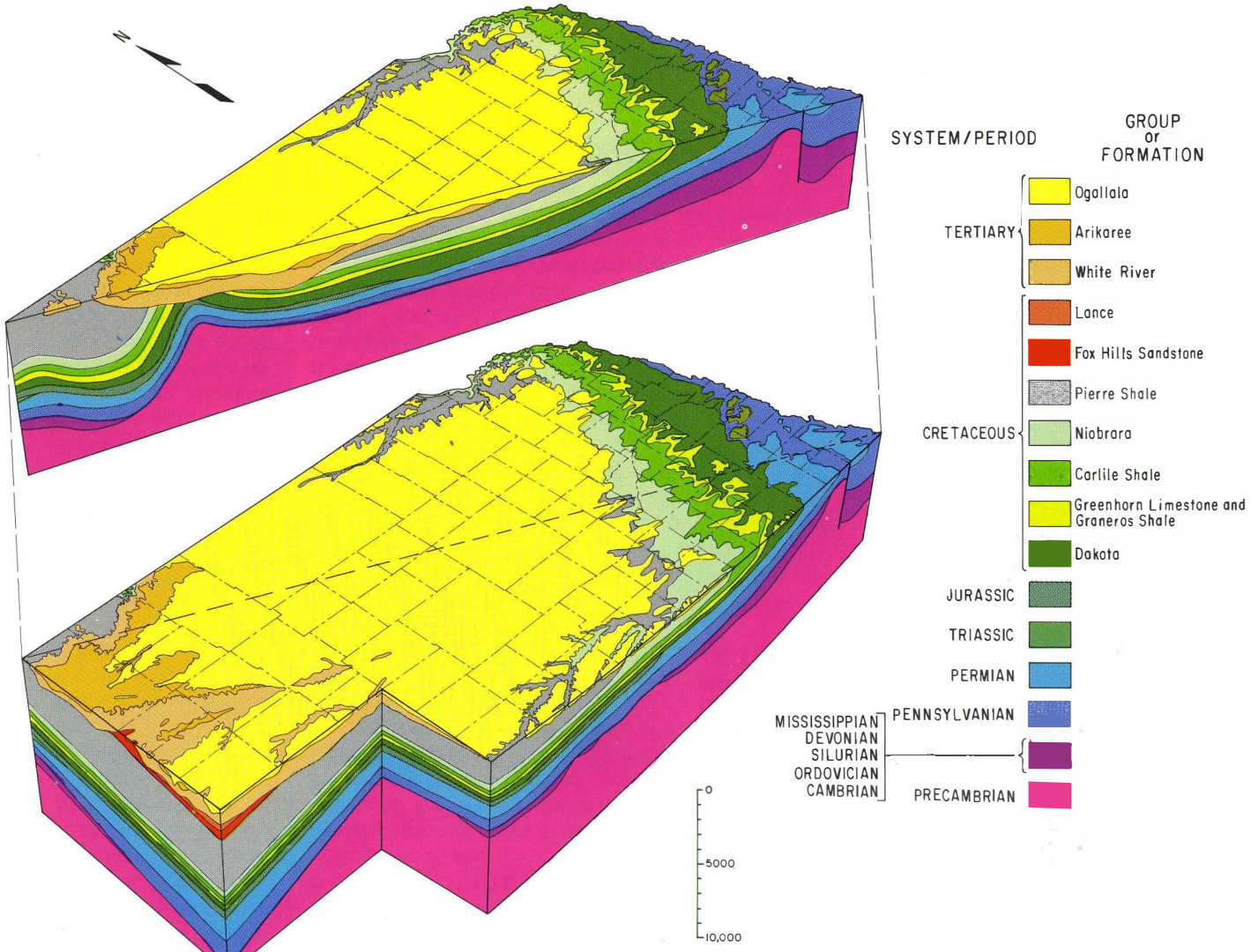
Region 9—**Republican River Valley and Dissected Plains:** Sand and gravel underlie the floodplains and terraces of the Republican River and its principal tributaries where they have cut into the uplands. Ogallala Group deposits are thickest in the northern and western parts of the region. Sand and gravel of Pliocene and Pleistocene age fill some buried paleovalleys. Cretaceous deposits of shale and chalk underlie the entire region and either are exposed or are thinly mantled by loess on the south side of the Republican River, where good-quality water is difficult to obtain.

Regions 10 and 11—**Nebraska Glacial Drift:** Glacial till of low permeability mantles most of the region. Pleistocene deposits of sand and gravel in buried paleovalleys and along stream valleys are one source of groundwater, but they are of limited extent. Sandstones of the Dakota Group are another source of groundwater. The shales and sandstones of the Dakota Group underlie much of the region, except for the southeastern part of Region 11, where older shales and limestones are the subcropping bedrock. In some locations, groundwater in the Dakota Group is very salty. The Dakota Group sediments are extremely variable, and prediction of yields from this group is difficult.

Region 12—**North Central Tableland:** The floodplains and terraces of the Niobrara River and its tributaries overlie sand and gravel deposits that generally yield small to moderate amounts of water. The eastwardly thinning Ogallala Group locally yields moderate amounts of water. Where the Pleistocene and Ogallala Group deposits have been eroded away, groundwater is available only by drilling several hundred feet to tap sandstones of the Dakota Group.

Region 13—**Hat Creek-White River Drainage Basin:** Because fine-grained deposits of Tertiary and Cretaceous age occur at the surface and underlie the region, groundwater is difficult to obtain here. Small yields are obtained from deposits underlying the river valleys and from sand lenses or fracture zones where the Brule Formation is saturated.

Figure 4:



Block Diagram of Geology

The block diagram provides several generalized perspectives of the distribution and thickness of the major units of sedimentary rocks overlying the Precambrian rocks in Nebraska. Under most of the state the Precambrian is composed of dense, crystalline igneous and metamorphic rocks. The overlying sedimentary rocks range in thickness from about 10,000 feet in western Nebraska to about 500 feet in eastern Nebraska. Most of these sedimentary rocks contain groundwater, but in differing amounts and of differing quality, depending on the region (see figure 22).

The oldest sedimentary rocks are of Cambrian and Ordovician age. These sandstones and sandy carbonates are major groundwater reservoirs in Iowa. Together with carbonate rocks of the Silurian and Devonian Periods, they were an important source of groundwater for industrial use in the Omaha area in the late 1800s and through the first half of this century. The rocks of the Mississippian Period are mostly carbonates, but they do have permeable zones. Very few data on water quality are available for these older rocks. Small yields of generally poor-quality water are obtained from rocks of the Pennsylvanian and Permian Periods in southeastern Nebraska.

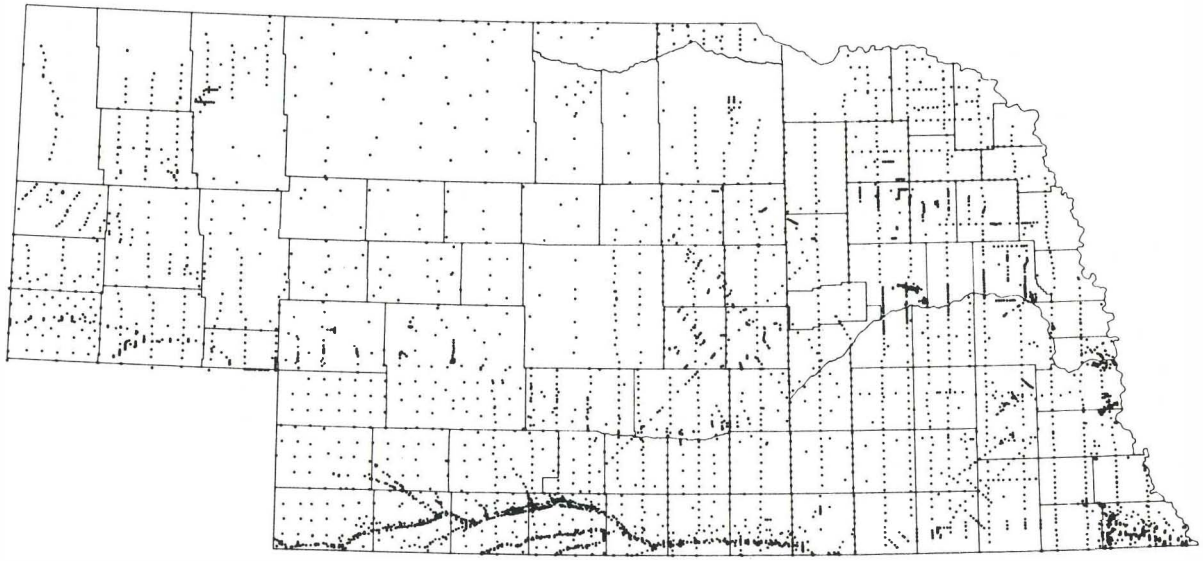
The Dakota Group is the best groundwater reservoir of rocks within the Cretaceous Period, and sandstones in this group constitute a groundwater reservoir in parts of eastern Nebraska. However, water in the Dakota can be moderately to highly saline. Most of the other Cretaceous units have low permeabilities. Fracture zones in the Niobrara Formation yield groundwater in northeastern Nebraska and in Nuckolls and Fillmore Counties. Limestone in the Greenhorn Formation and sandstones in the Carlile or Niobrara Formations and the Pierre, Fox Hills and Lance Formations have all supplied low-yield wells. Rocks of the Cretaceous and older periods have not been thoroughly evaluated as aquifers because other sources of water supply generally are more readily available.

All stratigraphic subdivisions of the Tertiary Period serve as groundwater reservoirs in various areas of the state. The Ogallala Group is the most widely distributed of these and constitutes a major part of the groundwater reservoir. The highly variable sediments younger than the Ogallala Group mantle a large portion of the state and comprise the remainder of the principal groundwater reservoir. These sediments are not illustrated on this generalized diagram.

The locations of test holes for hydrogeologic research are shown on this map. Test drilling is the major source of detailed information about the state's groundwater. Most of the test holes have resulted from a program of systematic drilling carried out as a cooperative project between the Conservation and Survey Division and the Water Resources Division of the U.S. Geological Survey. Other specific hydrogeologic research projects and stratigraphic investigations have also contributed test-drilling data. Data from these test holes have been systematically collected, interpreted and filed.

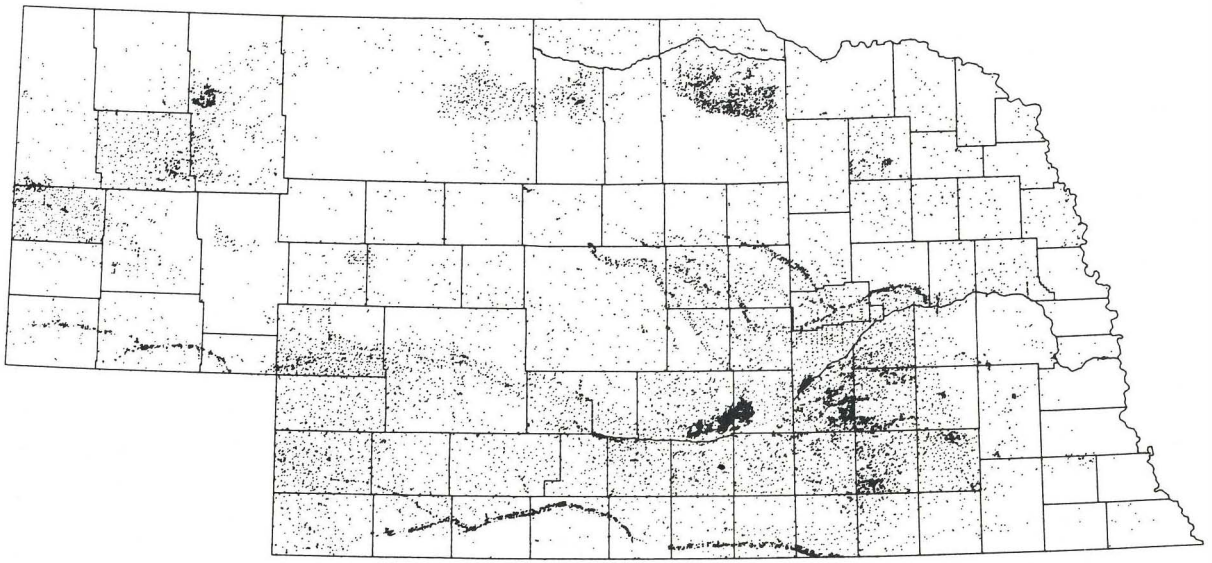
This framework of carefully documented information has been supplemented by the drilling records of private contractors and other state and federal agencies. The general hydrogeologic characteristics of the groundwater reservoir in Nebraska have been described in a number of state and federal publications. Although detailed research has been done in specific areas, there is still much to learn about the aquifer systems, particularly as they are subjected to the stresses of increasing rates of groundwater withdrawals and an increasing risk of contamination.

Figure 5:



Location of Test Drilling for Hydrogeologic Investigations

Figure 6:

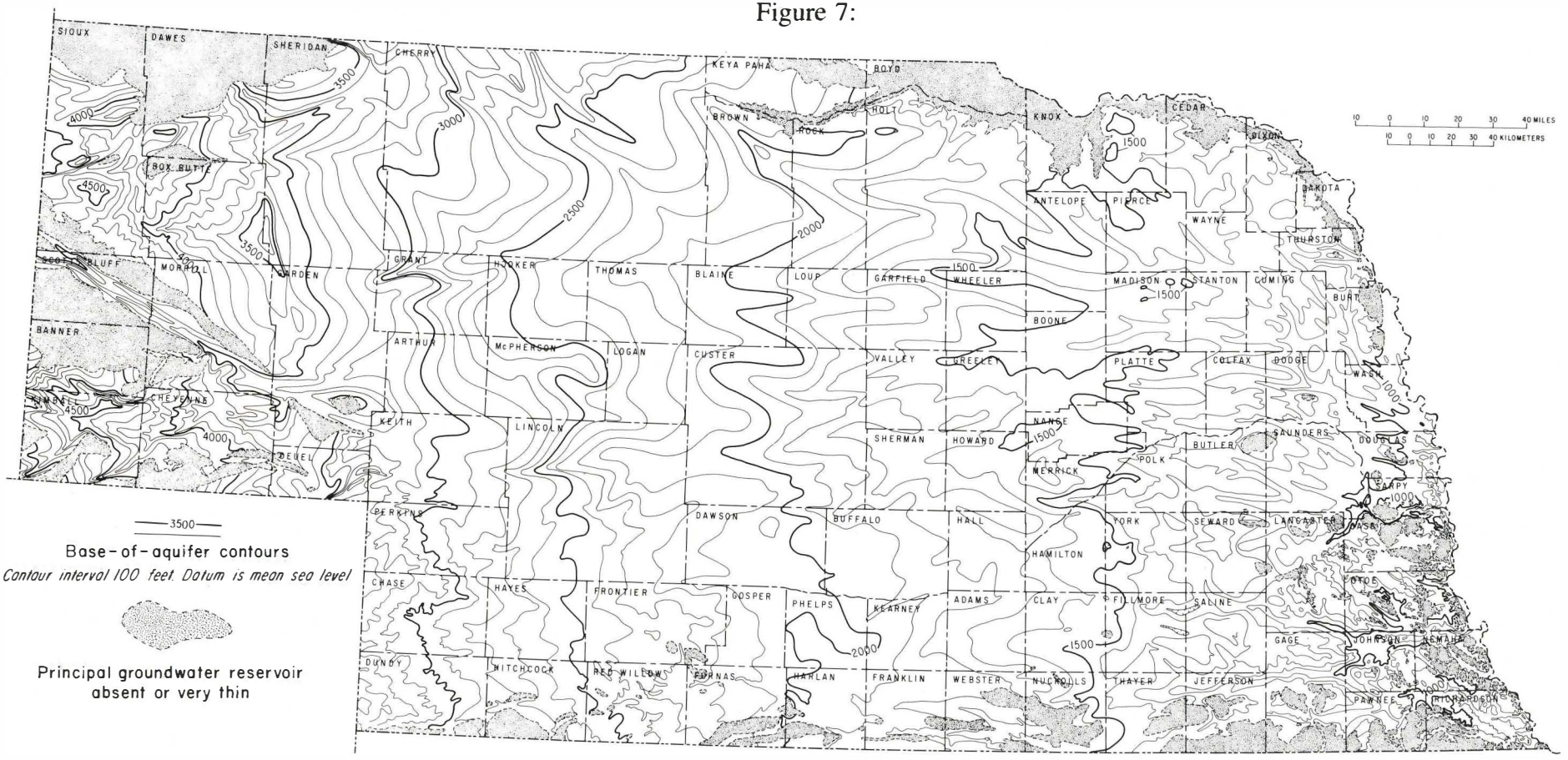


Location of Observation Wells for the Groundwater-Level Monitoring Program

A statewide project to monitor water levels began in 1930 as a part of the cooperative groundwater program between the Conservation and Survey Division and the Water Resources Division of the U.S. Geological Survey. This map shows the locations of wells measured during 1984. Over thirty agencies, including Nebraska's twenty-four natural resources districts, currently collect data related to this project. The cooperative program provides for a coordinated collection of data, the results of which are kept in a computerized data-storage system.

The statewide network has kept and has provided long-term data on changes in water in storage and currently indicates where locally significant water-level changes are occurring. As part of the cooperative program, the Conservation and Survey Division and the Water Resources Division of USGS publish an annual report summarizing the observation well data.

Figure 7:



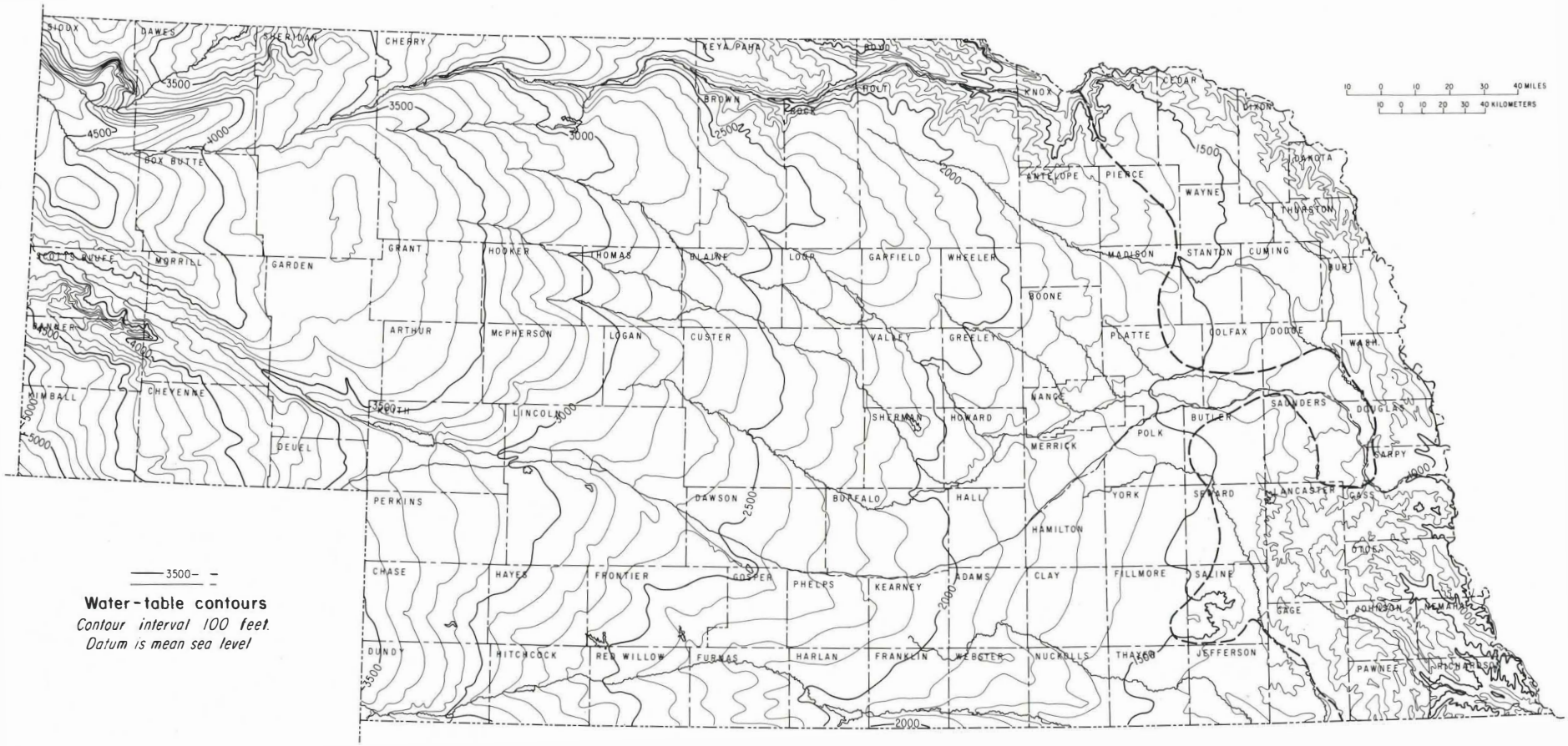
Configuration of the Base of the Principal Groundwater Reservoir

The shape of the bottom surface of the principal groundwater reservoir is shown by the contour lines on this map. Although rocks below that surface may be saturated, they would yield water mostly at slow rates or would yield water of poor quality. Exceptions to this generalization are siltstone and sandstone of Oligocene age and sandstone, chalk, limestone and dolomite of the Cretaceous and Paleozoic ages (see figure 22).

The bottom surface of the principal groundwater reservoir does not coincide with the bottom of a single stratigraphic layer in the rock sequence underlying Nebraska. Instead, it coincides with the bottom of different stratigraphic layers from one part of the state to another. For most of Nebraska's panhandle, the base of the principal groundwater reservoir is considered to be the base of the Arikaree Group; for much of the central part of the state, it is the base of the Ogallala Group; and for most of the eastern part, it is either the base of the Quaternary deposits or the base of the lowest coarse-textured sediments within those deposits. Rocks directly underlying the principal groundwater reservoir are of Pennsylvanian and Permian age in southeastern Nebraska, of Cretaceous age in most of the remainder of the state's eastern half and of the oldest Tertiary rocks (Chadron and Brule Formations of the White River Group) in its western half (see figure 4).

Data used in generating this map differ greatly in distribution and reliability from place to place in the state. As more data become available, refinement of the map will be possible. The larger scale (1:250,000) maps used in compiling this small-scale map and the other small-scale maps in this atlas related to the principal groundwater reservoir are available from the Conservation and Survey Division.

Figure 8:



Configuration of the Regional Water Table

The regional water table is generally defined as the upper surface of the water that fills spaces in unconsolidated sediments or in consolidated rocks throughout a given region. Such spaces are mainly between grains, in cavities caused by dissolution or in fractures. They allow water to be transmitted toward some point or area of discharge at the land surface.

As depicted on this map by the water-table contour lines (lines of equal elevation above mean sea level), the regional water table is a subdued reflection of the land surface. Thus, since the land surface of Nebraska slopes generally eastward, the water table slopes generally in the same direction. The land surface is irregular because streams have carved valleys into it, and the water table reflects those valleys that have been cut deep enough for groundwater to discharge. Even if streams were not shown on the map, their valleys could be located by the upgradient V's in the water-table contour lines.

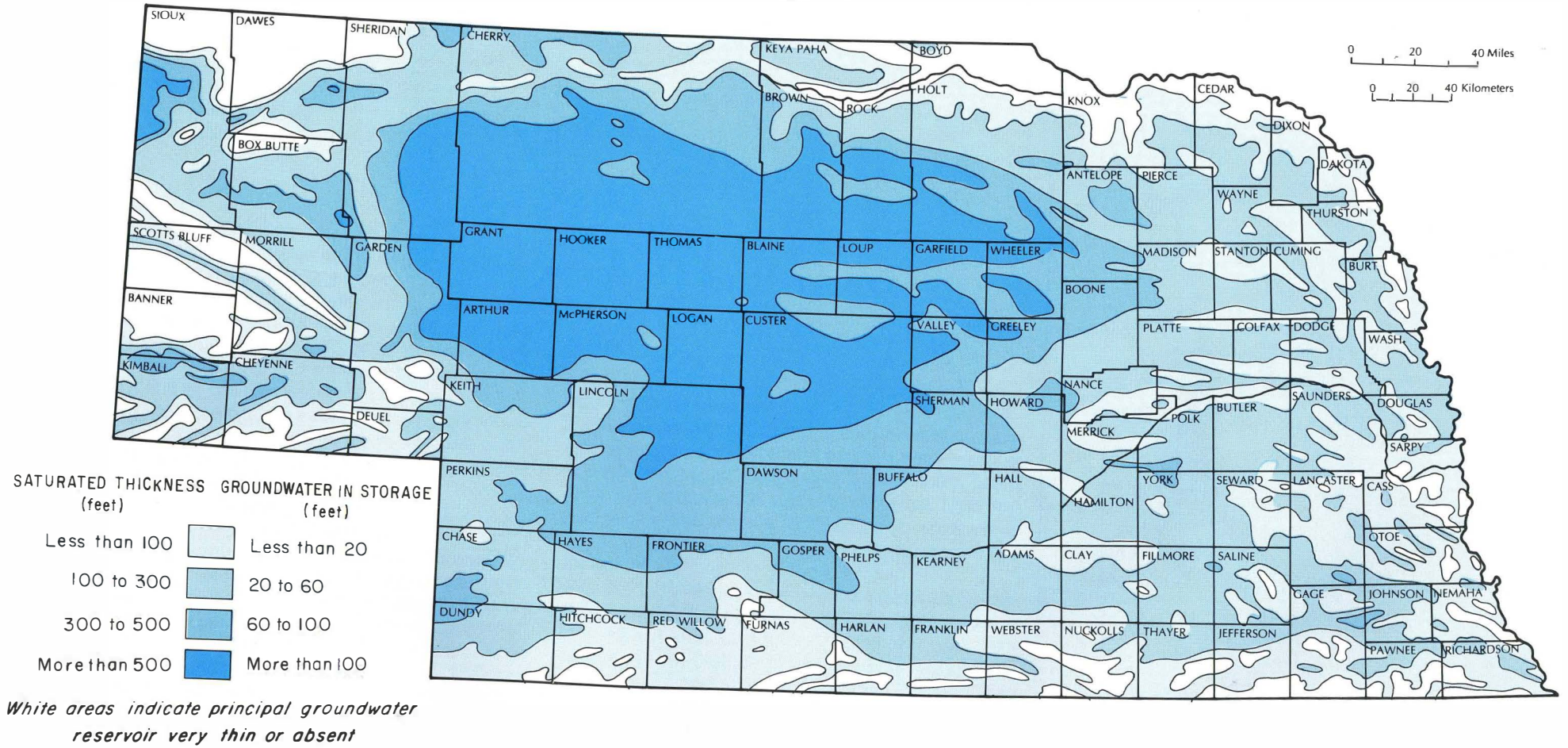
The points of control used for delineating the water-table configuration are water levels in wells not being pumped when those levels were measured in the spring of 1979 and of the topographic elevations anywhere groundwater is known to be discharging at the land surface. Admittedly, the water level in many wells does not coincide precisely with the water table since the position of the screen through which water enters a well and local geologic conditions can affect the level at which water stands in the well.

In many places in eastern Nebraska and in some places elsewhere in the state, layers of very fine textured sediments that retard downward movement of water are contained within deposits that are coarser textured and capable of transmitting water more freely. These fine-textured layers so hamper percolation of water that they may create a zone of saturation above them. Such zones are known as *perched groundwater* if they are separated from the regional zone of saturation by intervening unsaturated sediments. The existence of perched groundwater cannot be determined readily unless water-level data for both perched and regional zones of saturation are available. The existence of perched groundwater further complicates the accurate delineation of the regional water-table configuration.

The hydrologists who collaborated in making this map had to exercise their judgment in selecting water-level data representing the regional water table, especially east of the dashed line. Some control points east of the line may represent perched water levels or water levels resulting from the confinement of water under artesian pressure.

Natural rates of lateral groundwater movement range from a few inches per year to as much as a few feet per day. The movement is downgradient and perpendicular to the water-table contour lines. Pumping from a single well causes a temporary steepening of the water table around the immediate area of the well but has no appreciable effect on the representation of the water-table configuration. On the other hand, long-term pumping of large-discharge wells that are concentrated in a single area can cause distortion of the shape of the water table.

Figure 9:



Saturated Thickness of the Principal Groundwater Reservoir

The saturated thickness map was created by superimposing maps showing the regional water-table configuration in the spring of 1979 (see figure 8) on same-scale maps showing the configuration of the base of the principal groundwater reservoir (see figure 7) and then computing the differences between those two surfaces. In Nebraska, saturated thickness ranges from 0 to more than 1,000 feet. Those areas where the saturated zone is so thin as to be negligible are indicated by stippling. The areas of their greatest extent are in the panhandle and northeastern parts of the state. Such areas are also small but numerous along the southern border of the state and east of the dashed line. The areas of greatest saturated thickness—more than 600 feet—underlie the Sand Hills region, where current water use is relatively small. Thicknesses ranging from 100 to 400 feet underlie the areas where groundwater withdrawals, mostly for irrigation, are greatest.

Thicknesses on this map indicate water-saturated sediments ranging from fine to coarse texture. A thin saturated thickness of coarse-textured sediments may yield larger amounts of water than fine-textured sediments of a greater saturated thickness. Hence, saturated thickness is only one of several factors serving as guides to the development of water supplies.

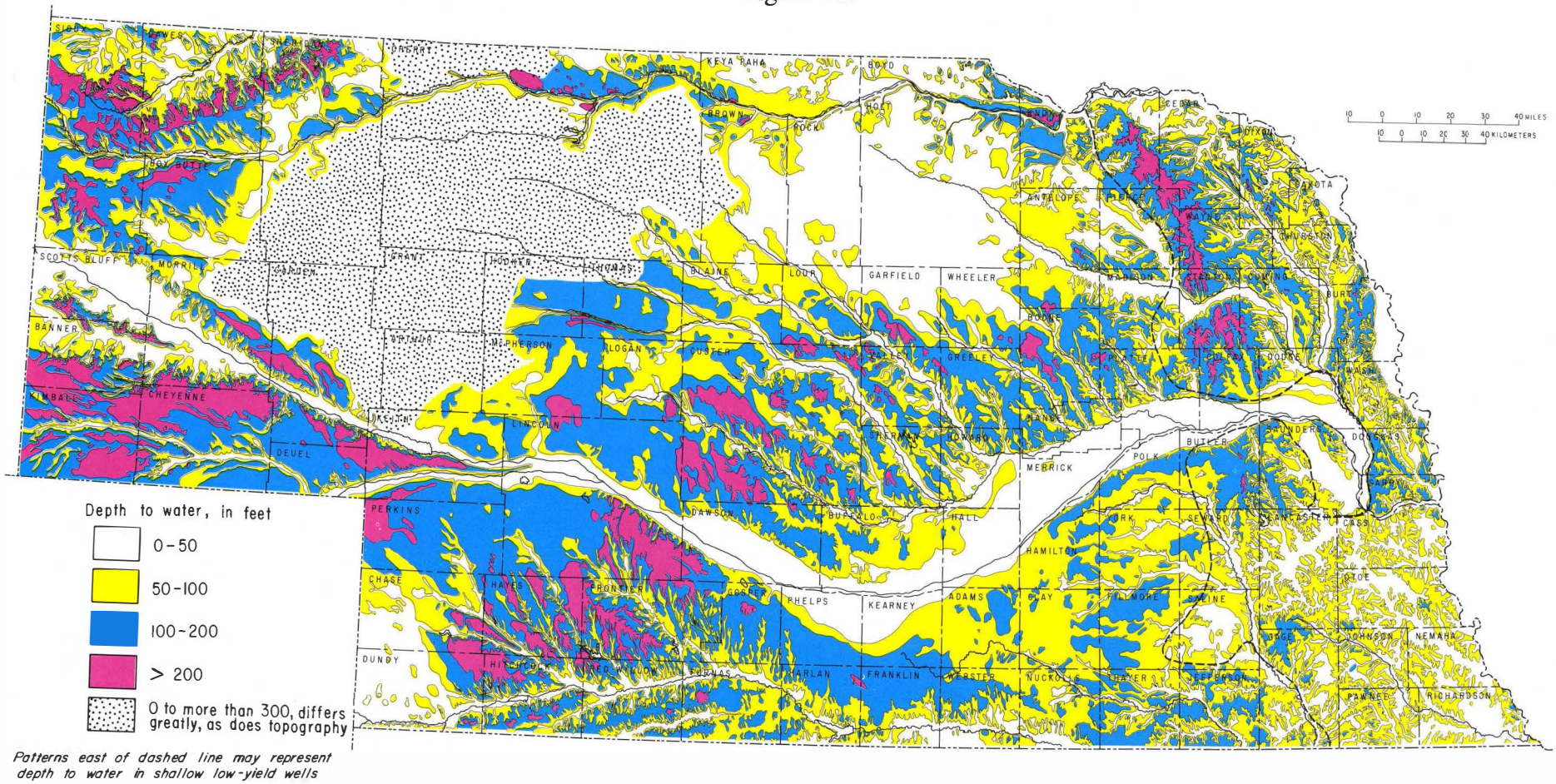
In evaluating the volume of the principal groundwater reservoir, it is also important to consider that this reservoir is part of a dynamic recharge and discharge system. Nearly all the recharge to a local aquifer results from precipitation falling on overlying land. Additional recharge may come from stream seepage and applied irrigation water. Groundwater is discharged from wells that are pumped, wells that flow without being pumped, springs, perennial streams and some lakes and swamps that are hydraulically continuous with saturated earth materials.

Before development of the water supply, a dynamic equilibrium existed that was reflected by relatively stable groundwater levels. Because recharge approximately equaled discharge in that condition, groundwater in storage remained about the same. Since the rate of intensive development of the state's groundwater began to accelerate during the 1940s and 1950s, pumping for irrigation and other uses has increased the amount of discharge. A decline of water levels reflects the removal of groundwater from storage. In some areas of the state, storage, transmission and application of surface water for irrigation have increased the amount of recharge and have raised groundwater levels (see figure 21).

All totaled, a conservative estimate of the volume of groundwater in storage represented by this map is 2 billion acre-feet. This volume is estimated by multiplying the saturated thickness by 0.2 (specific yield is assumed to be 20 percent). That estimate is conservative because it accounts for only the more readily available water in the coarse-textured portions of the groundwater reservoir. Not included are large amounts of water in secondary aquifers that may or may not contain water of usable quality.

The large volume of water stored in groundwater reservoirs in Nebraska is of interest because few other regions of a similar size have comparable amounts of readily available, good-quality water occurring at relatively shallow depths. However, the amount of water available for withdrawal is an issue subject to many diverse considerations, including economics, surface water-groundwater relationships, adverse environmental impacts and the use of a variety of management techniques, such as artificial recharge or the regulation of groundwater withdrawals.

Figure 10:



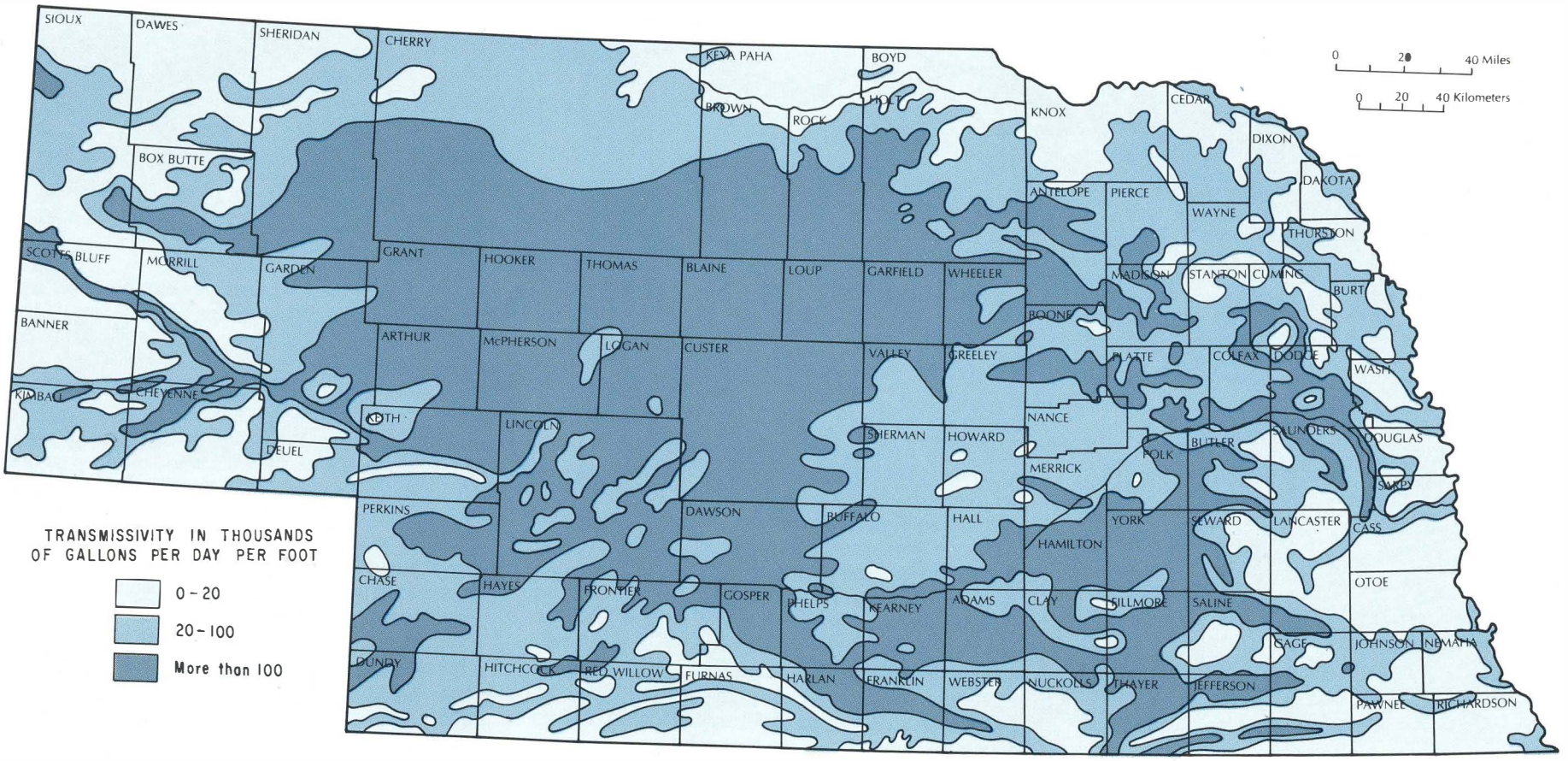
Depth to the Regional Water Table

The depth to the regional water table as shown on this map was derived by superimposing topographic quadrangle maps of the U.S. Geological Survey on same-scale maps showing the configuration of the regional water table (see figure 8) and then computing the differences between the two surfaces. The qualifications stated in the text describing the water-table configuration map apply to this map also. Depths to water differ greatly from place to place in the state. In many places they may range from about 50 feet to about 200 feet within a distance of less than 5 miles. In general, depths to water are least under the valleys of the principal streams, beneath a large area that includes most of Rock and Holt Counties in north-central Nebraska and beneath another, smaller area in Dundy and Chase Counties in the southwestern part of the state. Greater depths to water generally occur in the upland areas between the principal valleys.

In a large part of the Sand Hills region, the dune topography makes practically impossible any indication of depth-to-water patterns on a map of this size. Depth to water beneath the higher dunes may be greater than 300 feet and beneath intervening valleys may be less than 50 feet. In places, such a wide range would require four depth-to-water patterns within distances too small for them to be clearly represented on this map. Therefore, the stippled pattern distinguishes this area from the remainder of the state.

Depth to water is another important consideration in developing groundwater supplies. However, factors of more importance are the thickness of the saturated zone and the capacity of that zone to transmit water to wells. Depth-to-water data do indicate the thickness of deposits that must be penetrated to reach an unconfined zone of saturation, but they are only one factor indicating how much pumping lift is required to bring water to the land surface. Other important considerations regarding lift are the transmissivity of the aquifer being developed and the kind of well construction and development. Where groundwater is confined under much pressure, as in an artesian aquifer, water would rise in a well beyond the top of the confined saturated zone, and the pumping lift could be less than the depth to that confined zone. In addition, in the area where perched groundwater is common (east of the dashed line), water may occur in a well at a depth less than is indicated by the depth-to-water patterns. However, these shallow zones of saturation generally would yield only enough water for a domestic supply.

Figure 11:



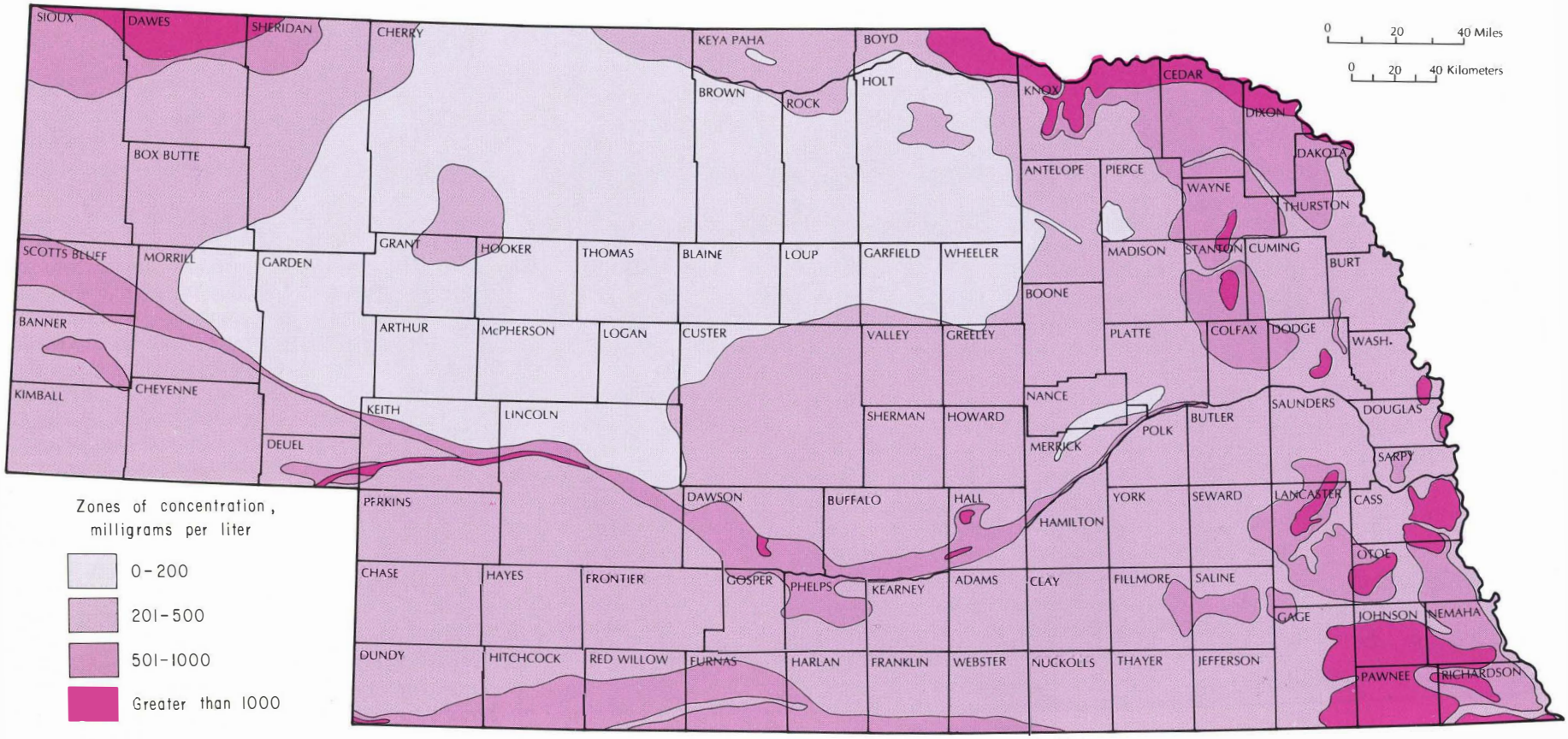
Transmissivity of the Principal Groundwater Reservoir

Transmissivity is a measure of the volume of groundwater that will flow through a given width of an aquifer under a specified slope of the water table. In practical terms, it provides a measure of the ability of an aquifer to supply water to wells. Transmissivity is dependent on a combination of the saturated thickness and the permeability of the aquifer. Thick aquifers of highly permeable materials have the highest transmissivity. The conversion of transmissivity values to potential well yields requires the consideration of more factors than transmissivity alone, such as the type of well construction and development, the amount of drawdown and whether the groundwater is confined or unconfined. Usually, where transmissivity values exceed 20,000 gallons per day per foot, wells can be developed with yields adequate for some types of irrigation. Where transmissivity values exceed 100,000 gallons per day per foot, high-capacity wells of more than one thousand gallons per minute can be developed for irrigation or other purposes.

Coarse-grained sediment is generally more permeable than fine-grained sediment. The areas showing the highest transmissivity have coarse-grained deposits of sand, sandstone and/or sandy gravel. Low transmissivity areas are characterized either by fine-grained deposits or by thin deposits of coarse-grained sediments. In such areas, the depth to bedrock generally is shallow or the overlying till is thick, as in the eastern part of the state.

The greatest thickness of saturated, coarse-grained deposits in the state underlies the Sand Hills region. Transmissivity values are high in this region, as they are in the North Platte River and South Platte River valleys, the Platte River valley and in much of the Big Blue River basin. Local areas of high transmissivity also occur where thick layers of sand and gravel fill bedrock paleovalleys. An example of the location of a paleovalley is the band of high transmissivity across southern Thayer, Jefferson and Gage Counties.

Figure 12:



Concentration of Total Dissolved Solids in the Principal Groundwater Reservoir

Concentration of total dissolved solids (TDS) is shown on this map and includes the major dissolved constituents: calcium, magnesium, sodium, potassium, bicarbonate, sulfate and chloride. Most groundwater in the principal reservoir contains low levels of total dissolved solids. In a few areas of the major river valleys, concentrations of TDS exceed 500 milligrams per liter in the principal groundwater reservoir. These areas have been affected by seepage from rivers that may have been enriched in total dissolved solids by evapotranspiration and by irrigation return flows. Other areas of concentrations of TDS higher than 500 milligrams per liter are in extreme northwest Nebraska, along the state's southern border and in the glacial till of the eastern part of the state.

The U.S. Public Health Service in 1962 recommended a limit of 500 milligrams per liter of TDS in drinking water. Regulations implemented in 1977 by the U.S. Environmental Protection Agency (EPA) do not contain a specific limit for TDS, but secondary guidelines that are based generally on aesthetic considerations include a limit of 500 milligrams per liter.

Although the concentration of total dissolved solids serves to indicate the level of mineralization of water in the principal groundwater reservoir, this is only one aspect of water quality. TDS is not an indicator of health-related contaminants, such as nitrates, radioactive and nonradioactive metals and organic compounds. In various locations across the state, water occurs in wells with concentrations of nitrates (as nitrogen) exceeding the EPA standard for drinking water of 10 milligrams per liter. Many organic chemicals become injurious to health at concentrations considerably less than one milligram per liter, and TDS levels usually offer no clues to the presence of these chemicals. Considerable variance from average quality can occur at different depths or times at any specific site. Analysis for specific potential contaminants in a well is warranted when there may be a health concern related to water.

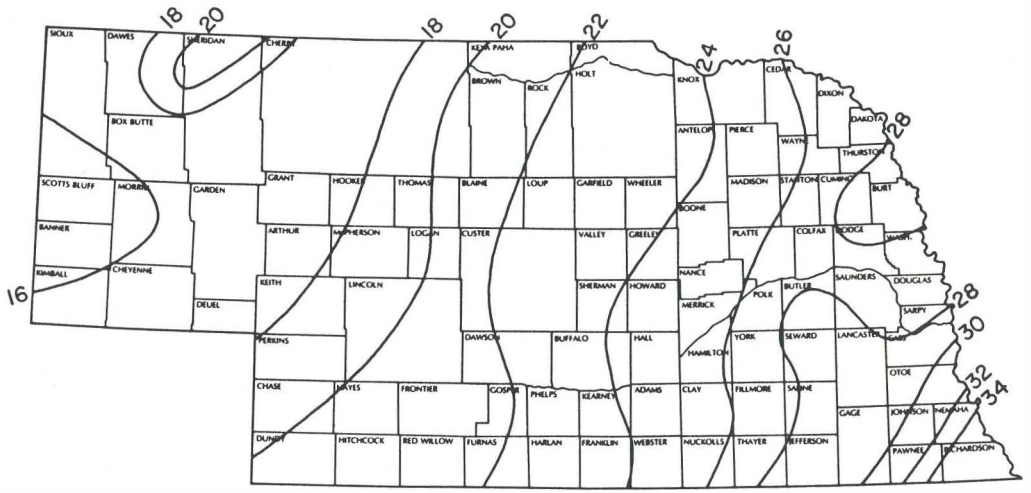
Historical Trends in Groundwater Use for Irrigation

Irrigation has had a fundamental role in making Nebraska a leading state in agricultural productivity. Surface water met most demands for irrigation supplies until about the mid-1930s. Since then, especially after the mid-1950s, the use of groundwater for irrigation has increased rapidly. By 1980 groundwater supplied an estimated 72 percent of all water withdrawn or diverted for irrigation in the state.

Compared to other uses of groundwater in Nebraska, irrigation is by far the largest, accounting for 94 percent of the estimated 7,160 million gallons per day of total groundwater withdrawn in Nebraska during 1980. In general, besides supplying almost three-quarters of the state's irrigation supplies, groundwater also comprises about 78 percent of public water supplies, about 85 percent of self-supplied industrial use, about 86 percent of rural domestic and livestock supplies and about 1 percent of the water used for cooling in thermoelectric power generation.

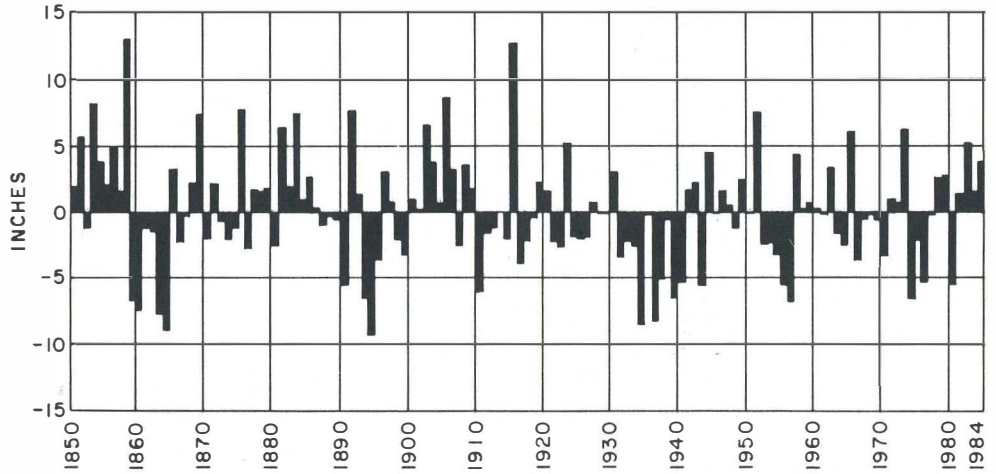
In much of Nebraska, irrigation is needed to supplement precipitation in order to satisfy the water demands of most crops. Many of the state's crops require at least 22 inches of water annually for maximum yield. Figure 13 shows that much of the state does not ordinarily receive this amount of annual precipitation. In addition, all of the annual precipitation is not available for plant use, and even in the more humid, eastern part of the state, dry weather during critical growing periods is common. Since 1936, when the total wells installed in the state numbered about 1,200 (see figure 15), the number of registered wells has multiplied almost 60 times, to more than 70,000 wells serving about 85 percent of the state's irrigated land.

Figure 13:



Mean Annual Precipitation in Inches, 1900-1979

Figure 14:



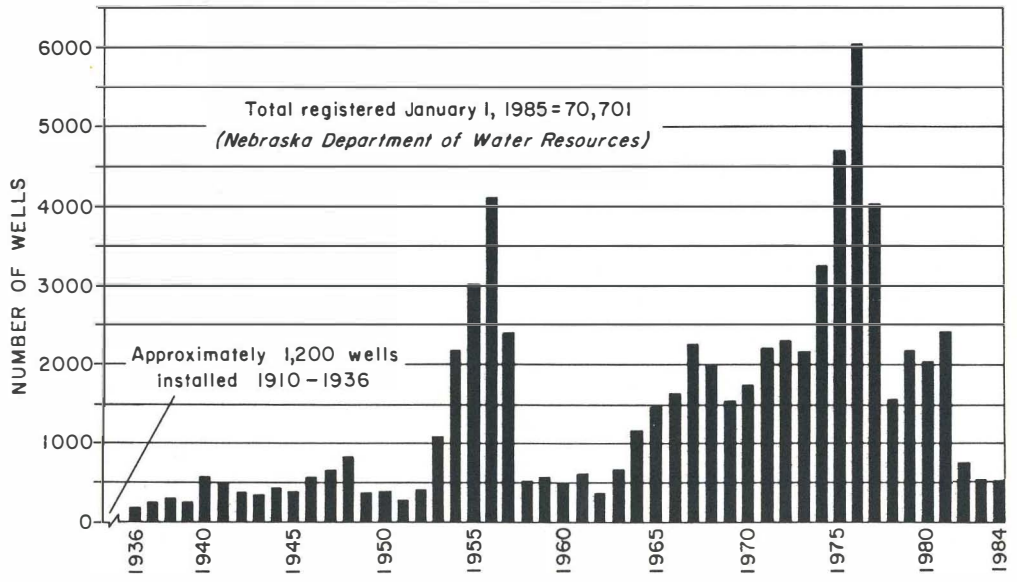
Annual Departures from Average Annual Precipitation, 1850-1984

Climate, as well as geography, has influenced the development of irrigation wells. The peaks of annual installation of irrigation wells shown in figure 15 correspond to periods when the state's mean annual precipitation has fallen more than 5 inches below normal (see figure 14). A combination of economic factors, such as good crop prices, low-cost energy, low cost of fertilizer, availability of credit and certain tax credit laws, also contributed to irrigation development through the 1970s.

By the end of 1984, a total of 70,701 irrigation wells had been registered in Nebraska. Although these wells have been installed in all of the state's 93 counties, their number and density differ greatly from one county to another because of variations in land use, distribution of irrigable land and availability of groundwater. About 60 percent of the registered irrigation wells are concentrated in a 13-county area comprising the upper part of the Big Blue River and Little Blue River basins and the central part of the Platte River valley. Buffalo, Dawson, Hall, Hamilton, Merrick and York Counties have more than 2,500 irrigation wells each. Counties nearby—Adams, Butler, Clay, Fillmore, Kearney, Phelps and Polk—have more than 1,000 irrigation wells each. Antelope, Boone, Chase, Custer, Dodge, Holt, Lincoln, Platte, Seward and Thayer Counties are the only other counties in the state that have more than 1,000 irrigation wells each.

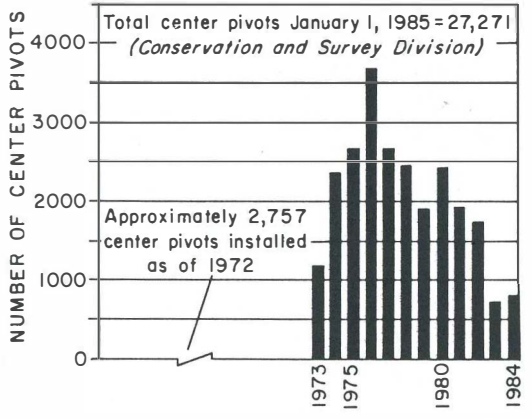
(continued on next page)

Figure 15:



Annual Installation of Registered Irrigation Wells, 1936-1984

Figure 16:



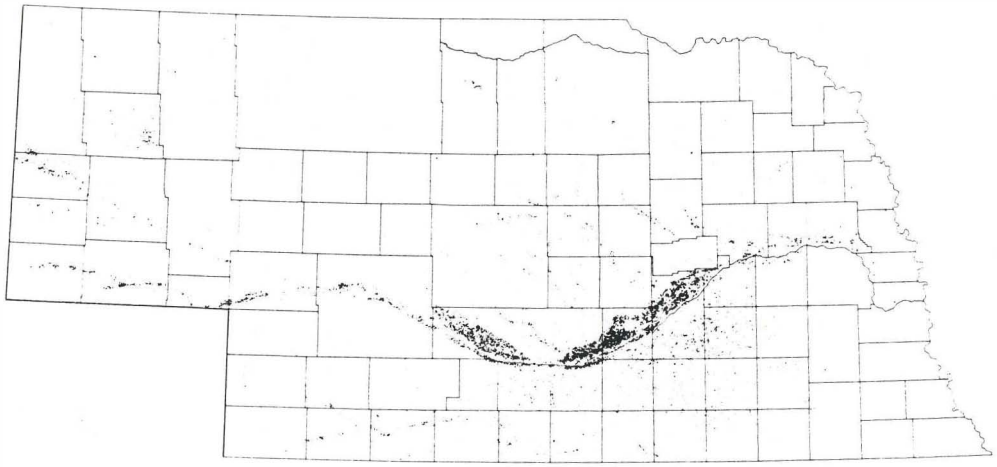
Annual Installation of Center-Pivot Irrigation Systems, 1973-1984

Historical Trends in Groundwater Use for Irrigation *(continued)*

Although the totals just mentioned provide some indication of the degree of groundwater development in a given county, the number of irrigation wells per square mile of land in that county is a better index of the intensity of development. A high density of irrigation wells in a county generally indicates a large percentage of irrigable land and large amounts of available groundwater. Very low densities generally characterize counties where development is limited by a general lack of irrigable land, by aquifers that yield only small amounts of water to wells or by both. Merrick County, averaging 7.7 irrigation wells per square mile of land, has the highest well density of any county in the state. Pawnee County has the lowest well density, averaging about one irrigation well per 217 square miles.

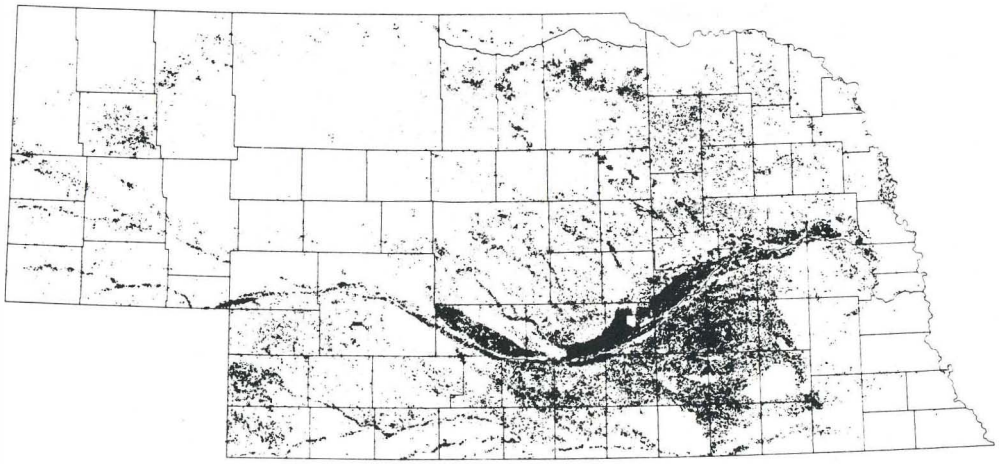
All the previously mentioned factors—geographic, climatic and economic—have also contributed to the increased use of center-pivot systems for irrigation in Nebraska. These systems are almost entirely supplied by groundwater. In recent years, center-pivot system installations have exceeded new irrigation well installations (see figures 15 and 16). This would indicate a conversion from gravity and other types of distribution systems to center-pivot systems.

Figure 17:



Location of Irrigation Wells, 1951

Figure 18:

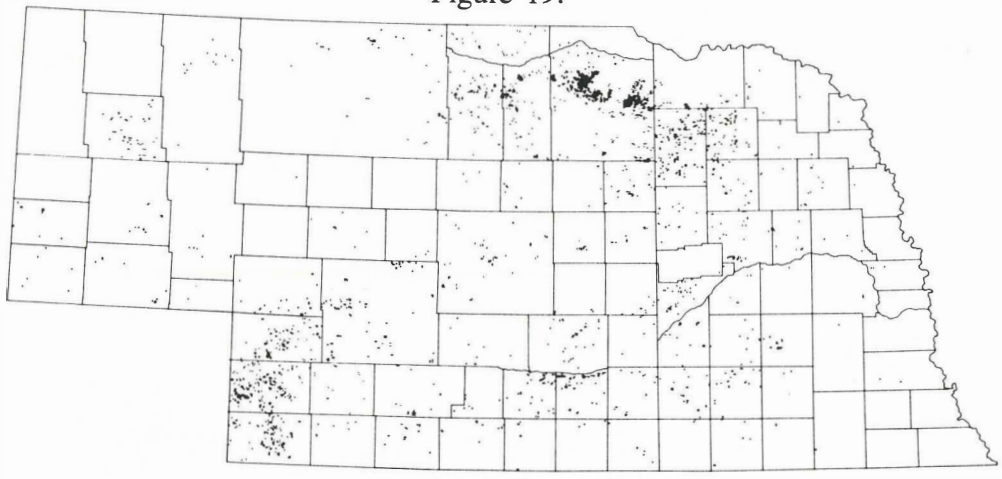


Location of Irrigation Wells, 1983

Center-pivot irrigation systems have played an important role in expanding irrigation from level land to hilly topography and sandy soils. Generally, the areas of new development are in the northeastern, central and southwestern parts of the state, where center-pivot irrigation systems provide a way to overcome limitations imposed by soil type and/or topography. However, the location of these systems has also been controlled by the availability of water. As the design and engineering of the systems advanced, land was irrigated in areas where such development had not been feasible in the past. Technological advancement is also a consideration in identifying patterns of future development and management of these systems.

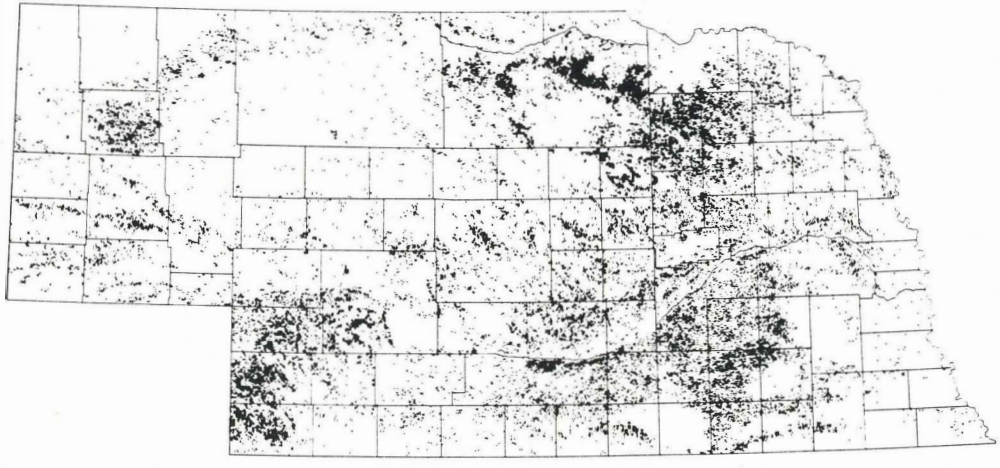
Figures 19 and 20 show the expansion of center-pivot irrigation from 1972 to 1984. The first inventory, conducted in 1972, counted 2,757 systems. By 1985 the number of systems had increased to 27,271. The average system irrigates about 133 acres, and some single systems irrigate fields of more than 500 acres. The total land area in Nebraska under irrigation by center-pivot systems in 1984 was about 3.4 million acres.

Figure 19:



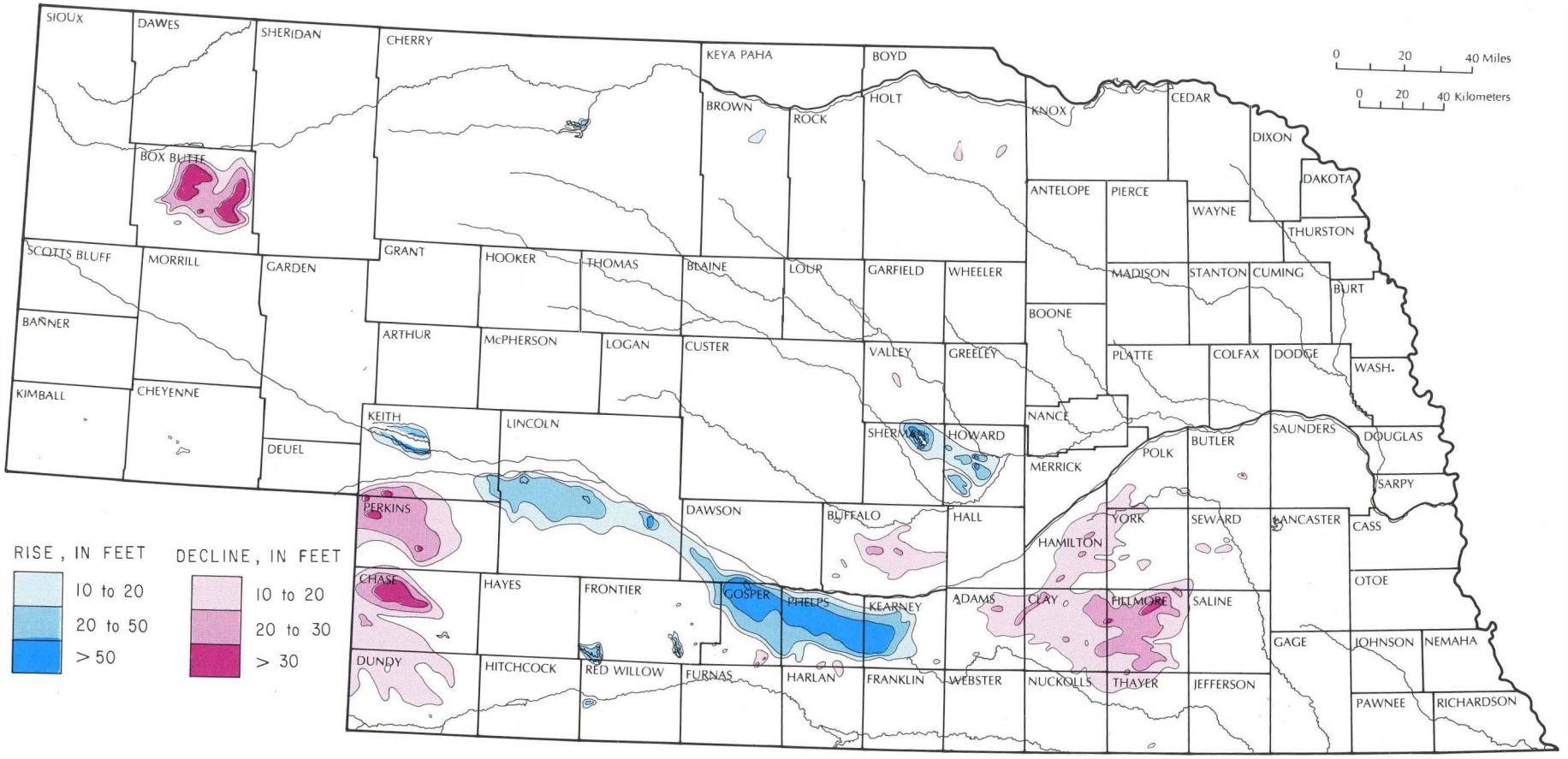
Location of Center-Pivot Systems, 1972

Figure 20:



Location of Center-Pivot Systems, 1984

Figure 21:



Significant Rises and Declines in Groundwater Levels, 1984

Variations in groundwater levels occur because of seasonal and longer term changes in the balance between natural aquifer recharge and discharge. These variations are usually small compared with the rises and declines shown on the map, which are due primarily to the development of the water resources of Nebraska. Intensive groundwater development for irrigation has caused areas of decline. Impoundment, transport and application of surface water for irrigation have contributed to groundwater-level rises.

Comparing recent groundwater levels with estimated predevelopment water levels delineates the significant areas of rises or declines. The estimated predevelopment value is the approximate average water level in a well prior to any development that significantly affected water levels near the well. Water levels in the early 1950s are assumed to represent predevelopment levels for most areas of the state. The panhandle area is based on 1946 levels, and the area associated with the Tri-County Irrigation District is based on 1940 levels. Water levels measured during the fall of 1984 were used for comparison.

An explanation of historical groundwater-level changes in a given area is generally fairly simple. In its annual water-level report, the division publishes hydrographs of key observation wells. These graphs depict groundwater-level changes over time. The cumulative or short-term effect of climate is illustrated on most well hydrographs; others demonstrate changes due to large groundwater withdrawals or to the incidental recharge from surface-water development. Most indicate trends in rate of change. Such trends may give a clue to expected changes in a given area but do not predict the future. Mathematical modeling of the hydrologic system can also be helpful in evaluating groundwater-level changes due to recharge and discharge and in forecasting future conditions.

Figure 22:

Era	Period	Epoch	Ages in millions of years[1]	Group or Formation	Lithology	Water-Bearing Properties
Cenozoic	Quaternary	Holocene	0.01		Sand, silt, gravel and clay	Principal groundwater reservoir, as defined in text; Ogallala is absent in east and northwest. Arikaree is present primarily in west.
		Pleistocene	~2.0			
	Tertiary	Pliocene	5		Sand, gravel and silt	
		Miocene	24	Ogallala	Sand, sandstone, siltstone and some gravel	
		Oligocene		Arikaree	Sandstone and siltstone	
			37	White River	Siltstone, sandstone and clay in lower part	Secondary aquifer in west; water may be highly mineralized.
		Eocene	58	Rocks of this age are not identified in Nebraska.		
		Paleocene	67			
Mesozoic	Cretaceous	Late Cretaceous		Lance	Sandstone and siltstone	Generally not an aquifer; yields water to few wells in west.
				Fox Hills		
				Pierre	Shale, some sandstone in west	Generally not an aquifer; sandstones in west yield highly mineralized water to few industrial wells.
				Niobrara	Shaly chalk and limestone	Secondary aquifer where fractured and at shallow depths, primarily in east
				Carlile	Shale; in some areas, contains sandstones in upper part	Generally not an aquifer; sandstones yield water to few wells in northeast.
				Greenhorn-Graneros	Limestone and shale	Generally not an aquifer; yields water to few wells in east.
			98			
		Early Cretaceous		Dakota	Sandstone and shale	Secondary aquifer, primarily in east; water may be highly mineralized.
			144			
	Jurassic		208		Siltstone, some sandstone	Not an aquifer
	Triassic		245		Siltstone	Not an aquifer
Paleozoic	Permian		286		Limestones, dolomites, shales and sandstones	Some sandstone, limestone, and dolomites are secondary aquifers in east. Water may be highly mineralized.
	Pennsylvanian		320			
	Mississippian		360			
	Devonian		408			
	Silurian		438			
	Ordovician		505			
	Cambrian		570			
Precambrian						

[1]Estimated ages of time boundaries from the Geological Society of America, 1983 Geologic Time Scale

Water-Bearing Properties of Major Rock Units in Nebraska

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Many additional publications related to groundwater or other natural resources are available from the division and cover various areas of the state. These include reports, maps and diagrams. For a complete publications list, write to: Conservation and Survey Division, 113 Nebraska Hall, University of Nebraska, Lincoln, Nebraska 68588-0517.

Glossary

Alluvium - a general term for clay, silt, sand, gravel or similar unconsolidated material deposited by a stream or other body of running water.

Aquifer - a water-bearing layer of rock or sediment capable of yielding supplies of water.

Aquifer, Confined (or Artesian) - an aquifer overlain by a low-permeability layer or layers, in which pressure head will force water to rise above the aquifer.

Aquifer, Perched - an aquifer containing unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone.

Aquifer, Principal - the aquifer or combination of related aquifers in a given area that is the important economic source of water to wells—not necessarily synonymous with groundwater reservoir.

Aquifer, Secondary - any aquifer that is not the main source of water to wells in a given area—includes perched aquifers, and in Nebraska, the Chadron Formation, the Dakota Group in some areas and several Paleozoic units.

Aquifer, Unconfined (or Water Table) - an aquifer in which the upper surface is the water table.

Bedrock - a general term for any consolidated rock, commonly applied in Nebraska to pre-Miocene rocks.

Discharge - the flow of surface water in a stream or canal or the outflow of groundwater from a well, ditch or spring.

Drawdown - the vertical drop of the water level in a well during groundwater pumping; the difference between a static water level and a subsequent, lowered level (pumping level).

Evapotranspiration (ET) - the process by which water is transmitted as a vapor to the atmosphere as the result of evaporation from any surface and transpiration from plants.

Groundwater - water occupying voids within the saturated zone.

Hydrograph - a graph which illustrates a specific hydrologic measurement, such as water level, discharge or velocity, over a period of time.

Hydrologic Cycle - the continuous movement of water among the oceans, the air and the earth in the form of precipitation, evapotranspiration and stream discharge.

Leaching - the downward transport by percolating water of minerals in a soil.

Loess - a wind-blown deposit of silt having little or no stratification.

Mantle - a general term for an outer covering of earth material.

Paleovalley - a valley of the geologic past, frequently buried under younger sediments.

Porosity - the proportion, commonly stated as a percentage, of the total volume of a rock material that consists of pore space or voids.

Permeability - the capacity of a porous rock, sediment or soil to transmit a fluid.

Reservoir (Groundwater) - for any given area, the subsurface storage space between the water table and the base of the principal aquifer—includes one or more aquifers and any associated fine-grained material (usually excludes any perched aquifer).

Runoff - water that flows over the land surface after rainfall, snowmelt or irrigation that eventually reaches streams, lakes, marshes, etc.

Self-Supplied Industrial Water Use - a water supply that is developed by a factory or industry for its own use.

Specific Yield - a ratio of the volume of water that a unit volume of subsurface material will yield by gravity, divided by that unit volume; a measurement associated with unconfined aquifers.

Stratigraphy - a discipline of geology dealing primarily with the chronologic order and geographic distribution of rock layers (strata).

Transmissivity - a measure of the ability of an aquifer to transmit water.

Water Table - the level at which the pore pressure equals atmospheric pressure and below which the pore spaces generally are saturated. A term generally associated with unconfined aquifers.

Zone of Saturation - porous earth materials in which all pore spaces are filled with water.