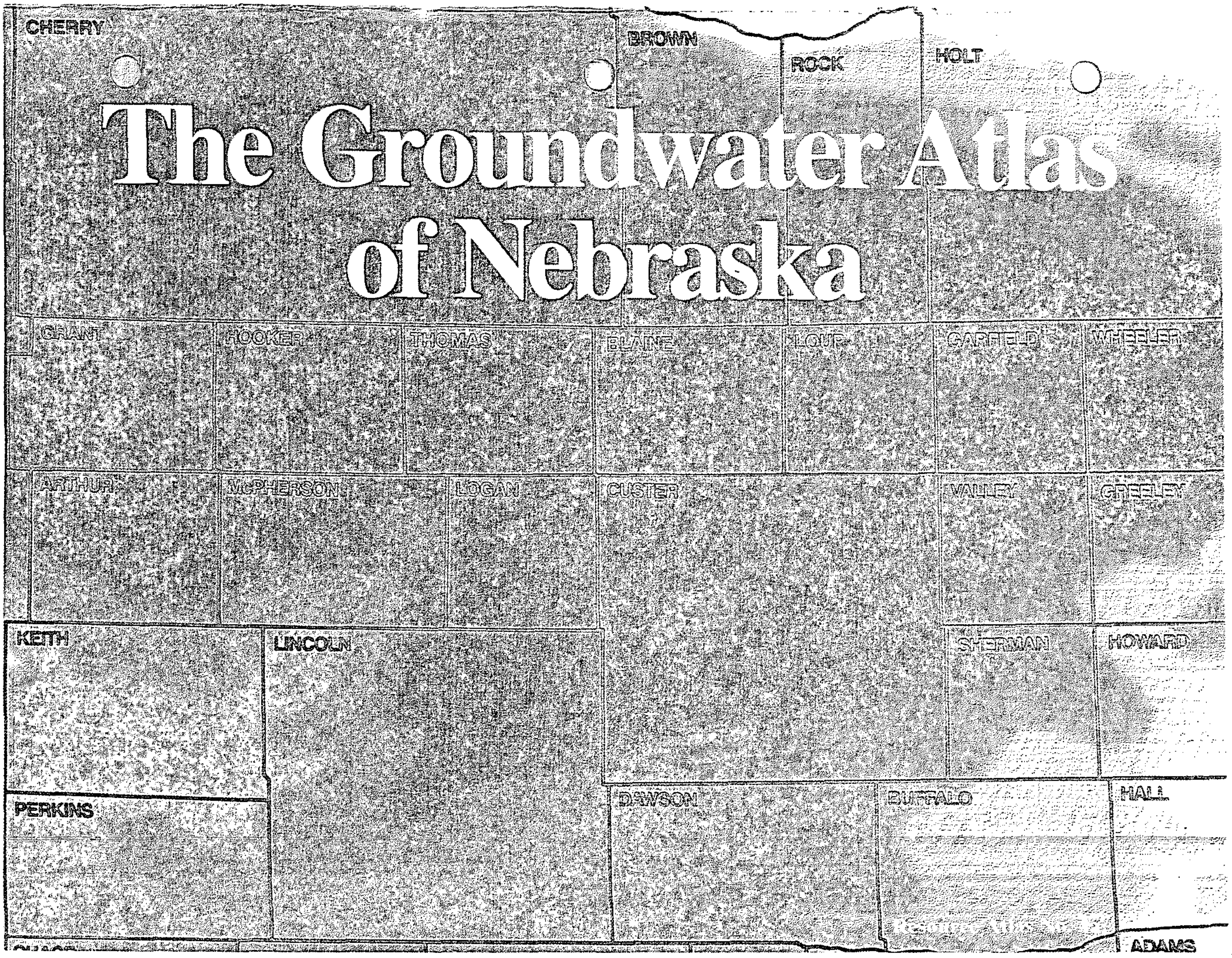
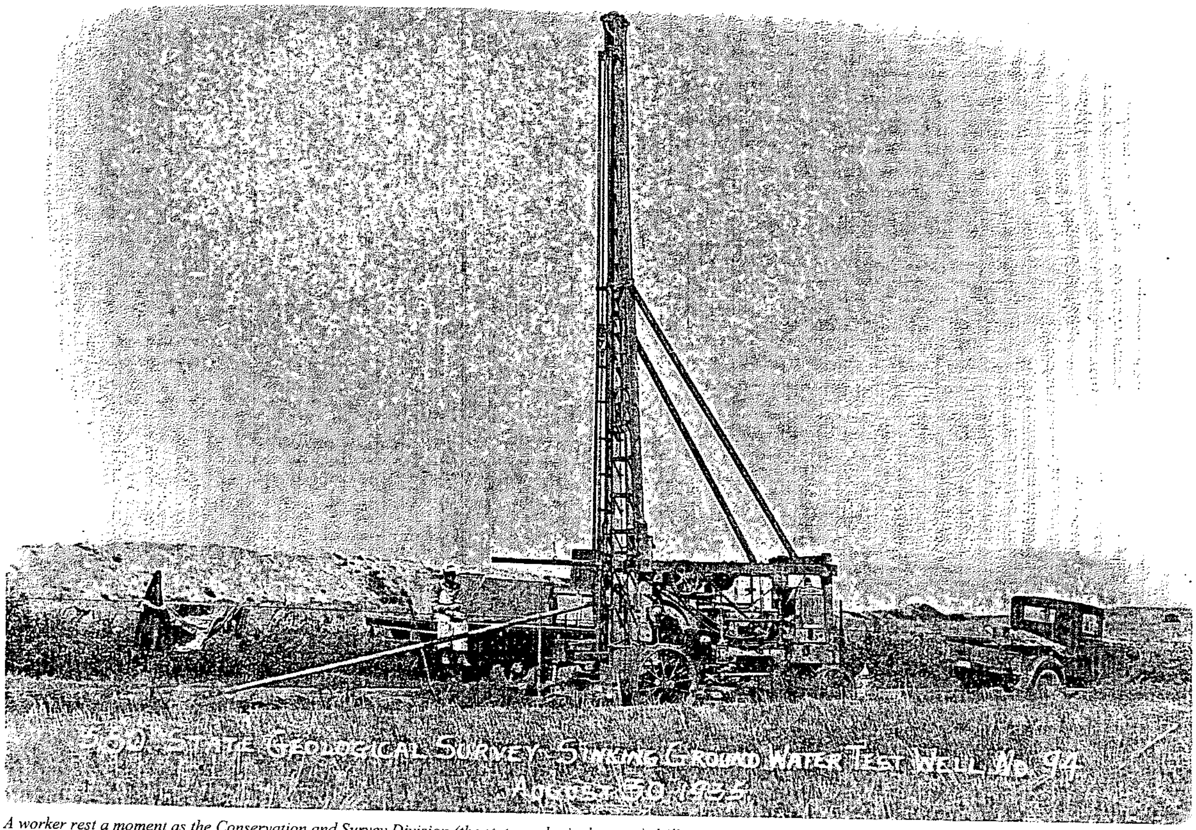
Conservation and Survey Division
Institute of Agriculture and Natural Resources
The University of Nebraska–Lincoln

The Groundwater Atlas of Nebraska



Resource Atlas No.



A worker rest a moment as the Conservation and Survey Division (the state geological survey) drills a test hole four miles northwest of Columbus with a Dempster rotary-hydraulic rig near the Loup Power Canal, August 30, 1935. In a state with few outcrops (exposed rock), test drilling is fundamental to understanding the groundwater geology of the state. A cooperative drilling program with the U.S. Geological Survey began in 1930.

The Groundwater Atlas of Nebraska

Resource Atlas No. 4a/1998
Second (revised) edition

First edition supported by the Nebraska Bankers Association
Second edition supported by The Groundwater Foundation, Lincoln, Nebraska

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

University of Nebraska-Lincoln

Administration

James C. Moeser, Ph.D., Chancellor, University of Nebraska-Lincoln
Irvin T. Omtvedt, Ph.D., Vice Chancellor for Agriculture and Natural Resources
Mark S. Kuzila, Ph.D., Director, Conservation and Survey Division
Duane A. Eversoll, M.S., Associate Director, Conservation and Survey Division

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

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, Lincoln, Nebraska 68588-0517.

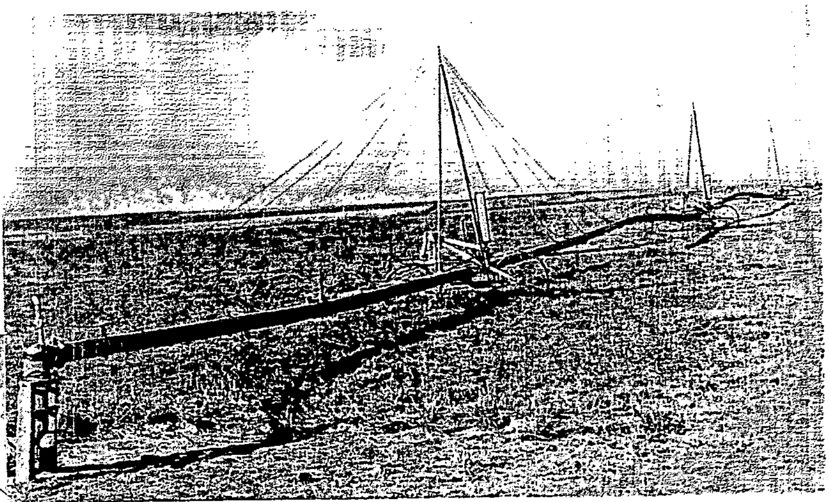
It is the policy of the Conservation and Survey Division, as it is of the University of Nebraska-Lincoln, not to discriminate on the basis of and to provide information and educational programs to all regardless of sex, age, handicap, race, color, religion, marital status, veteran's status, national or ethnic origin or sexual orientation.

Publication and price lists are furnished upon request.

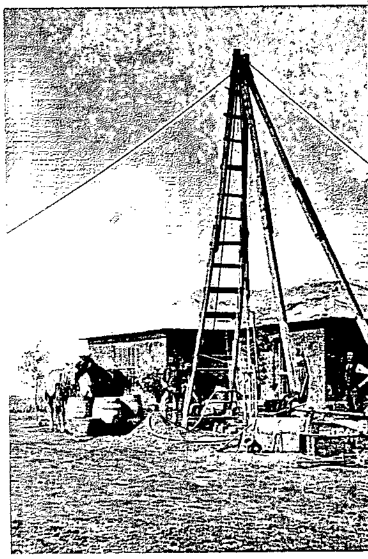
1998

Factors for Converting English Units to the International System of Units (SI)

Multiply English Units	By	To obtain IS units
	Length	
inches (in)	25.40	millimeters (mm)
feet or foot (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	4047.00	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
acre-feet (acre-ft)	1233.00	cubic meters (m^3)
	Flow	
gallons per minute (gpm)	0.00006309	cubic meters per second (m^3/s)



Frank Zybach's first center-pivot irrigation system (above) waters what might be wheat near Strasburg, Colorado, in the late 1940s. Zybach, a tenant wheat farmer, envisioned a way to replicate rainfall by pumping groundwater and so bring life-giving water to arid eastern Colorado. His invention transformed the western prairie and high plains. Photo courtesy of Nebraska State Historical Society.



C. Layton, in the foreground, and his mother put down a well near Cliff Table, presumably Nebraska, 1889 (left). These wells were 350 to 400 feet deep and hand to be dug by hand in the early days of settlement. Without them, settlers away from water courses had to hand-carry water many miles or catch water in a pond or lagoon. Photo courtesy of Nebraska State Historical Society.

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.

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

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

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 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.

Groundwater Reservoir - 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 semi-perched aquifer).

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 materials.

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

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

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

Principal Aquifer - 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.

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

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

Secondary Aquifer - 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.

Semi-perched aquifer/water - an aquifer containing unconfined groundwater separated from an underlying body of groundwater by an unsaturated zone. Was once called ***perched aquifer/water***.

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). *Stratigraphic* means related to this discipline.

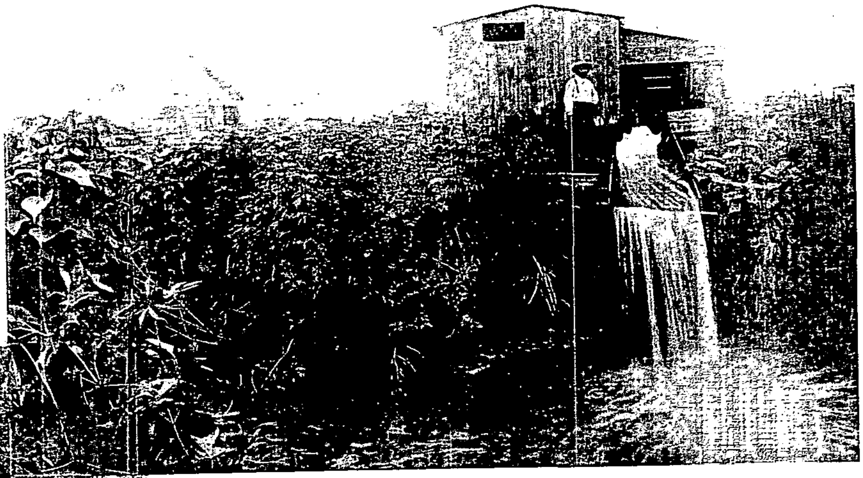
Transmissivity - a measure of the ability of an aquifer to transmit water.

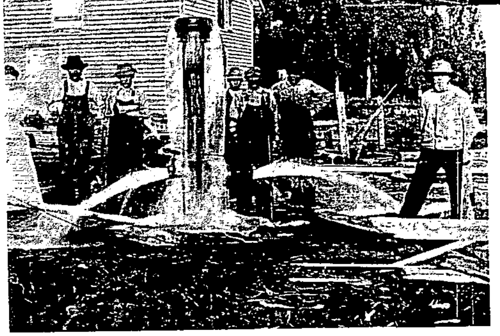
Unconfined (or Water Table) Aquifer - an aquifer in which the upper surface is the water table.

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.

Contents

An artesian well flows into a pond near Lynch, Boyd County, Nebraska. Date unknown, would appear to be near the turn of the century. Photo courtesy of the Nebraska State Historical Society.





An artesian well north of Columbus, on the Grathern farm, Platte County, Nebraska. Before adequate pumping technology was developed, groundwater had to be raised by buckets or flow to the surface as a result of the pressure of a confining layer of sediment or other sufficient pressure head. Photo courtesy of Nebraska State Historical Society.

Selected References

Burchett, R. R., compiler, 1969, Geologic bedrock map of Nebraska: Conservation and Survey Division, University of Nebraska, 1:1,000,000.

Chen, A.H., and Wigley, Perry B., Groundwater-level changes in Nebraska, 1994: Conservation and Survey Division, University of Nebraska-Lincoln, Nebraska Water Survey Paper No. 74, 7 p. with 1,000,000-scale map (Available annual editions date from 1960; some may be out of print but are available for study or copying.)

Conservation and Survey Division, 1981, Main text: Groundwater reservoir management policy issue study—a contract report for the Nebraska Natural Resources Commission: University of Nebraska-Lincoln, 76 p.

____, 1981, Appendix A: Atlas illustrating the characteristics of groundwater in Nebraska, *from* Groundwater reservoir management policy issue study—a contract report for the Nebraska Natural Resources Commission: University of Nebraska-Lincoln, 16 plates with text.

Diffendal, R.F., Jr., 1993, Understanding groundwater starts with the rocks—geologic framework, groundwater occurrence and irrigation development in Nebraska, *in* Kuzelka, R.D., project mgr., and Flowerday, C.A., ed., Flat Water—A History of Nebraska and Its Water: Conservation and Survey Division, University of Nebraska-Lincoln, 291 p.

Elder, J. A., 1969, Soils of Nebraska: Conservation and Survey Division, University of Nebraska, Resource Report No. 2, 60 p.

Engberg, R. A., and Spalding, R. F., 1978, Groundwater quality atlas of Nebraska: Conservation and Survey Division, University of Nebraska-Lincoln, 1:500,000 map with assorted reference maps.

Gosselin, D.C., Headrick, J., Chen, X-H., Summerside, S., Tremblay, R., and Bottger, K., 1996, Domestic Well-water Quality in Rural Nebraska—a data-analysis contract report for the Nebraska Department of Health (NDOH): Conservation and Survey Division, UNL, and Bureau of Environmental Health, NDOH, State of Nebraska.

Keech, C. F., and Bentall, Ray 1971, Dunes on the plains: Conservation and Survey Division, University of Nebraska, Resource Report No. 4, 18 p.

Kuzelka, R.D., project mgr., and Flowerday, C.A., ed.,1993, Flat Water—A History of Nebraska and Its Water: Conservation and Survey Division, University of Nebraska-Lincoln, Resource Report No. 12, 291 p.

Lawton, D. R., Veys, C. L., and Goodenkauf, O., 1983, An inventory of public, industrial, and power-generating water use in Nebraska, 1979 and 1980: Conservation and Survey Division, University of Nebraska-Lincoln, Nebraska Water Survey Paper No. 54, 58 p.

Reed, E. C., compiler, 1969 Underground water areas: Conservation and Survey Division, University of Nebraska, map plus descriptive text (out of print).

Reed, E. C., and Dreeszen, V. H., 1965, Revision of the classification of the Pleistocene deposits of Nebraska: Conservation and Survey Division, University of Nebraska, Nebraska Geological Survey Bulletin No. 23, 65 p.

Rundquist, D. C., Li, R. Y., Di, L., Liu, M., 1989. Applying concepts of geographic systems and expert systems to the "DRASTIC" ground water-vulnerability model: Water Resources Center, University of Nebraska-Lincoln.

Rundquist, D. C., Rodekohr, D. A., Di, L., Peters, A. J., Ehrman, R. L., Murray, G., 1991,. Statewide groundwater-vulnerability assessment in Nebraska using the DRASTIC/GIS model: Geocarto International, Vol. 6, No. 2.

Rundquist, D. C., and Yamamoto, Paul, 1990, Center-pivot systems in Nebraska, 1988: Conservation and Survey Division, University of Nebraska-Lincoln, 1:1,000,000 map with text and tables. (Available annual editions are from 1976-1988; data available for 1972-1988.)

Exner, M.E., and Spalding, R.F., 1990, Occurrence of pesticides and nitrate in Nebraska's groundwater: Water Center, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, 34 p.

Steele, E. K., 1988, Estimated use of water in Nebraska, 1985: Conservation and Survey Division, University of Nebraska-Lincoln, Nebraska Water Survey Paper No. 64, 48 p., 52 figs., appendix 126 p. (28 tables).

Weeks, J.B., Gutentag, E.D., Heimes, F.J., Luckey, R.R., 1988, Summary of the High Plains Regional Aquifer—System Analysis in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, U.S. Geological Survey Professional Paper No. 1400-A.

More publications on groundwater or other resources are available from the division, the U.S. Geological Survey and other agencies. For a complete division publications list, write to: Conservation and Survey Division, 113 Nebraska Hall, University of Nebraska, Lincoln, Nebraska 68588-0517; by e-mail to csdsales@unlinfo.unl.edu; or through the Internet at http://csd.unl.edu/csd.html.

Table 1

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.
			98	Greenhorn-Graneros	Limestone and shale	Generally not an aquifer; yields water to few wells in east.
		Early Cretaceous	144	Dakota	Sandstone and shale	Secondary aquifer, primarily in east; water may be highly mineralized.
	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 the Major Rock Units in Nebraska

Preface and Acknowledgments

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 division's faculty and staff took the opportunity to honor Vince upon the publication of the first edition of this atlas in 1986 and do so again in 1998. This dedication is to honor his service as CSD acting director from 1967-1969 and as director from 1969-1987. Joining the division in 1949, he served the state and its citizens for nearly 40 years through research, lectures, legislative testimony, publishing and in helping the public and other natural resources agencies solve groundwater and other resource-related problems.Under his guidance, the division consistently provided a steady stream of basic data and counsel regarding the state's groundwater. This information has contributed significantly to the appropriate use and conservation of Nebraska's water and other natural resources.

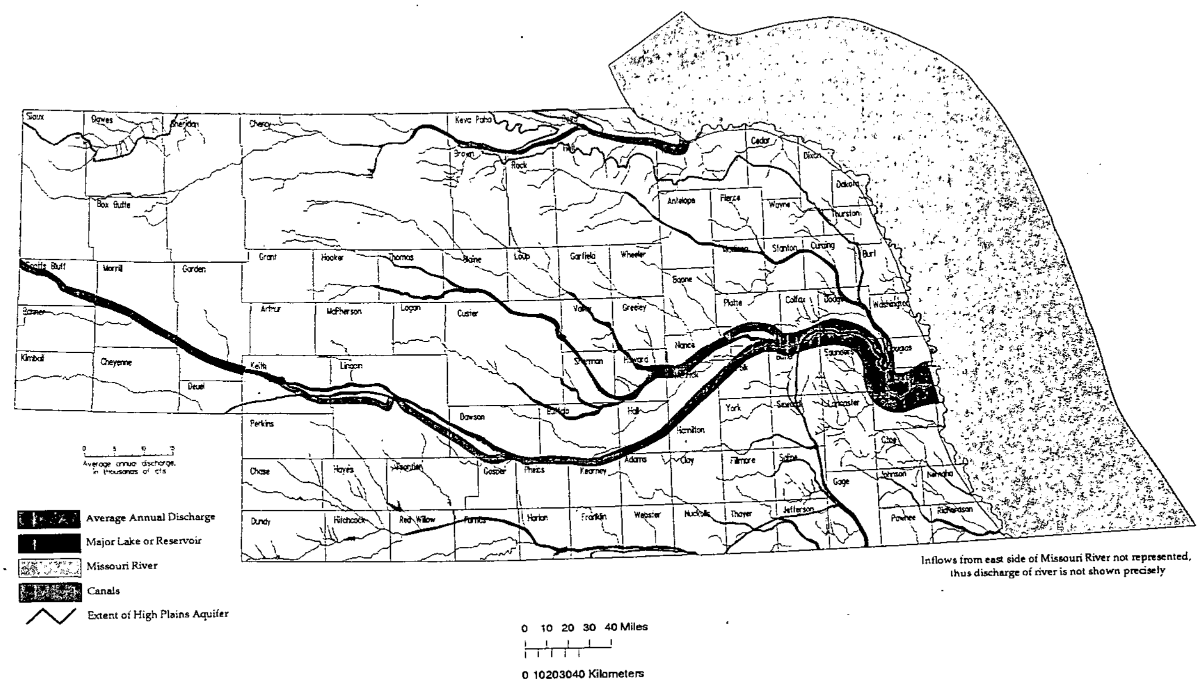
The first edition of this atlas was prepared as a cooperative project by the professional, cartographic and clerical staff of the Conservation and Survey Division (CSD) of the University of Nebraska-Lincoln. Bob Kuzelka, then CSD water resources planner, now assistant to the director, UNL Water Center/Environmental Programs, and Darryll Pederson, formerly research hydrogeologist with CSD and UNL professor of groundwater geology, now UNL professor of groundwater geology, served as project leaders for the first edition and co-compilers of the second. Charles A. Flowerday, CSD editor and publications officer, edited both versions of the atlas and was senior co-compiler of the second edition. David C. Gosselin and Robert F. Diffendal, Jr., were also contributors to the second edition. Scott Summerside, CSD assistant geoscientist, was very helpful with comments and assembling graphic material. Dee Ebbeka, Ann Mack and Jerry Leach, CSD graphics specialists, contributed the lion's share of the drafting for the first edition. Jim Weir, CSD GIS specialist, provided electronic editions of various new maps and updates for the second edition.

Most of the material for the first edition was compiled as "Appendix A—Atlas Illustrating the Characteristics of Groundwater in Nebraska" of the Groundwater Reservoir Management Policy Issue Study (NNRC, 1981), a contract report by CSD for the State Water Planning and Review Process of the Nebraska Natural Resources Commission. Marv Carlson, CSD research geologist and then assistant director, compiled most of Appendix A for that study.

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 for support of printing costs for the first edition, published at a time when groundwater was receiving considerable public attention, helped ensure the broadest possible distribution of the that edition to those interested in Nebraska's groundwater resource. It allowed the division to print 10,000 copies in that first run and send more than 3,000 of those free to secondary school and college libraries across the state.

Finally, these maps show general, regional conditions only. They should not be the basis for economic or legal decisions about site-specific conditions. 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, 68588-0517; by e-mail at csdsales@unlinfo.unl.edu; or through the Internet at http://csd.unl.edu/csd.html.

Figure 1



Inflows from east side of Missouri River not represented, thus discharge of river is not shown precisely

Average Annual Discharge of Streams and Major Reservoirs

Groundwater Quantity and Quality (continued)

In July 1992, the Little Blue NRD said it would begin restricting the amount that groundwater users could pump on January 1, 1993. But after a re-evaluation of decline records corrected some inaccurate measurements, the groundwater control area was dissolved.

Groundwater quality control areas

Another way to regulate stress on the groundwater supply was through a groundwater management area. The Groundwater Management Act was revised in 1981 to become the Groundwater Management and Protection Act (GWMPA) to allow NRDs to request a groundwater-quality control area unrelated to de-watering of an aquifer. And in 1984, as an outgrowth of the Kerrey administration's Water Independence Congress, the legislature passed LB 1106, which required each NRD to prepare a groundwater-management plan in which it would, among other things, stipulate a life goal for its aquifer. These plans were reviewed and approved by DWR.

The GWMPA was revised again in 1986. One revision said an NRD could propose a groundwater management area to protect water quality, rather than solely to stop deterioration. Restrictions in GMAs generally involved some combination of the following: requiring best management practices (BMPs)—such as irrigation scheduling, buffer strips, crop-nutrient testing, integrated pest management and crop rotations; attendance at educational programs about water quality; allocation of groundwater use; rotation of groundwater use; well-spacing requirements; and flow meters.

Another option on nonpoint groundwater-quality problems was the special protection area or *SPA*. If a city, county or state agency believes that nonpoint contamination needs to be regulated, or if an NRD lacks funding or expertise to handle it, the NRD could request the state, through the Department of Environmental Quality, to study contamination in the area. If an SPA was designated, the NRD had 6 months to draw up an action plan to address the problem, which had to include educational programs for water users. In addition, the plan had to include selected BMPs and/or any other "reasonable" measures needed to make the plan work.

One remarkable aspect of the SPA program was that, while some states have regulations protecting groundwater from pesticides, very few have such programs regarding fertilizer. Nebraska was on the forefront of nonpoint-pollution control regarding fertilizers.

Another important issue to emerge, but hardly the most glamorous, was the need to cap what are probably more than a hundred thousand out-of-use wells statewide. Such wells provide conduits for the transport of contaminants, particularly agricultural chemicals, can harbor unsanitary decomposing wildlife and also pose safety hazards to children and pets.

In 1986, the Water Well Standards and Licensing Act stipulated that landowners discovering such wells were responsible for their capping, a processing called *decommissioning*. But the exact regulations for doing this plugging required some discussion and collaboration among various state agencies. The 1994 revision of this act included new definitions for out-of-use and abandoned (decommissioned) water wells and clarified the procedures to be used. The results of this effort were summarized in the Conservation and Survey Division publication *Guidelines for Decommissioning Water Wells—How to Plug Water Wells*, released in 1995 with financial support from the Nebraska Department of Health and available through the division or Cooperative Extension.

Integrated management and a single category

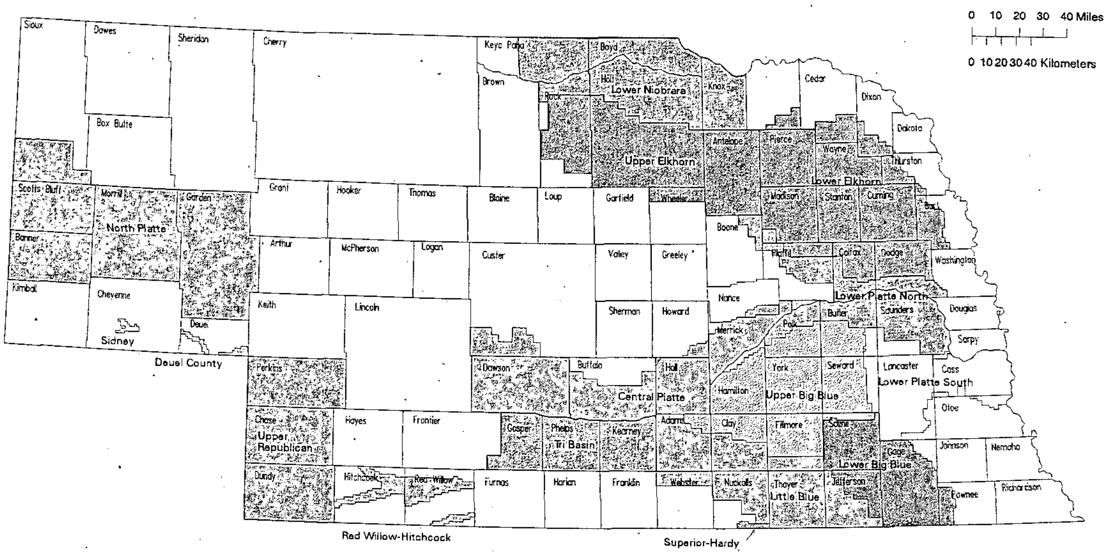
However, while keeping these various reasons for regulating groundwater, the state legislature did away with the multiple designations and instituted a single category in 1996. While the fundamental issues affecting groundwater remain essentially unchanged, the legal means to managed those issues, and another related to joint management of groundwater and surface water, were all pulled together under a single designation called *a groundwater management area*. The ways to request or impose them remained as they were.

The law, known as the *integrated water management law*—LB 108—consolidated statutes on groundwater control areas, groundwater (quality) management areas and special (groundwater quality) protection areas. The intent behind this law was to legally recognize the connection between groundwater and surface water. Some of this recognition was propelled by the threat of a lawsuit with Kansas, in which it could charge that Nebraska has not been delivering enough Republican River water to Kansas near Superior and Guide Rock as guaranteed by legal agreement in 1941.

The exact details of the administration of this new provision regarding integrated management will probably be first implemented in the Republican River valley. Tests of groundwater flow patterns and studies of the regional groundwater system by CSD began in the summer of 1997 and will help determine the nature of any controls needed in the basin as the result of a lawsuit with Kansas if such develops. Kansas pulled out of multi-year negotiations in spring 1997.

Groundwater management areas depicted are all for water quality except for those in the North Platte, the Upper Republican, the Central Platte and the Upper Big Blue NRDs. These NRDs have areas designated for both quantity and quality.

Figure 19



Groundwater Management Areas, 1996

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 or 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 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 (fig. 1).

Counties and geographic features illustrated in the atlas are derived from the base map (fig. 1). In addition, because of a new emphasis on groundwater-surface water interaction, depictions of average annual discharge of streams (streamflow) have been shown. Average annual inflow and outflow for the state's major river basins, as of late 1996, are as follows. Data is from the U.S. Geological Survey (USGS). The period of record is listed after the basin; ***average annual figures are in bold italics.*** Numbers for water year 1996 are in parentheses behind the average annual figures.

Inflow: *Niobrara River basin, 1956-1994:* ***2,630*** (2,340) acre-feet; *North Platte River basin, 1929-1996*—North Platte River: ***565,500*** (559,300) acre-feet; canals diverted in Wyoming from this basin (Interstate, Mitchell-Gering and Ft. Laramie): ***738,400*** (649,000) acre-feet; *South Platte River basin, 1902-1996:* ***394,600*** (425,000) acre-feet; *Republican River basin, 1929-46-1996:* ***114,080*** (89,900) acre-feet. Total inflow: ***1,815,210*** (1,727,240) acre-feet.

Outflow: *Niobrara River at Verdel, 1938-1996:* ***1,202,000*** (1,740,000) acre-feet; *Platte River at Louisville, 1953-1996:* ***5,023,000*** (7,061,000) acre-feet; *Republican River at Hardy; and Cortland Canal, 1958-1996:* ***317,770*** (646,540) acre-feet; *Weeping Water Creek, 1951-1996; and Big Nemaha, 1944-1996, and Little Nemaha, 1950-1996, rivers:* ***759,140*** (702,400) acre-feet; *Big Blue, 1933-1996, and Little Blue, 1910-1996, rivers at Barneston and Fairbury (respectively):* ***909,000*** (945,700) acre-feet. Total outflow: ***8,210,910*** (11,095,640) acre-feet.

Groundwater characteristics and studies

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* (evaporation and plant transpiration).

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.

In addition, groundwater in the Sand Hills and nearby discharges to streams in that region at a relatively constant rate. Little runoff occurs due to the sandy soils, so this groundwater is responsible for most of the streamflow in the Dismal River, the Loup river system, and the Niobrara and Elkhorn rivers. Most of the groundwater feeding the Loup system enters the Platte where it joins the Loup and helps supply municipal well fields in aquifers near the river in the lower Platte River valley. Groundwater also discharges in lesser quantity to most other streams in the state.

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 semi-perched aquifers *(see glossary)* or rock units older than Miocene age. Secondary aquifers such as the Chadron Formation of the White River Group, the Dakota Group, the Niobrara Formation and other rock units are not emphasized and are shown only on the block diagram of Nebraska's geology (fig. 6) and on the water-bearing properties chart (table 1).

In addition, water quality concerns (figs. 14, 18 and 19) continue to crop up in some places, particularly since the first edition of this atlas. These concerns are mostly about nitrate contamination in areas with high water tables, sandy soils and much irrigated agriculture, such as parts of the central and lower Platte River valley, the Holt Table area in north-central Holt County and the Big Blue Basin. Other areas with selective nitrate problems are parts of northeastern Nebraska, the Lodgepole Creek area near Sidney, parts of the North Platte Valley in Scottsbluff County and certain parts of the Republican Valley.

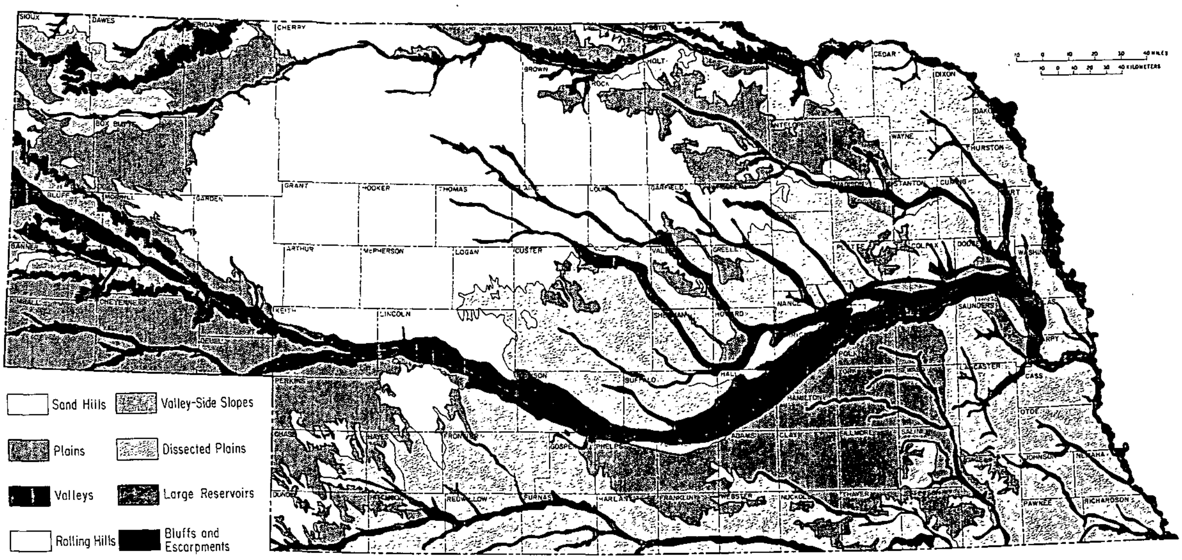
The cooperative groundwater research program

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 USGS. Much of the information in this publication is the result of this ongoing joint effort.

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.

A Note of Caution: Since it is impossible on the scale of this atlas to show all the hydrogeologic conditions in the state, this publication includes only general maps showing regional conditions. Local variations from the conditions shown in these maps and illustrations may occur. No legal or economic decisions about any site-specific conditions should be made from these maps.

Figure 2



Topographic Regions

Groundwater Quantity and Quality

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 spring of 1994 were used for comparison.

A determination of historical groundwater-level changes in a given area is generally fairly straight-forward but can be complicated by semi-perched water levels and by sketchy estimates of the local predevelopment water level. 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 hydrographs 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.

History of groundwater management programs

Groundwater control areas for quantity

Since the 1970s, concern about the quantity and quality of groundwater in certain parts of the state has led to a number of different programs with which to manage a significant decline in water levels or water quality. In 1975, the state legislature passed the Groundwater Management Act. Its primary intent was to slow groundwater declines in critical areas by authorizing an NRD to request the state Department of Water Resources (DWR) to designate all or part of it as a groundwater control area. It also said that management areas for groundwater quality could be designated if groundwater use had caused or was contributing to quality problems.

On August 1, 1977, the Upper Republican NRD above the Republican River—almost all of the district—was declared the state's first groundwater control district. The area includes the counties of Perkins, Chase and most of Dundy. The first controls on irrigators included the following (cities, towns and domestic users are subject to restrictions also, but since agricultural use is the largest, only those on irrigators are listed here): flow meters on all wells by 1980; documentation of irrigated acres so as to allocate water; designating critical *townships* where the annual water-level decline exceeded 1 percent of the average saturated thickness in that township; and well-spacing requirements prohibiting new irrigation wells within 3,300 feet of any other well in critical townships. The area has gone through a number of allocation periods generally authorizing about 12-15 inches per year. In 1984 DWR approved regulations proposed by the Upper Republican NRD to protect groundwater *quality* in a *quantity* control area. The NRD required annual permits for each irrigation well that applied agricultural chemicals *(chemigation)* and stipulated a properly working check valve on all such wells. The regulations did not apply, however, to nonpoint pollution from ag chemicals.

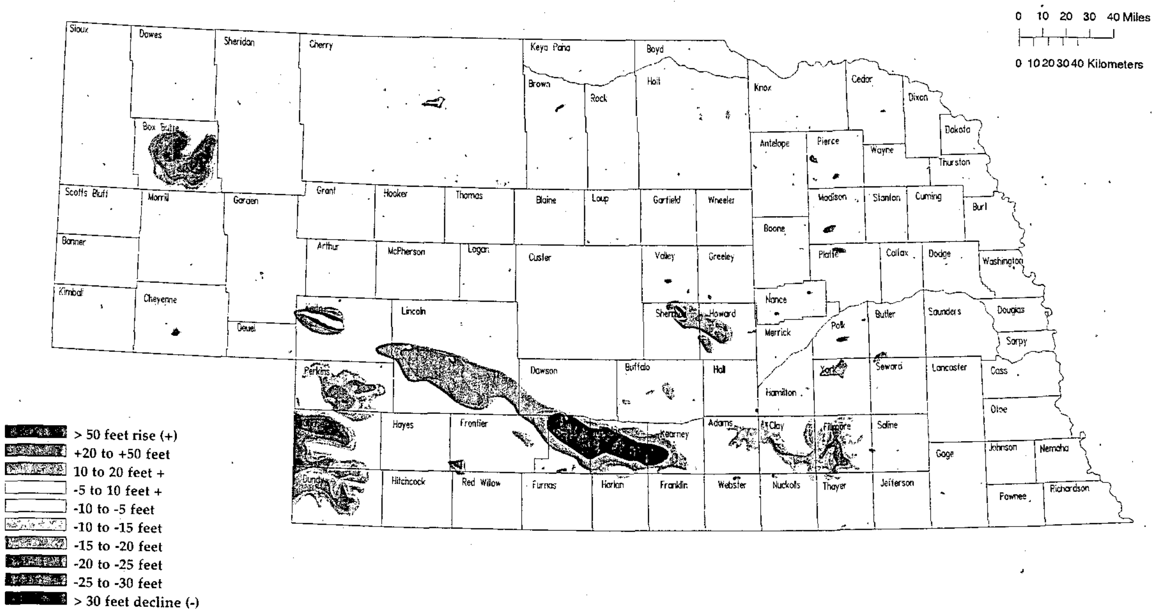
Shortly after the designation in the Upper Republican NRD, on December 9, 1977, a quantity control area was designated in another region with major declines, the Upper Big Blue NRD. Counties affected included all or parts of Adams, Butler, Clay, Fillmore, Hamilton, Polk, Seward and York. The initial goal of the control area was to hold the decline rate to the average rate for the 1976-1978 period. Through conservation and due to above-average precipitation, that goal was met. The new goal became to hold the water level above the 1978 level.

Conservation measures promoted by the district (and similar to those encouraged by other control areas) were the following: 1) use of irrigation reuse systems; 2) the most economical use of groundwater; 3) crop rotations; 4) controlling runoff from center-pivot irrigation systems; 5) water storage and land treatment where needed; 6) irrigation scheduling; 7) using surface water where available; 8) maintaining pumping plant efficiency; 9) minimum tillage; 10) gathering all available information on water-use and efficiency; 11) installation of flow meters. (Use of moisture blocks were also encouraged for some areas.)

Not long after the first two designations, in January of 1979, the northern part of the Little Blue NRD became a groundwater control area. This included parts of Adams, Clay, Fillmore, Nuckolls and Thayer counties. The NRD's goal became maintaining the same average water level as that of spring 1981, and allocation did not occur immediately. If the average district water level dropped lower than 18 inches below that baseline level, mandatory allocation would go into effect. Even before allocation limits, the NRD certified irrigated acres and flow meters and gathered yearly pumping data from groundwater irrigators.

(continued on p. 39)

Figure 18



Rises and Declines in Groundwater Levels, 1994

Regions of similar physical features of Nebraska's land surface (fig. 2) are outlined on this map. It reflects the surface and some subsurface geology and illustrates the effects of water, wind and ice 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 (fig. 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.

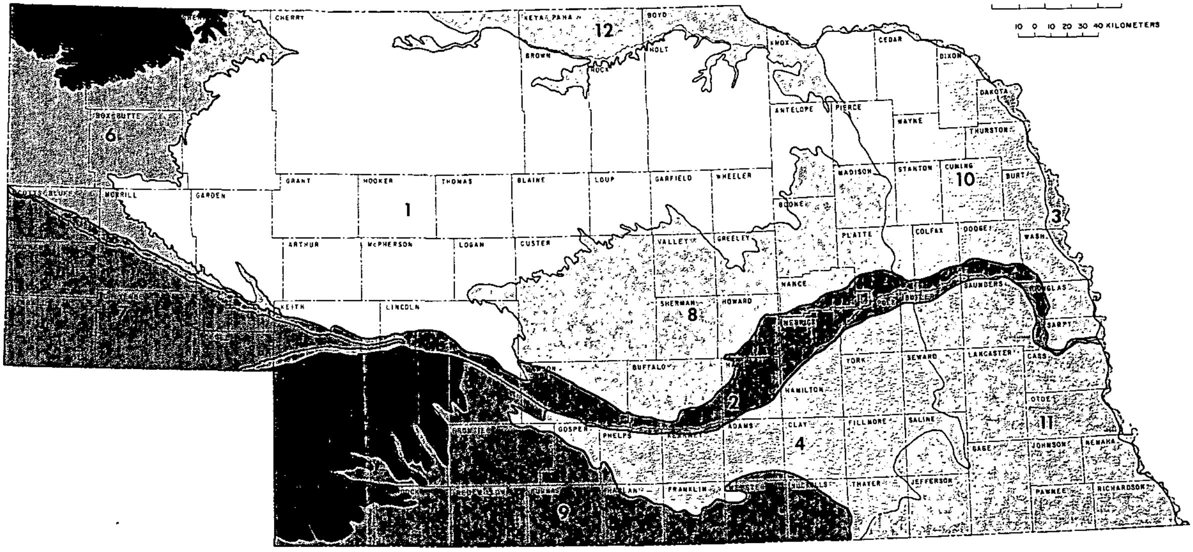
Sand Hills are regions composed of a mantle of low to high relief sand dunes that have been stabilized by vegetation. Sandstone and stream-deposited silt, sand and gravel underlie the dunes. The sandy soils permit rapid infiltration of precipitation. Streams originating in the area have a relatively 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 boulder-clay tills relatively low in primary permeability. 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.

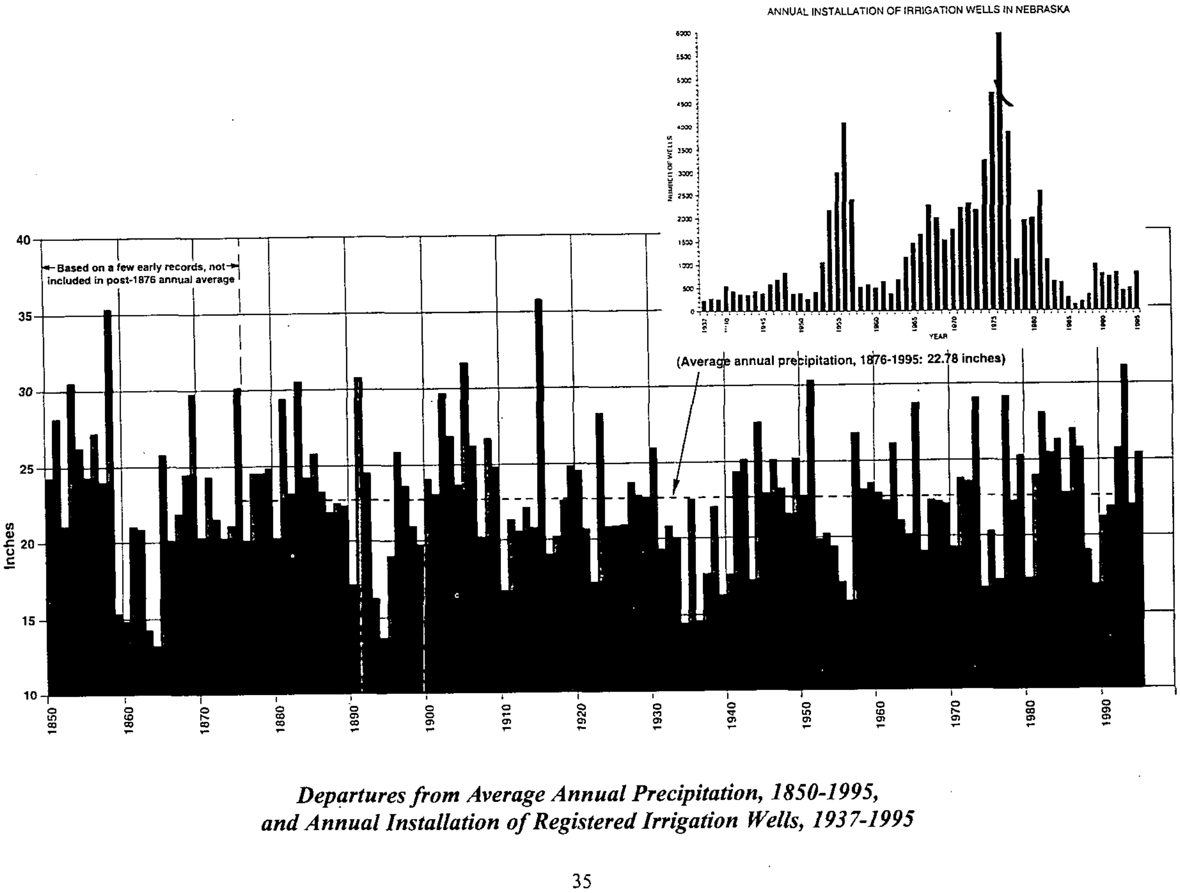
Valley-Side Slopes are regions of moderate to steep slopes between the bluffs and escarpments and the nearly level valleys in western Nebraska. These areas are mostly siltstone bedrock covered by silt, sand or gravel. Intensive agricultural use is limited, and soil-moisture conditions permit moderate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

Figure 3



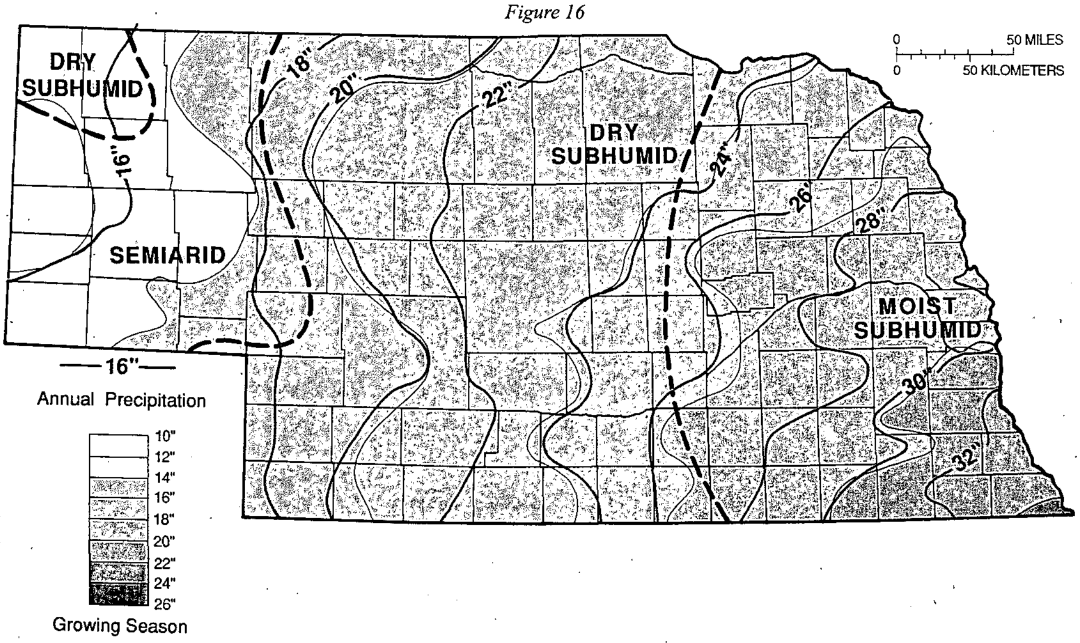
Groundwater Regions

Figure 17



Departures from Average Annual Precipitation, 1850-1995,
and Annual Installation of Registered Irrigation Wells, 1937-1995

Figure 16



Average Annual and Average Growing Season Precipitation

Historical Trends in Groundwater Use (continued)

One example has been the development of the eastern Sand Hills known as *sand sheets* that took place during the 1970s. Much of the development of the eastern Sand Hills for row crops was curtailed or eliminated by the mid- to late 1980s, as crop prices declined, tax incentives were eliminated and pressure from environmental organizations grew.

Center-pivot systems numbered 2,757 such systems in 1972, the first year the UNL Conservation and Survey Division conducted an inventory. They had expanded to 26,741 systems in 1988, the last year of the inventory. Funding for the annual center-pivot inventory was not renewed after 1988, so no surveys have been done since then.

Current estimates from industry officials place the 1996 totals at about 30,000 to 35,000 systems statewide. At 30,000 systems, assuming the average center-pivot system irrigates 133 acres, and some can irrigate 500 acres or more, total land under pivot irrigation would be nearly 4 million acres. Total land under center pivots in 1988 was more than 3.5 million acres.

Thirteen groundwater regions in the state are identified on this map (fig. 3). Within each region groundwater occurs under similar kinds of conditions. Boundaries between regions generally represent zones of gradual change. Discussions of total dissolved solids are a general appraisal of water quality determined by the total of dissolved material in the groundwater. (For more information on the water-bearing properties of the major rock units in the state, see fig. 4 and table 1.)

Sand Hills—Region 1: The Ogallala Group and the Broadwater and Long Pine formations, all of Tertiary age (table 1), and the dune sands of Quaternary age are the primary sources for large yields of good quality water. As defined by the U.S. Geological Survey (Weeks and others, 1988), these units are part of the High Plains (or Ogallala) aquifer that extends from South Dakota to Texas.

The term *High Plains aquifer* is preferred to *Ogallala aquifer* because Ogallala rocks constitute only one part of this groundwater system. Runoff rarely occurs because precipitation readily infiltrates the sandy soils. This recharge feeds a groundwater reservoir that ranges in thickness from 200 to about 900 feet. Depth to water depends on position in the landscape; it may be 300 feet or greater under the top of a dune, 100 feet or less under a dry interdunal valley and near to or at the surface in valleys where groundwater discharges into lakes, marshes, or subirrigated meadows. The natural quality of the groundwater is good; total dissolved solids generally are less than 200 milligrams per liter.

Platte River Valley—Region 2: High yields of good quality water are can be obtained from river-deposited (alluvial) sand and gravel. Where present, the Ogallala Group is also used for groundwater. It underlies the river-deposited sediments (alluvium) west of Grand Island to near Lake McConaughy on the North Platte and to the Colorado border on the South Platte. It consists of complex deposits of sand, silt, clay, and gravel interbedded with lime- or silica-cemented sandstone.

Depth to the water table is usually less than 50 feet. The saturated thickness of the principal aquifer ranges from about 100 feet or less to about 500 feet or more in Lincoln County. Dissolved solids range from 500 to 1,000 or more milligrams per liter in the western two-thirds of the region. In some parts of the Platte Valley, fertilizer applications are contributing nitrates to groundwater.

Missouri River Lowlands—Region 3: Large yields of water can obtained from the principal aquifer, which is composed primarily of Quaternary alluvial sand and gravel beneath the floodplain of the Missouri River. These deposits are generally less than 100 feet thick and consist primarily of fine- to medium-grained sand and fine-grained gravel interlayered with lesser amounts of silt and clay. Depth to water is usually less than 50 feet. Saturated thickness of the principal aquifer is less than 100 feet. Water is more mineralized than in the Platte Valley but is still of usable quality.

South Central Plains—Region 4: Abundant groundwater can be found in the Pliocene and Pleistocene sand and gravel deposits, as well as the Ogallala Group. The Ogallala occurs in the western part of the region. As much as 200 feet thick, it consists of lime-cemented sand and gravel, loess-like silt, and unconsolidated sand and gravel. The overlying Pliocene/Quaternary system consists of more than 500 feet of clay, silt, sand, and gravel deposited by glacial and river-related processes. Deposits of wind-blown silt (loess) mantle the surface. Groundwater levels have risen in the west where water diverted from the Platte River for irrigation has seeped out of canals.

Southwestern Tablelands—Region 5: The Ogallala Group's sand and gravel, sand, and sandstone are the principle groundwater-bearing rocks. The group thins from almost 400 feet in the north to being absent in the south. It ranges from 300 feet on the west side of the region to 100 feet on the east. Depths to groundwater vary from about 50 feet or less in western Dundy County to about 200 feet or more in northwestern Perkins County. Total dissolved solids range from 200 to 500 milligrams per liter. Groundwater levels have declined progressively since development began.

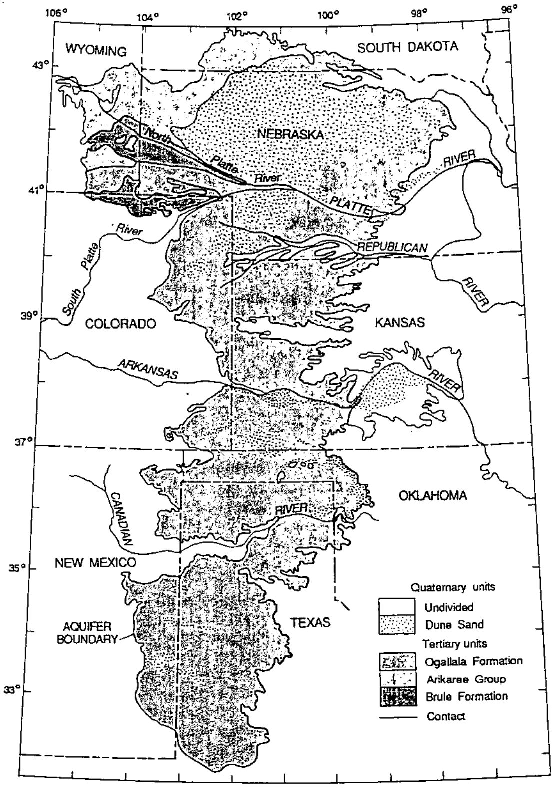
Panhandle Tablelands—Regions 6 and 7: In the north (Region 6), the Arikaree Group is heavily developed as a source of groundwater for irrigation in Box Butte County and, to a lesser degree, in northern Sheridan County. The overlying Ogallala Group is present mostly as channel deposits, but it is an important source of groundwater in Box Butte County and Sheridan counties. Holocene alluvium is developed as a source of water primarily along the Niobrara River. The thickness of the primary groundwater-bearing units ranges from about 100 feet or less to about 500 feet or more. In upland areas, depth to water may be greater than 200 feet, but may be less than 50 feet in the bottomlands of the principal valleys. Total dissolved solids in the groundwater vary from 200 to 500 milligrams per liter.

In the south (Region 7), the most widespread groundwater-bearing unit is the Ogallala Group. The Holocene alluvium along the major drainages is also very important (table 1). Fracture zones and possibly pseudokarst in the Brule Formation of the White River Group have created significant secondary permeability in localized areas in the valleys of Lodgepole and Pumpkin creeks. Most of these secondary permeability zones are fairly shallow, highly permeable and can yield high volumes of groundwater.

The thicknesses of the saturated groundwater-bearing units are generally less than 300 feet. Depth to the regional water table differs with topographic location. In upland areas, depth to water may be about 200 feet or more, whereas it may be about 50 feet or less beneath the bottomlands in the principal valleys. The groundwater generally contains between 200 and 500 milligrams per liter (mg/L) total dissolved solids, except along the North Platte Valley, where total dissolved solids range from about 500 to 1,000 mg/L.

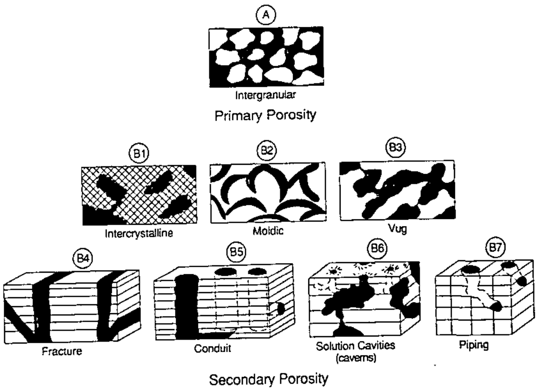
(continued on p. 13)

Figure 4



Distribution of principal geologic units in the High Plains aquifer (after Weeks and others, 1988).

Figure 5



Types of porosity (pore space in blue): a) primary porosity: small-scale intergranular; b) secondary porosity: small scale (<1 inch in diameter): B1—intercrystalline; B2—moldic: fossil shells dissolved, rock matrix undissolved; B3—vug: parts of rock matrix dissolved; large-scale, usually >1 inch long or wide: B4—fracture; B5—conduit; B6—solution cavities (caverns); B7—piping in weathered sediments. *[Intergranular is the most common porosity in Nebraska and produces by far the most water. Some fracture zones and solution cavities also exist in the state.—Ed.]*

Starting at about 38 million years ago, volcanic eruptions from the Rocky Mountains west and south into Mexico produced vast clouds of volcanic ash that rained down on Nebraska periodically and produced most of the deposits known as the White River and Arikaree groups of rocks [figs. 4 and 6]. These eruptions became less common beginning about 17 million years ago. Then rivers transported proportionately more sediments eroded from Colorado's and Wyoming's Rocky Mountains. These sediments began to be deposited across Nebraska, forming the initial parts of the High Plains (Ogallala) aquifer. The U.S. Geological Survey has included all of the sediments and sedimentary rocks of the White River [including the Brule Formation], Arikaree and Ogallala groups and most younger sediments beneath the area shown on the aquifer map [fig. 4]. The thickest parts of the aquifer and the greatest quantities of water are in Nebraska.

—Text, diagrams and captions are from Diffendal (1993).

Historical Trends in Groundwater Use for Irrigation

Irrigation has played 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, and surface water projects continued to be developed until about the late 1970s and early 1980s, when the federal government developed more stringent funding and cost-benefit requirements.

Current surface water irrigation projects are shown in green in figure 15. Since the mid-1930s and especially after the mid-1950s, the use of groundwater for irrigation has increased rapidly. The extent of registered irrigation wells in the state is also shown in figure 15.

These patterns of distribution are also relevant to the patterns of rises and declines in the state (fig. 18). Rises correspond roughly to surface-water transport and application, and declines correspond to certain, but not all, areas of intense irrigation-well development.

In 1995 groundwater supplied an estimated 77 percent of all water used for irrigation and 81 percent of all water used in the state. In that year, the latest for which the U.S. Geological Survey has water-use estimates, irrigation accounted for 93 percent of the estimated 6,195 million gallons per day of groundwater used in the state. This use was by far the largest amount of any kind of use. In general, besides supplying more than three-quarters of the state's irrigation supplies, groundwater also makes up about 81 percent of public water use, about 85 percent of self-supplied industrial use and about 82 percent of rural domestic and livestock supplies.

To satisfy the water demands of the most popular and profitable crops, irrigation is needed to supplement precipitation in much of Nebraska—about the western half of the state—and in drought years probably much more. Many of the state's crops require at least 22 inches of water a year for the best possible yield. Figure 16 shows that much of the state doesn't usually get this much precipitation in a year. Also, all the yearly rain and snowfall isn't available for crop use, and even in the more humid eastern part of the state, extended dry weather during the growing season is common.

Even if streamflow is available, only a limted number of acres can be served by surface-water diversions. Therefore, groundwater irrigation expanded almost exponentially once groundwater supplies were determined to be extensive and a method of moving groundwater, such as the center-pivot irrigation system, was developed that could apply water to crops grown in sandier soils, which are more porous, or on land that isn't relatively flat. Center-pivot systems distribute water with a boom that forms the radius of a circle around the pump. Since 1936, when the total wells installed numbered about 1,200 (fig. 17), the number of registered wells has multiplied more than 80 times, to about 98,000 wells serving about 85 percent of the state's irrigated land.

Climate, as well as geography, has influenced the rate of development of irrigation wells. The peaks of annual installation of irrigation wells shown in figure 17 correspond to periods when the state's average annual precipitation has fallen more than five inches below normal (fig. 17). In addition, during the 1970s, a combination of economic factors, such as good crop prices, low-cost energy and fertilizer, easy credit due to high land prices and certain tax credit laws, also contributed to irrigation development through the 1970s.

By the end of 1996, a total of 98,000 irrigation wells had been registered in the state. 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. Nearly 40 percent of the registered irrigation wells are concentrated in a 15-county region—basically the Big Blue and Little Blue basins and the central Platte area. Adams, Buffalo, Clay, Dawson, Fillmore, Hall, Hamilton, Kearney, Merrick, Phelps York counties have more than 2,000 irrigation wells each. Counties nearby—Butler, Polk, Saline, Seward—have more than 1,000 irrigation wells each. Antelope, Boone, Box Butte, Chase, Custer, Dodge, Dundy, Franklin, Holt, Keith, Lincoln, Platte, and Thayer counties are the other counties in the state that have more than 1,000 irrigation wells each.

Although the totals just mentioned provide some idea of the degree of groundwater development in a given county, the number of irrigation wells per square mile in a county is a better index of the intensity of development. A high density of wells generally indicates a large percentage of irrigable land and large amounts of readily available groundwater. Very low densities generally characterize counties where development is limited by a general lack of irrigable land or aquifers that yield relatively small amounts of water or both. Merrick County, in central Nebraska, averaging 9.17 irrigation wells per square mile, has the highest density; Pawnee County, in southeastern Nebraska, with an average of about one irrigation well every 200 square miles, has the lowest.

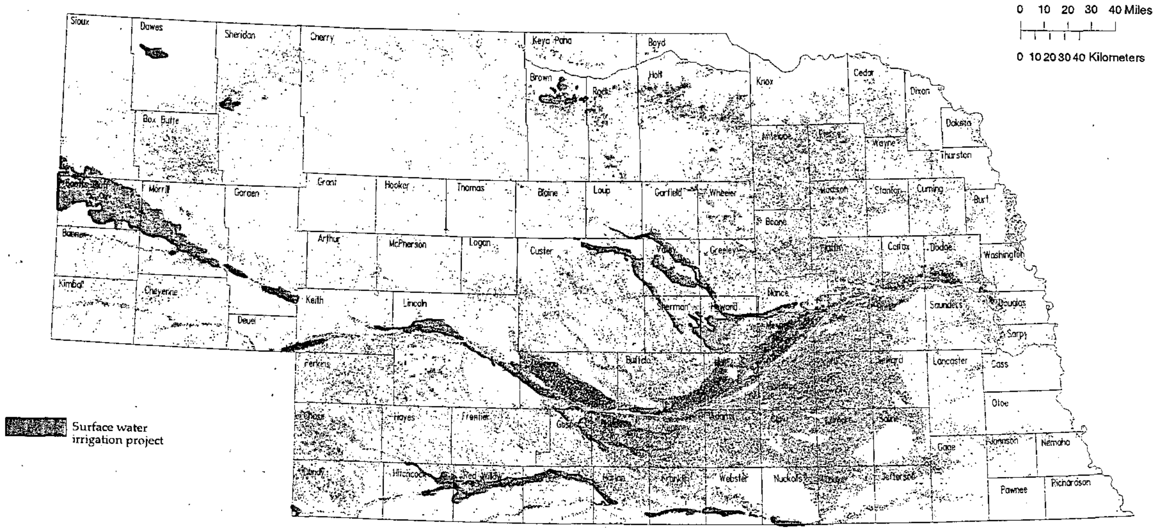
All the previously mentioned factors—geographic, climatic and economic—have also contributed to the increased use of center-pivot irrigation systems in Nebraska. These systems are virtually always supplied with groundwater. In recent years, center-pivot system installations have exceeded new well installations, which would indicate a conversion from gravity and other distribution systems to center-pivot systems.

Center-pivot irrigation systems have played an important role in expanding irrigation from flatter land with fine-grained soils, over which water moves relatively efficiently, to hilly topography and sandier soils not suited to gravity distribution. Generally, the areas of new development have been in the north-central, central and southwestern parts of the state, where center-pivot irrigation systems provide a way to overcome the problems discussed above.

To a lesser degree than with surface water diversions, the location of these irrigation systems has also been controlled by the availability of water. As the design and engineering of the systems advanced, the land that could be irrigated increased and included areas where irrigation development was seen as not possible and perhaps not prudent.

(continued on p. 34)

Figure 15



Surface-water Irrigation Projects and Registered Irrigation Wells

Grounwater Regions (continued)

East Central Dissected Plains—Region 8: The Ogallala Group of Tertiary age, composed of fine- to medium-grained silty sand and sandstone, siltstone and sandy and clayey silt, is the principal groundwater-bearing unit. As much as 400 feet thick in the western part of the region, it thins eastward until it is virtually absent in south-central Madison County, most of Platte County and a small area in eastern Buffalo County. The Ogallala Group is overlain by a complex series of Quaternary deposits consisting of river-deposited silt, sand and gravel and wind-deposited silt and sand that are thickest where they fill ancient valleys (paleovalleys).

The Quaternary deposits and the Ogallala Group are the primary units from which groundwater is pumped (table 1). The thicknesses of the primary groundwater-bearing units range from about 100 feet or less to about 500 feet or more. In upland areas, depth to water may be greater than 200 feet, whereas it may be less than 50 feet below the bottomlands in the principal valleys. The general water quality is good; natural dissolved solids range from 200 to 500 parts per million.

Republican River Valley and Dissected Plains—Region 9: The principal groundwater-bearing units in this region are the Ogallala Group of Tertiary age and the overlying Quaternary sand and gravel deposits (table 1). Alluvium and terrace deposits are an important source of groundwater, yielding small to large quantities of water in the Republican River valley and its major tributaries. Sand and gravel of Pliocene and Pleistocene age also fill some ancient valleys (paleovalleys).

Depth to the regional water table ranges from about 50 feet or less in the Republican River valley to about 200 feet or more in the uplands. The saturated thickness of the principal groundwater-bearing units ranges from about 100 feet or less to about 300 feet or more.

Nebraska Glacial Drift (Till)—Regions 10 and 11: The Pliocene-Pleistocene sand and gravel deposits that fill buried valleys (paleovalleys) are the principal sources of water to high-capacity wells. In the western part of the region, some wells obtain water from the Ogallala Group. Course-grained alluvial deposits beneath present-day river systems, such as the Elkhorn and Platte rivers and their major tributaries, yield large amounts of groundwater for some high-capacity irrigation and many municipal wells, particularly along the lower Platte.

In many locations not underlain by these geologic units, perched or semi-perched groundwater is used. Perched or semi-perched water conditions occur where water moves readily through the overlying sediments but not through glacial till. This water forms mounds on these lenses of till. Many domestic farm and stock wells have been developed in these perched water bodies. Depending on the water-bearing unit and its location, total dissolved solids may range from 200 to more than 1,000 milligrams per liter (mg/L). Because of the variability in water quality and in the limited distribution of groundwater-bearing units, rural water districts are common.

North Central Tableland—Region 12: Availability of groundwater in this region is highly variable and depends mainly on the thickness of the Ogallala Group, which is the main source of groundwater in the western part of the region. In limited areas, the Ogallala Group contains coarse sediments of substantial thickness that yield substantial groundwater to large-volume public water-supply wells.

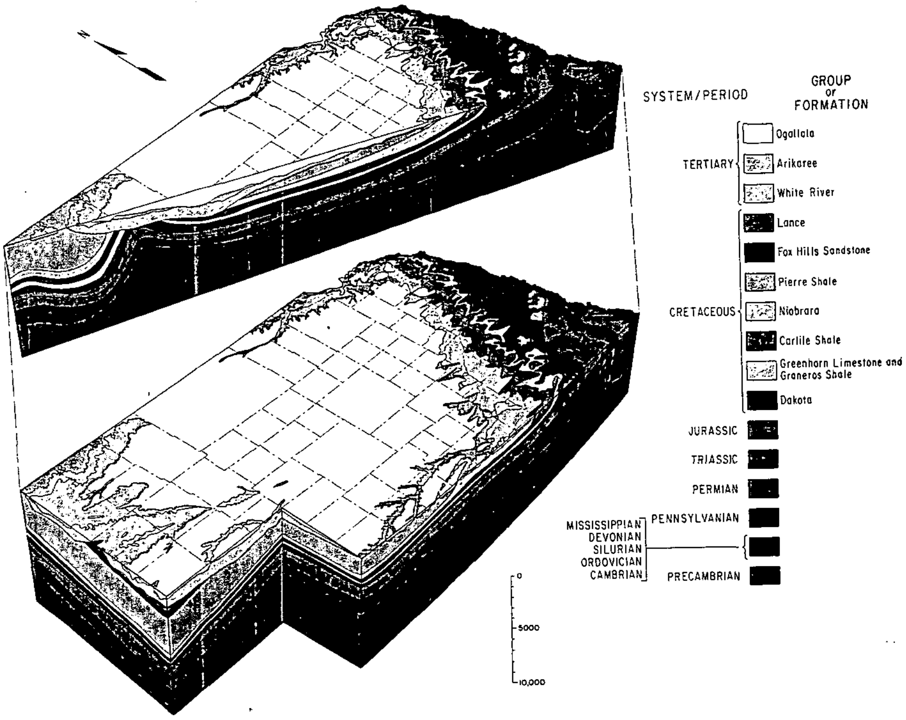
In the eastern part of the region, where Tertiary deposits have been eroded, the main source of groundwater is alluvial Quaternary deposits. These deposits are sporadic in their distribution and in places support only low-yielding wells. In the eastern upland areas, groundwater can be developed only from deposits of Cretaceous age. The shallowest Cretaceous unit that has yielded groundwater is the Codell Sandstone Member of the Carlile Shale. Low-yielding domestic and stock wells have been developed in this unit.

Depth to the regional water table differs as a function of topographic location. In upland areas, depth to water may be greater than 200 feet, whereas it may be less than 50 feet below bottomlands in the principal valleys. Total dissolved solids range from 200 to 500 milligrams per liter (mg/L) in the west and can exceed 1,000 mg/L in the east.

Hat Creek-White River Drainage Basin—Region 13: The area is characterized by a lack of any substantial groundwater resource. The Pierre shale crops out at the surface or is present at shallow depth in much of the northern part of this area. This impermeable shale does not yield sufficient quantities of water for domestic or livestock use. Groundwater developed in the northern part of this region is limited to a few isolated low-yield wells drilled into river-deposited sediments along the major drainages. In the areas underlain by the Pierre shale, water is piped many miles for domestic or livestock use.

The White River Group of Tertiary age underlies the southern part of the region and has been locally developed as a source of groundwater. This group consists of the Chadron and Brule formations. Near uranium deposits in the Crawford area, groundwater from the Chadron Formation is not suitable for domestic or livestock purposes because of high radium concentrations.

Figure 6



Block Diagram of Geology

This map portrays the relative vulnerability to or potential for contamination of groundwater. This assessment is based on a standardized methodology referred to as *DRASTIC* which was developed by the U.S. Environmental Protection Agency and the National Water Well Association. The method incorporates weighted factors affecting contaminant transport to groundwater. The scale at which this analysis was performed (1:250,000) restricts the usefulness of this map to relative evaluations on a regional basis and does not allow site-specific applications.

DRASTIC was developed to provide a systematic evaluation of the potential for groundwater contamination that is consistent on a national basis. Each letter of the name refers to one of the hydrogeologic factors used in the evaluation. They are: **D**epth to water; **R**echarge to the aquifer (net); **A**quifer media; **S**oil media; **T**opography (slope); **I**mpact of vadose (unsaturated) zone; **C**onductivity (hydraulic) of the aquifer.

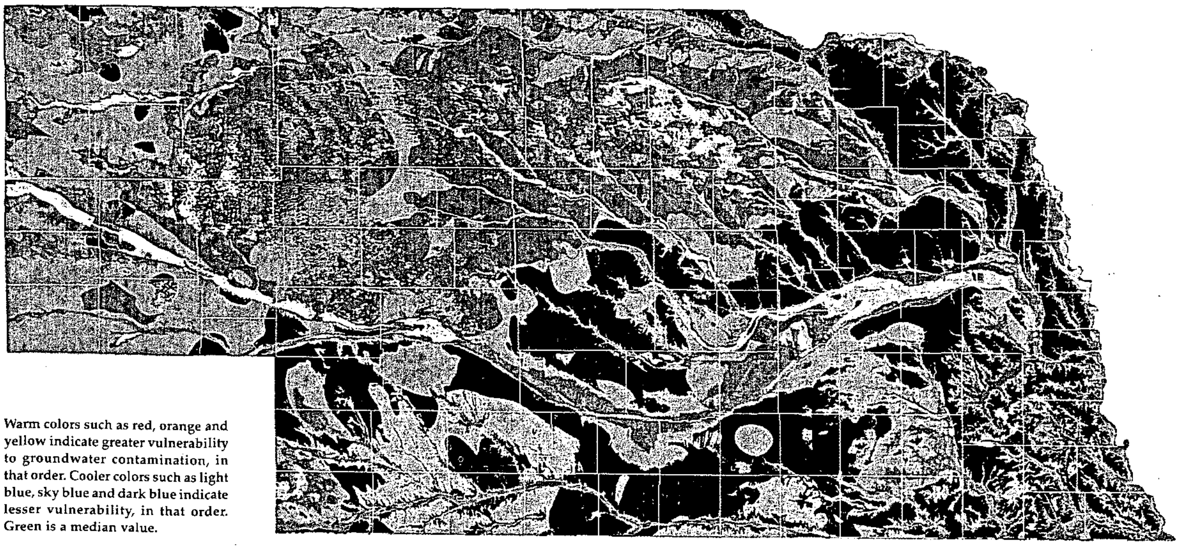
Each factor (or parameter) was mapped according to a standard ranking of various values. Parameter maps at a scale of 1:250,000 were then superimposed according to a weighting based on the relative importance of each to potential groundwater contamination. Each parameter map was related to the other parameter maps by overlaying cells 640 meters by 640 meters in size. The final map pictured above represents the combination of the seven parameter maps.

Areas with relatively low potential for groundwater contamination, such as upland areas with greater depths to water and silty soils, are represented by cool colors like gray and blue. Areas with relatively great potential for groundwater contamination, such as valleys with shallow depths to water and sandy soils, are represented by warm colors like red and yellow. The actual hierarchy of values from highest to lowest potential is as follows: red, yellow, light green, dark green, light blue, dark blue, gray. Dashed line shows the maximum extent of glaciation in the eastern part of the state.

DRASTIC makes four major assumptions: 1) the contaminant is introduced at the ground surface; 2) thecontaminant is flushed into the groundwater by precipitation; 3) the contaminant has the mobility of water; and 4) the area evaluated is 100 acres or larger.

Land-use practices such as application of irrigation water or agricultural chemicals were not considered. These factors are known to be important in the occurrence of nonpoint-source contamination. The map was produced by the Center for Advanced Land Management Information Technologies, Conservation and Survey Division, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, under contract to the Nebraska Department of Environmental Control. For more information the reader is referred to Rundquist and others (1989) and Rundquist and others (1991).

Figure 14



Warm colors such as red, orange and yellow indicate greater vulnerability to groundwater contamination, in that order. Cooler colors such as light blue, sky blue and dark blue indicate lesser vulnerability, in that order. Green is a median value.

Groundwater Vulnerability to Contamination Using the DRASTIC Method

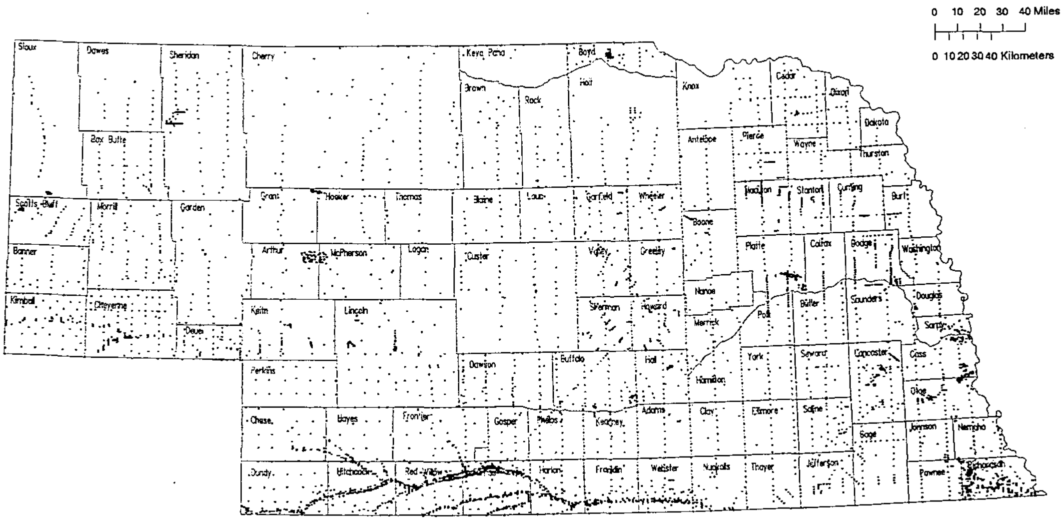
The block diagram provides a broad, general perspective of the distribution and thickness of the major sedimentary rocks in Nebraska. Under these rocks in most of the state, the Precambrian is composed of dense, crystalline igneous and metamorphic rocks. The overlying sedimentary rocks range in thickness 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 (table 1).

The oldest sedimentary rocks are of Cambrian and Ordovician age. These sandstones and sandy carbonates are major groundwater reservoirs in Iowa but not in Nebraska. Together with carbonate rocks of the Silurian and Devonian systems, 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 System are mostly carbonates, but they do have permeable zones where fractured. Very few data on water quality are available for these older rocks. Small yields of generally poor-quality water are obtained from carbonate rocks of the Pennsylvanian and Permian systems in southeastern Nebraska.

The Dakota Group is the best groundwater reservoir within the Cretaceous System, 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-age rocks have low permeabilities. Exceptions are fracture zones in the Niobrara Formation yielding groundwater in northeastern Nebraska and in Nuckolls and Fillmore counties. Some limestones in the Greenhorn Formation and sandstones in the Carlile or Niobrara formations and the Pierre, Fox Hills and Lance formations have supplied low-yield wells. Generally, rocks of Cretaceous age and older 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. 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.

Figure 7



Location of Test Drilling for Hydrogeologic Investigations

Transmissivity is a measure of the rate of groundwater 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 other factors, such as the type of well construction and development, amount of drawdown and whether the groundwater is confined or unconfined.

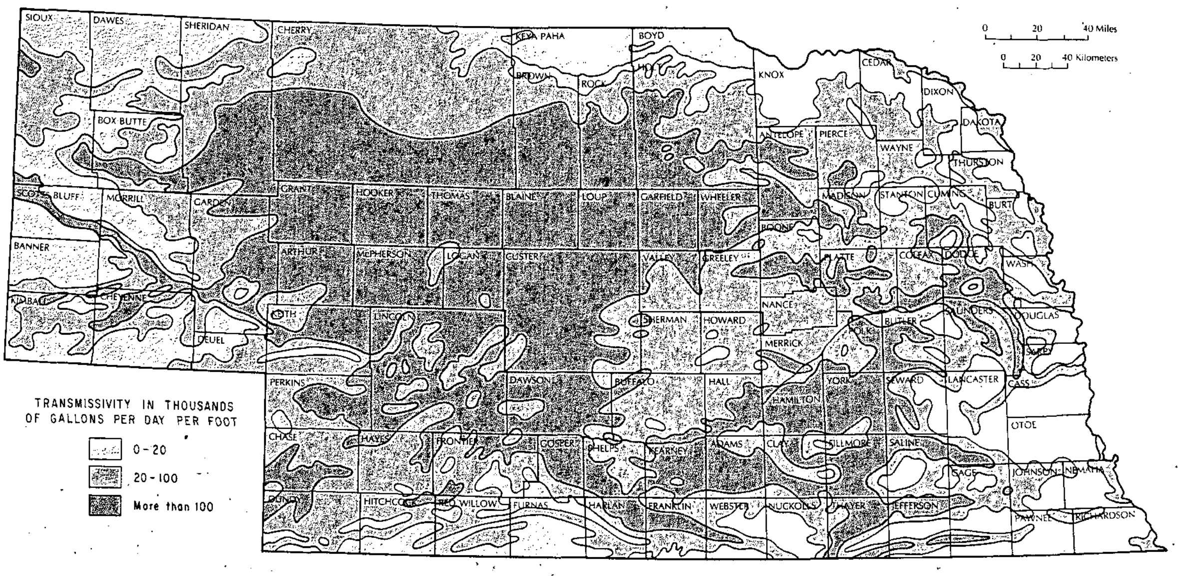
Usually, where transmissivity values exceed 20,000 gallons per day per foot, wells can be developed with yields adequate for some types of irrigation. Where transmissivity values exceed 100,000 gallons per day per foot, high-capacity wells of more than one thousand gallons per minute can be developed 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 buried valley is the band of high transmissivity across southern Thayer, Jefferson and Gage counties.

Figure 13



Transmissivity of the Principal Groundwater Reservoir

The locations of test holes for research in groundwater geology (hydrogeology) 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 since 1930. Other specific hydrogeologic research projects and stratigraphic investigations have also contributed test-drilling data.

The systematic test drilling in the state was halted in 1990 when contract drilling by other agencies could no longer be supported. At present, more than 4,500 test holes have been drilled in nearly every part of the state. The only places lacking closely spaced grid-style drilling are Keya Paha, western Knox and northern Holt counties and parts of the western Sand Hills.

In addition to storing the samples and logs of its own drilling, which are extensively analyzed and catalogued, the Conservation and Survey Division by law is the repository for all public drilling samples and cores in the state. It also houses extensive samples donated by the private sector.

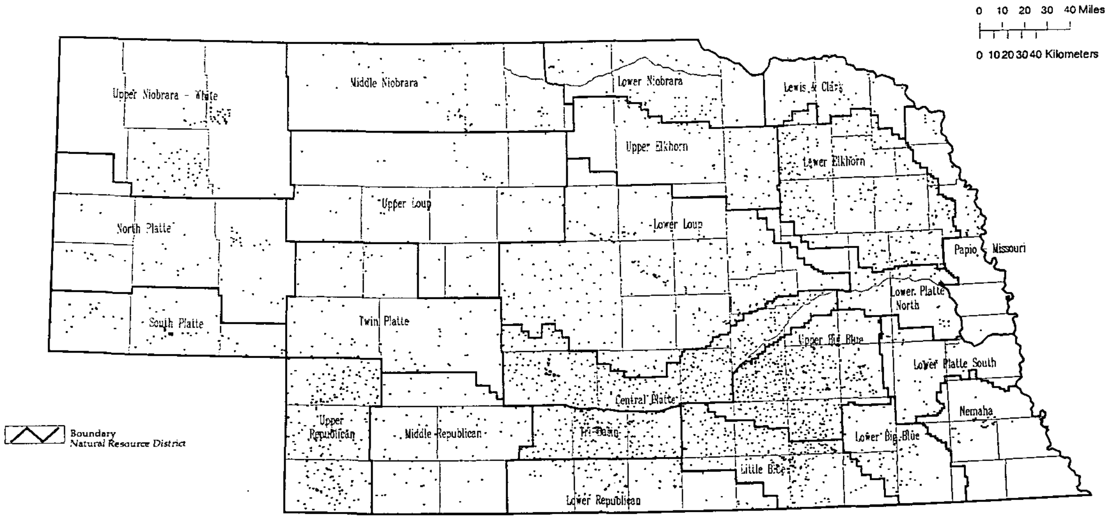
Compilations of test hole records are also available for many counties from the Conservation and Survey Division. While many are quite recent, some are older log books from the 1950s or 1960s. And some are out of print. The division is working consistently to update all county test-hole log books. Call or write for more information.

What is test drilling?

While test drilling may seem lacking in glamor or great importance, to geological researchers, in a state with few outcrops (rock exposures), test drilling is a necessity, a life's blood. In fact, Nebraska has drilled more test holes than any other state in the nation. Test drilling is often long, hard work in the heat or in near-freezing to sub-freezing temperatures. It requires constant supervision and concentration. It often goes on into the night or early morning and generally occurs many miles from food or shelter; water, however, is a necessity, in order to make drilling mud, and is usually brought in a separate tank truck.

The sheer logistics of maneuvering a drill rig into place can be very demanding, even exasperating, especially if the equipment gets bogged down in sand or mud. Samples must be caught in order and rocks or sediments recorded carefully. If the crew is moving on to another place the next day, the researcher running the geophysical equipment must log (record readings from) the hole then and there, a task that often takes until midnight or later. In short, many important scientific and economic decisions depend on the data gained from this kind of publicly sponsored drilling.

Figure 8



Location of Observation Wells for the Groundwater-Level Monitoring Program with Natural Resources Districts

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 (fig. 10) and then calculating the differences between the two surfaces. The qualifications stated in the text describing the water-table configuration map apply to this map also.

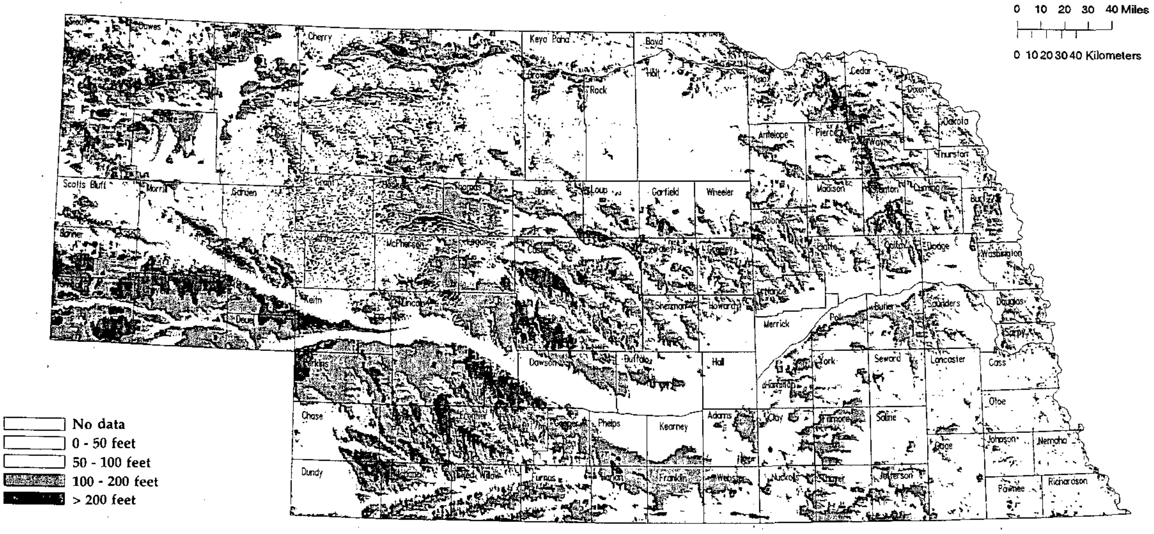
Depths to water differ greatly from place to place in the state. In many places they may range from about 50 feet to about 200 feet within a distance of less than 5 miles. In general, depths to water are least under the valleys of the principal streams, beneath a large area that includes most of Rock 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 it practically impossible to indicate 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. Therefore, the stippled pattern distinguishes this area from the remainder of the state.

Depth to water is a consideration in developing groundwater supplies. These 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, a technical and economic consideration, 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 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 an area where semi-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 12



Depth to the Regional Water Table

A cooperative statewide project to monitor water levels began in 1930 as a part of the 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 1994.

Nearly 4,160 observation wells monitored by 36 federal, state, and local agencies, including Nebraska's 23 natural resources districts (NRDs), are used to currently measure groundwater levels in Nebraska. The state's NRDs in particular make important use of the water-level data in formulating and executing their state-mandated groundwater management plans.

Most of the observation wells are located in areas where irrigation-well density is great and considerable amounts of groundwater are withdrawn. These data are used to determine annual and long-term water-level changes. Water-level measurements are made for a variety of reasons; therefore, the distribution of observation wells in the state is nonuniform. The number of observation wells per county ranges from none in some counties to more than 200 in others, with the greatest density in areas where substantial changes in water levels have occurred. Water-level changes in some areas may not be detected or delineated because of insufficient data.

In Nebraska, because use of water for irrigation causes the most significant water-level fluctuations, most observation wells are measured in the spring and late fall. Spring measurements are useful in determining amounts of groundwater in storage prior to irrigation and the system's response to groundwater withdrawals the previous summer, whereas fall measurements are useful in evaluating the seasonal effects of irrigation. All annual water-level reports for years prior to 1994 were based on fall measurements.

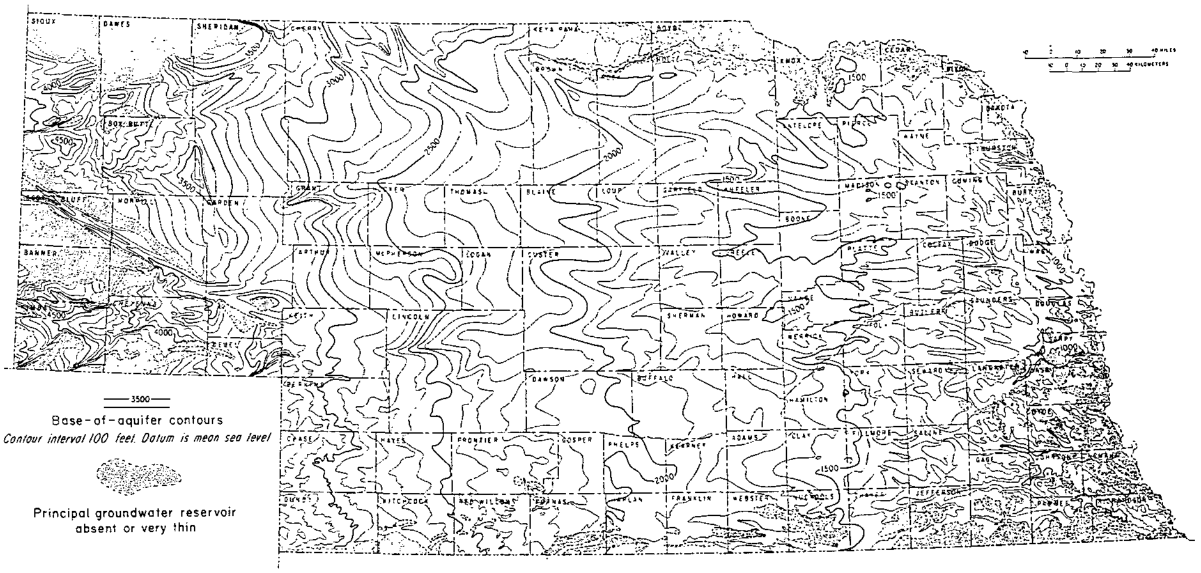
New developments in water-level monitoring

In 1996, approximately 10,000 water-level measurements in about 4,160 wells were included in the computerized data base of historical water-level records maintained by the U.S. Geological Survey and the Conservation and Survey Division. Records of nearly all agencies in Nebraska that make water-level measurements have been compiled and entered into this data base. As of December 31, 1996, this data base contained records of approximately 564,000 water-level measurements made in approximately 18,900 wells. The number of water-level records available for each well varies depending upon the number of years water levels were measured in that well and the frequency of measurements.

Beginning in 1994, spring measurements were used because they provide a better reflection of the system's response to groundwater withdrawals and recharges. During the first half of 1997, CSD began to revamp the water-levels monitoring program by hiring a full-time coordinator and by preparing to put the annual water-levels report on the World Wide Web and compact disk, or in a print-on-demand format available at the division office or by mail. The electronic information eventually will have well data that can be opened to reveal the hydrograph, historical records and a geographic information system that uses a global positioning system to locate wells.

Records of water-level measurements or long-term water-level data in the form of hydrographs from selected observation wells in the state may be obtained from the Conservation and Survey Division, University of Nebraska-Lincoln, 113 Nebraska Hall, Lincoln, Nebraska 68588-0517 (see e-mail and Web site addresses at the end of the *Preface*) or from the U.S. Geological Survey, Room 406, Federal Building, 100 Centennial Mall North, Lincoln, Nebraska 68508.

Figure 9



Configuration of the Base of the Principal Groundwater Reservoir

The thickness of the saturation of the principal groundwater reservoir was created by superimposing maps showing the regional water-table configuration in the spring of 1979 (fig. 10) on same-scale maps showing the configuration of the base of the principal groundwater reservoir (fig. 9) and then calculating 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 white. 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.

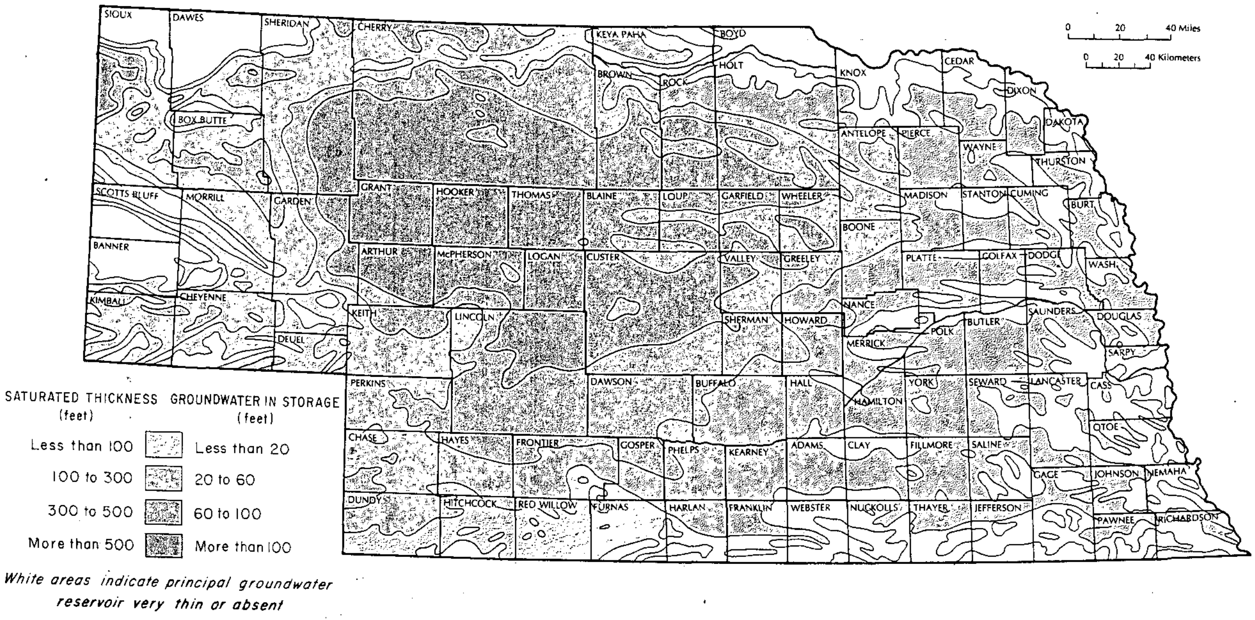
In evaluating the volume of the principal groundwater reservoir, it is also important to consider that this reservoir is part of a dynamic recharge and discharge system. Nearly all the recharge to a local aquifer results from precipitation falling on overlying land. Additional recharge may come from 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 (fig. 18).

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*, an estimate of pore space, is assumed to be 20 percent). That estimate is conservative because it accounts for only the readily available water in the coarse-textured parts 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 11



White areas indicate principal groundwater reservoir very thin or absent

Saturated Thickness of the Principal Groundwater Reservoir

The configuration 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 (table 1).

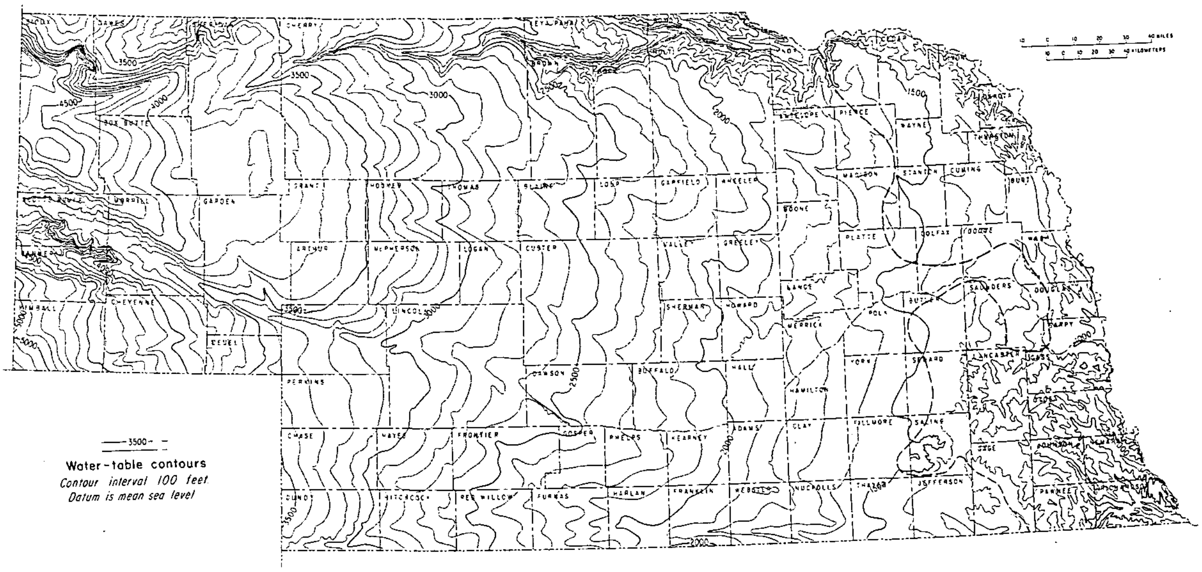
The bottom surface of the principal groundwater reservoir does not coincide with the bottom of a single stratigraphic layer in the rock sequence underlying Nebraska. Instead, it coincides with the bottom of different stratigraphic layers from one part of the state to another.

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 (fig. 4 and fig. 6).

Data used in generating this map differ greatly in distribution and reliability from place to place in the state. 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 10



Configuration of the Regional Water Table

The regional water table is generally defined as the upper surface of the water that fills pore spaces (voids) 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 stored and transmitted toward some point or area of discharge at the land surface.

Water-table contour lines represent lines of equal elevation above mean sea level. The regional water table depicted is a subdued reflection of the land surface. Because the land surface of Nebraska slopes generally eastward, the water table slopes generally in the same direction. The land surface is irregular locally because streams have carved valleys into it, and the Local depressions of 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 measured in the spring of 1979 in wells not being pumped and of the topographic elevations anywhere groundwater is know 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 retard percolation of water that they may create a zone of saturation above them. Such zones are known as *semi-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. This 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 regional 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.