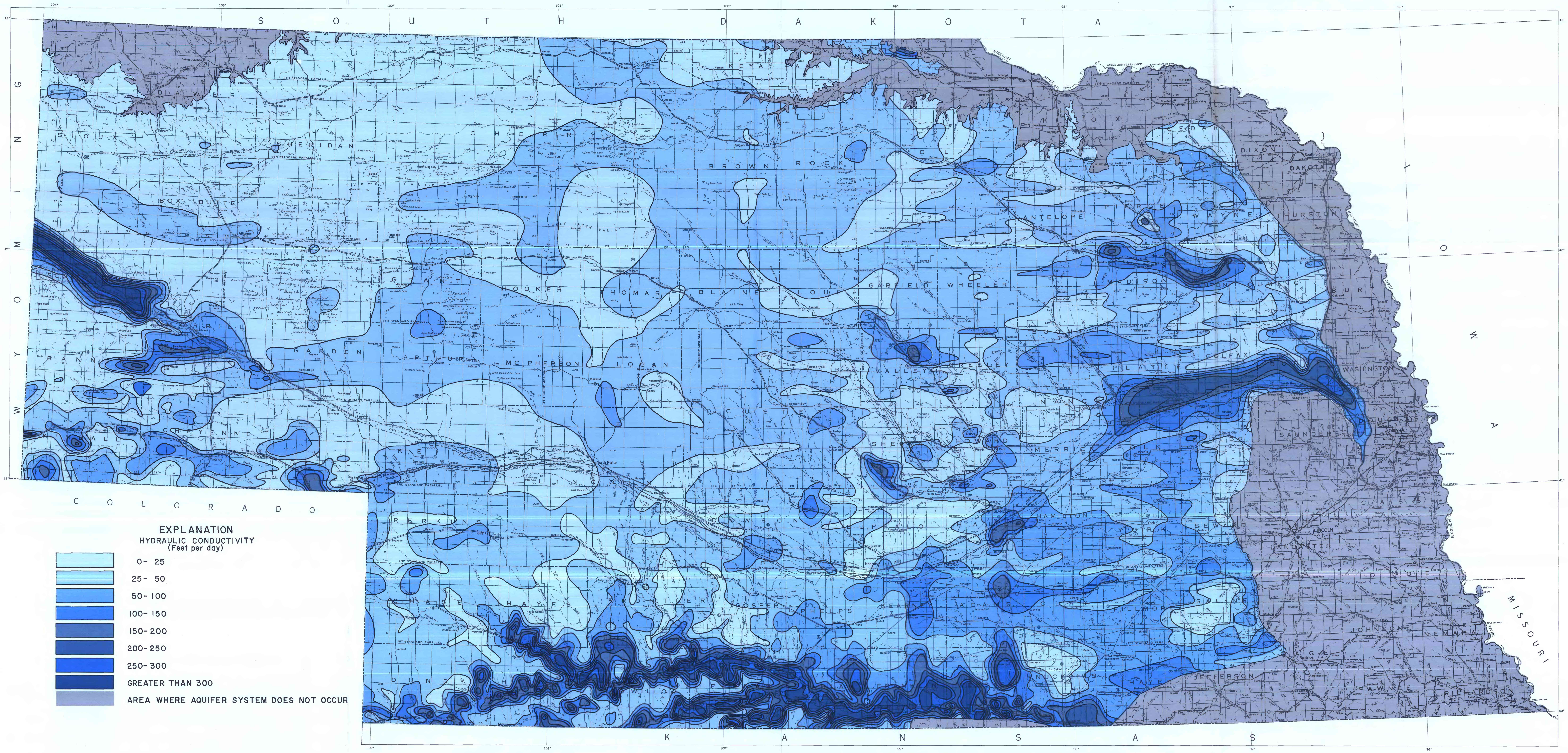
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

WATER RESOURCES INVESTIGATIONS
REPORT 82-4014
SHEET 1 OF 3



MAP SHOWING HYDRAULIC CONDUCTIVITY OF HIGH PLAINS AQUIFER SYSTEM

INTRODUCTION

In 1977 the U.S. Geological Survey began a 5-year regional study of an aquifer system that underlies 177,000 square miles of the High Plains section of the Great Plains Physiographic Province (Fenneman, 1931). This vast aquifer system, which extends from near the southern Rocky Mountains on the west to the Central Lowlands on the east and from southern South Dakota to mid-Texas, underlies parts of eight states, including 64,770 square miles in Nebraska. The geologic units comprising the aquifer system are the Ogallala Formation of Tertiary age and other Tertiary and Quaternary deposits that are saturated and hydraulically connected to the Ogallala.

The objectives and work plan for the regional study (Weeks, 1978) provided for the collection and interpretation of hydrologic information by Geological Survey personnel in the individual states and for the preparation of interpretive reports of both State and regional scope. The purpose of this report is to present for Nebraska, in more detail and at a larger scale than could be accommodated in the regional reports, interpretive information about the hydraulic conductivity and specific yield of the aquifer system and about the volume and distribution of water pumped for irrigation from the aquifer system during 1980. The data used in preparing this report have been correlated and integrated with data from adjoining states, where appropriate, and are stored in the regional water-resources, data-storage-and-retrieval system.

This is the second report by U.S. Geological Survey personnel in Nebraska that presents interpretive information for the High Plains aquifer system in the State. The first report (Pettijohn and Chen, 1982) provides a description of the boundaries of the system, of the sediments comprising the system, of the geology and configuration of the base of the system, of the saturated thickness of the system, and of the potentiometric surface of the system.

This report and the first report are complementary; information from both can be used to compute certain aquifer properties, knowledge of which is essential in the development of a management plan for the aquifer system. For example, information on hydraulic conductivity, in this report, can be used with information on saturated thickness of the aquifer, in the first report, to compute transmissivity. Similarly, information on specific yield, in this report, can be used with information on saturated thickness of the aquifer to estimate the volume of water recoverable from the aquifer.

HYDRAULIC CONDUCTIVITY OF AQUIFER SYSTEM

The hydraulic conductivity of the aquifer system in the High Plains area of Nebraska is shown on the above map. Hydraulic conductivity of an aquifer system is the volume of water that will move in unit time under a unit hydraulic gradient through a unit area of the system measured at right angles to the direction of flow (Lohman and others, 1972). In this report, hydraulic conductivity is expressed in feet per day. It is dependent largely on the nature of the pore space in the aquifer-system deposits. If the pore spaces are large and well connected, and the deposits are predominantly sand and gravel, the hydraulic conductivity is large. Conversely, if the pore spaces are small and not well connected, and the deposits are predominantly silt and clay, the hydraulic conductivity is small. Because pore space is a function of particle-size distribution, hydraulic conductivity of a deposit can be estimated from the size distribution of the particles comprising the deposit.

The map portrays, by ranges, weighted-average hydraulic conductivity. To derive the information for the map, hydraulic conductivity was first estimated for about 2,700 test-drilling sites from information in drilling logs. For each site, a hydraulic conductivity value was assigned to each lithologically distinct layer of material between the potentiometric surface and the base of the aquifer system. This value was determined from a table that relates grain-size distribution and hydraulic conductivity (Lappala, 1978, p. 70). The hydraulic conductivity values assigned to the individual layers were then weighted by the thicknesses of the layers, and a weighted-average hydraulic conductivity was computed for the entire thickness of the system.

The weighted hydraulic conductivities for approximately 2,700 sites were plotted on a base map, and lines of equal hydraulic conductivity were drawn to delimit the ranges shown on the map. Areas with hydraulic conductivities greater than 200 feet per day, because the saturated deposits are predominantly sand and gravel, occur in parts of the North Platte, Platte, and Elkhorn River valleys and in most of the Republican River valley. Areas with hydraulic conductivities less than 25 feet per day, because the saturated deposits are predominantly very fine sand, silt, and some clay, are widely distributed throughout the State, but predominate in the northwest.

The hydraulic-conductivity map, in conjunction with the saturated-thickness map (Pettyjohn and Chen, 1982), may be used to estimate relative well yields. For example, in some areas the weighted hydraulic conductivity may be large; but because the saturated deposits are thin, the aquifer may yield relatively small quantities of water to wells. Conversely, in some areas the weighted hydraulic conductivity may be small; but because the saturated deposits are thick, the aquifer may yield relatively large quantities of water to wells.

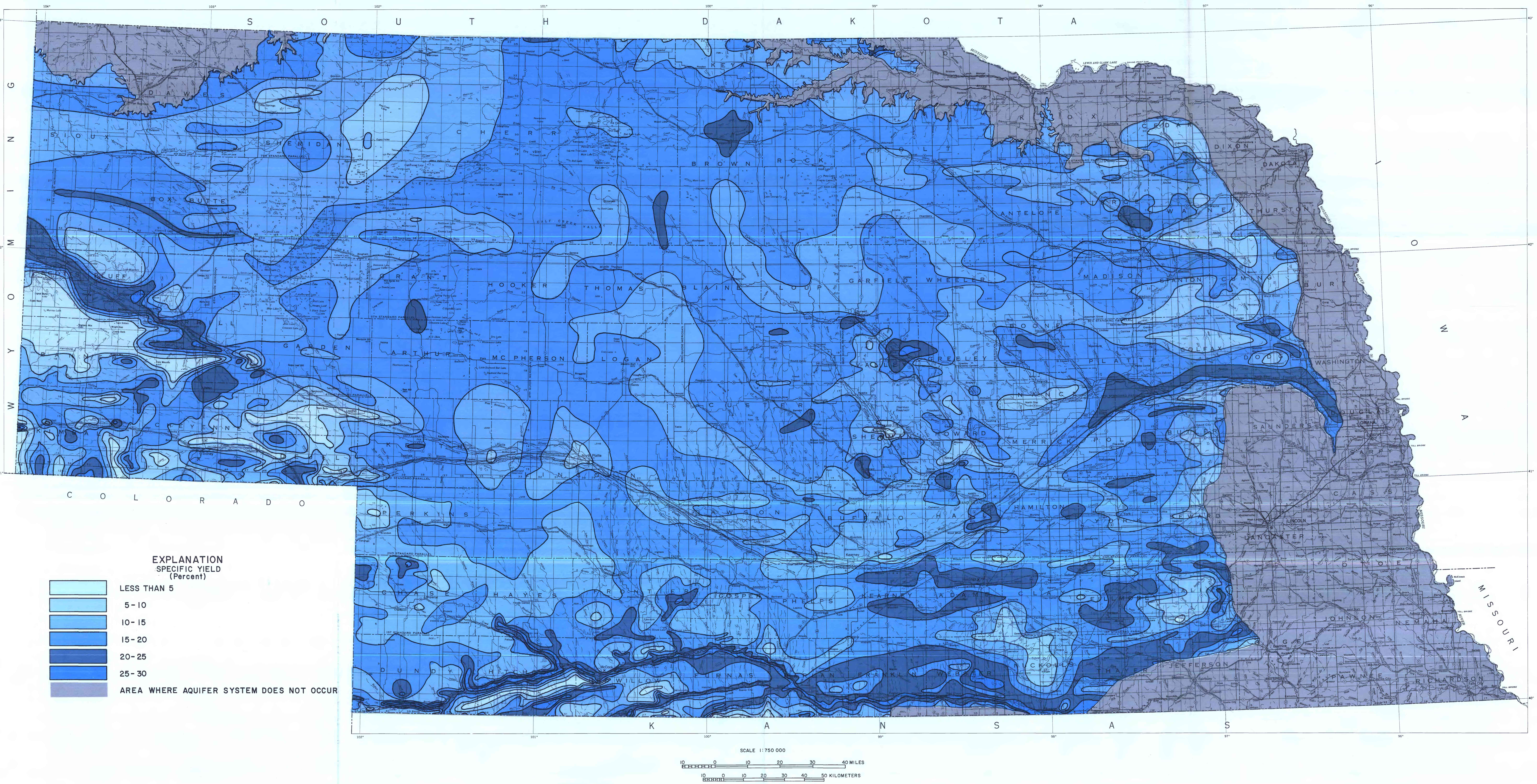
Hydraulic conductivity, together with saturated thickness of the aquifer system, provides a means for estimating the transmissivity of the aquifer system at a selected location. Transmissivity is the rate at which water is transmitted through a unit width of the entire saturated thickness of an aquifer under a unit hydraulic gradient (Lohman and others, 1972). It may be used in the Theis equation along with values of other aquifer properties to estimate drawdown in pumping wells and to calibrate digital computer models of confined aquifer systems. Transmissivity is estimated by multiplying the hydraulic conductivity of the aquifer system at a chosen location by the saturated thickness of the system at that location, as summarized in the following table. For example, if the hydraulic conductivity was 100 feet per day and the saturated thickness was 400 feet, the transmissivity would be 40,000 feet squared per day.

Hydraulic conductivity (feet per day)	Aquifer thickness (feet)							
	100	200	300	400	500	600	800	1,000
	Transmissivities of aquifer system (feet squared per day)							
25	2,500	5,000	7,500	10,000	12,500	15,000	20,000	25,000
50	5,000	10,000	15,000	20,000	25,000	30,000	40,000	50,000
100	10,000	20,000	30,000	40,000	50,000	60,000	80,000	100,000
150	15,000	30,000	45,000	60,000	75,000	90,000	120,000	150,000
200	20,000	40,000	60,000	80,000	100,000	120,000	160,000	200,000
250	25,000	50,000	75,000	100,000	125,000	150,000	200,000	250,000
300	30,000	60,000	90,000	120,000	150,000	180,000	240,000	300,000

Base from U.S. Geological Survey
State base map, 1962

HYDRAULIC CONDUCTIVITY, SPECIFIC YIELD, AND PUMPAGE-HIGH PLAINS AQUIFER SYSTEM, NEBRASKA

By
Robert A. Pettijohn and Hsiu-Hsiung Chen



MAP SHOWING SPECIFIC YIELD OF HIGH PLAINS AQUIFER SYSTEM

SPECIFIC YIELD OF AQUIFER SYSTEM

The estimated specific yield distribution of the aquifer system in the High Plains area of Nebraska is shown on the above map. The specific yield of an aquifer is the ratio of the volume of water that the aquifer, after being saturated, will yield under the force of gravity to the volume of the aquifer. Specific yield depends on particle size, shape and distribution of pores, compaction of the deposits, and time of drainage. If the aquifer is composed of medium to coarse, uniformly sorted sands, the specific yield may be as much as 30 percent. In contrast, if the aquifer is composed of nonuniformly sorted fine sand, silt, and clay, specific yield may be less than 5 percent. The map portrays, by ranges, weighted-average specific yield. To derive the information for the map, specific yield was first determined for about 2,700 test-drilling sites from information in drilling logs. For each site, an estimated specific yield value was assigned to each lithologically distinct layer of material between the potentiometric surface and the base of the aquifer system. The specific yield values assigned for the individual layers were then weighted by the thicknesses of the layers, and a weighted-average specific yield was computed for the entire saturated thickness of the system.

Specific yield values were assigned to the individual layers of material according to particle-size distribution using a table of values modified from Johnson (1967). This method is described by Olmsted and Davis (1961); a similar method was used by Lappala (1978).

The weighted specific yields for the approximately 2,700 sites, which were not uniformly distributed over the High Plains area, were plotted on a base map, and lines of equal specific yield were drawn to delimit the ranges shown on the map. Specific yields of the High Plains aquifer system range from 10 to 20 percent in most of the State, and average 16 percent. Specific yields are less than 10 percent where the aquifer system consists primarily of silt-size particles. Specific yields are greater than 20 percent where the aquifer system is composed almost entirely sand and gravel. Although areas where specific yield is greater than 20 percent are principally in the upper North Platte, lower Platte, and Republican River valleys and buried valleys of eastern Nebraska, areas where specific yield is greater than 20 percent also occur locally in upland areas in many places in the High Plains of Nebraska. Areas where specific yield is less than 10 percent occur principally along the southern border of Nebraska where the aquifer is thin loess deposits, in eastern Nebraska where the aquifer system interfingers with glacial deposits, and in the Panhandle area where fine-grained Tertiary deposits occur on ridges.

Specific yield multiplied by saturated thickness provides an estimate of the volume of water which would be yielded from the aquifer in an area if the aquifer were completely drained by gravity. Volumes of water recoverable from a square mile of aquifer for various specific yields and saturated thicknesses of the aquifer are listed in the following table.

Specific yield (percent)	Saturated thickness (feet)							
	100	200	300	400	500	600	800	1,000
	Volume of water recoverable from 1 square mile of aquifer system (acre-feet)							
5	3,200	6,400	9,600	12,800	16,000	19,200	25,600	32,000
10	6,400	12,800	19,200	25,600	32,000	38,400	51,200	64,000
15	9,600	19,200	28,800	38,400	48,000	57,600	76,800	96,000
20	12,800	25,600	38,400	51,200	64,000	76,800	102,400	128,000
25	16,000	32,000	48,000	64,000	80,000	96,000	128,000	160,000

The estimated volume of water recoverable from the High Plains aquifer system in Nebraska is 2,237 million acre-feet. This estimate was obtained by multiplying the average specific yield of 16 percent by 13,984 million acre-feet, the volume of the saturated thickness of the aquifer system (Pettijohn and Chen, 1982).

FACTORS FOR CONVERTING INCH-POUND UNITS TO
INTERNATIONAL SYSTEM OF UNITS (SI)

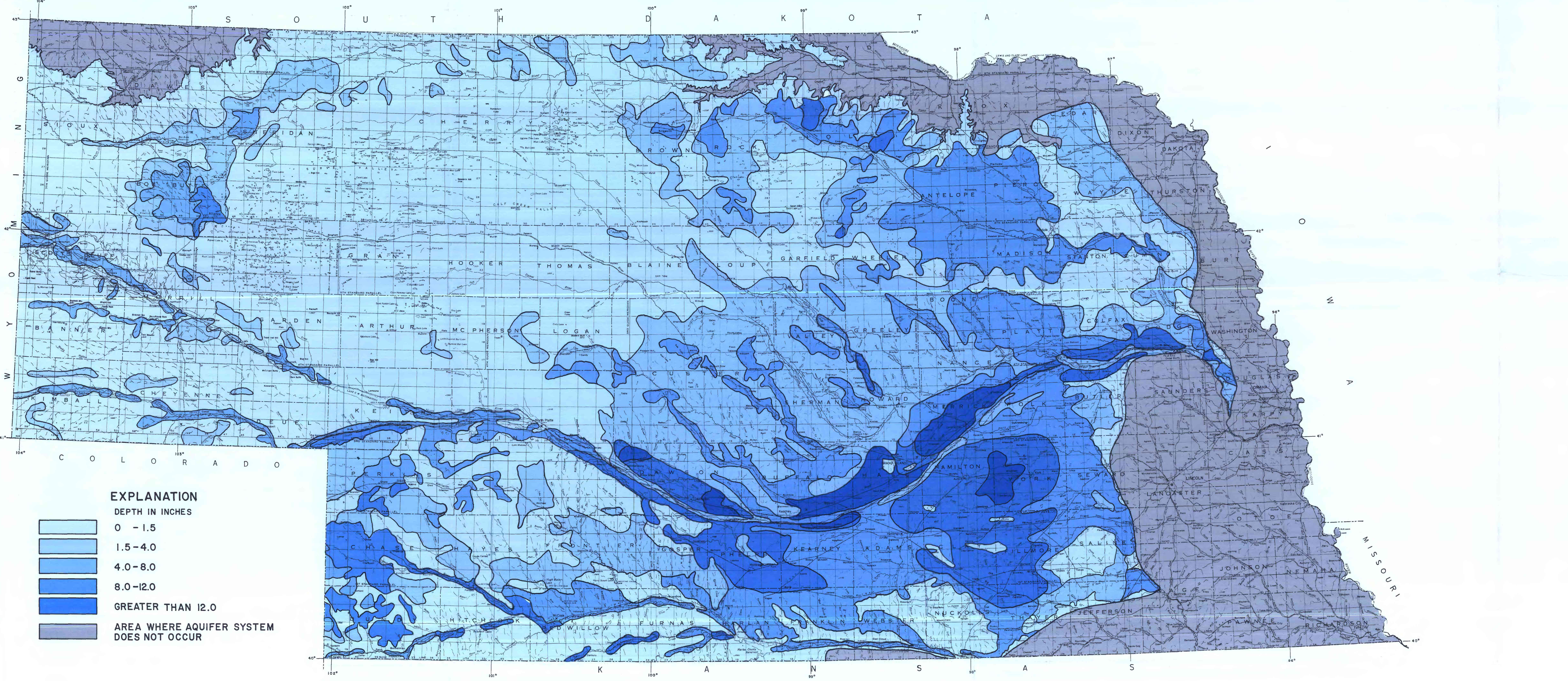
Multiply inch-pound units	By	To obtain SI units
acre	4,047	square meter
acre-foot	1,233	cubic meter
foot	0.3048	meter
foot per day	0.3048	meter per day
foot squared per day	0.0929	meter squared per day
inch	25.40	millimeter
mile	1.609	kilometer
square mile	2,590	square kilometer

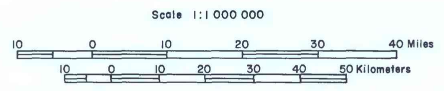
Base from U.S. Geological Survey
State base map, 1962

HYDRAULIC CONDUCTIVITY, SPECIFIC YIELD, AND PUMPAGE-HIGH PLAINS AQUIFER SYSTEM, NEBRASKA

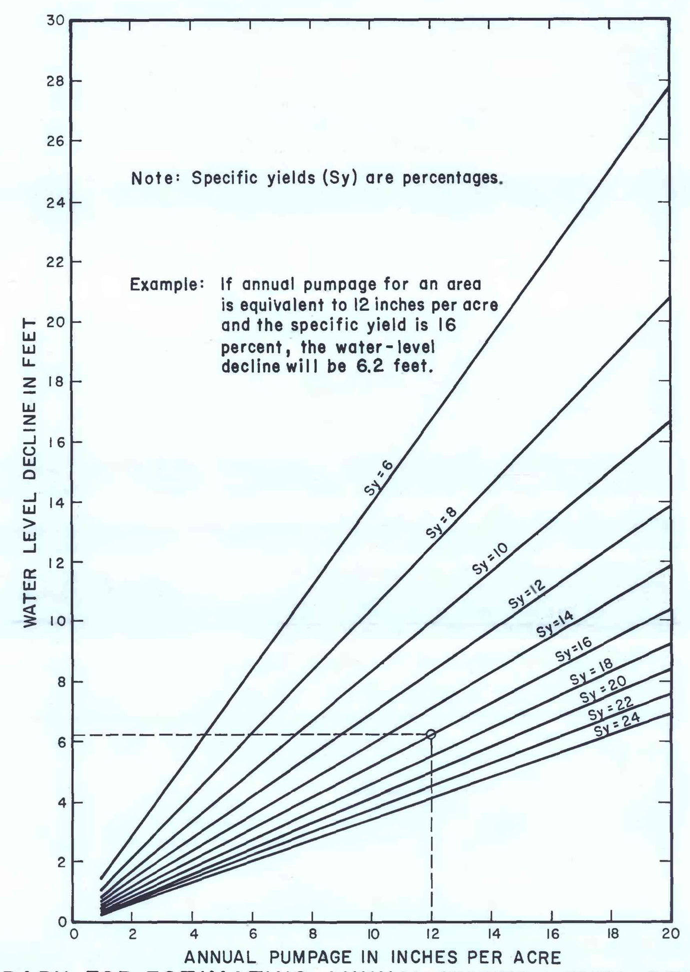
By
Robert A. Pettijohn and Hsiu-Hsiung Chen

WATER RESOURCES INVESTIGATIONS
REPORT 82-4014
SHEET 3 OF 3

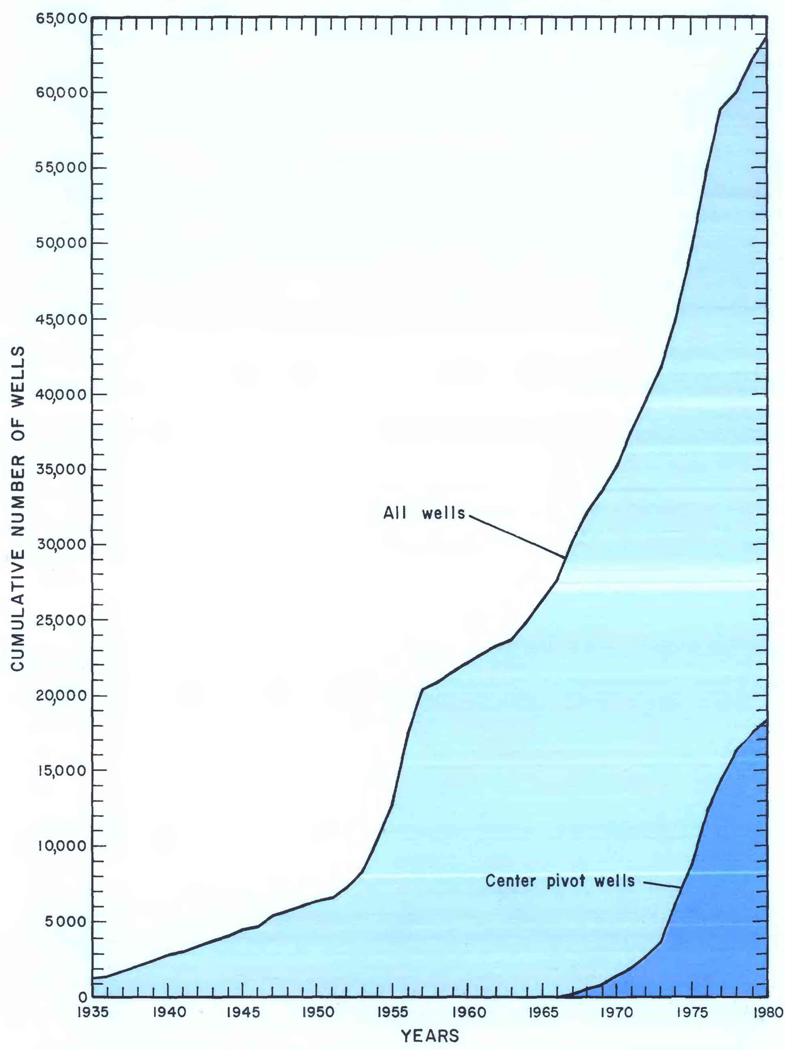




MAP SHOWING HYPOTHETICAL DEPTHS TO WHICH WATER PUMPED FROM DIFFERENT AREAS OF THE HIGH PLAINS AQUIFER SYSTEM IN 1980 WOULD COVER THE LAND SURFACE



GRAPH FOR ESTIMATING ANNUAL WATER LEVEL DECLINE IN AQUIFER SYSTEM FROM PUMPAGE AND SPECIFIC YIELD, ASSUMING NO RECHARGE



GRAPH SHOWING RATE OF IRRIGATION WELL DEVELOPMENT IN HIGH PLAINS AREA OF NEBRASKA, 1935-80

PUMPAGE FOR IRRIGATION FROM AQUIFER SYSTEM, 1980

Pumpage for irrigation during 1980 from the High Plains aquifer system in Nebraska is presented above in two different formats. The first is a map that shows, by area, the range in depth that water would cover the land surface of each area if all the water pumped during 1980 from the aquifer underlying the area could be spread evenly over the surface of the area. The second is a table that presents the number of acres irrigated and quantity of water pumped in each of the counties.

The areas shown on the map were delimited from irrigation-well density, which ranged from 3 wells per 100 square miles in Grant County to more than 700 wells per 100 square miles in Merrick County. The quantity of water withdrawn per well during 1980 ranged from an average of 22 million gallons in Hall and Merrick Counties, in the Platte River basin, to an average of 50 million gallons in the Niobrara River basin (E. K. Steele, U.S. Geological Survey, unpublished data, 1981). The depth that water would cover the surface in the delimited area was computed by multiplying the average quantity of water a well pumped by the number of wells in a unit area. Because both well density and well pumpage varied within a delimited area, a range of depths was used.

The map shows that the inches of water withdrawn from the aquifer system during 1980 varied from less than 1.5 in the sandhills of north-central Nebraska to more than 12 in the Platte River valley and the Blue River basin. The large variation in annual withdrawal is directly related to the density of irrigation wells, which is limited principally by the suitability of the land for irrigation and by the availability of ground water. Other factors such as land use, energy costs, and monetary return also affect the development of ground water for irrigation. However, the relative effect of the various factors changes as the economy and technology change. As a result, areas such as the sandhills whose ground-water resources heretofore have been relatively undeveloped, are now considered potential development areas. Therefore, data such as that provided by the above map may help managers and others develop a plan to manage the aquifer system in the High Plains of Nebraska to avoid unwanted results such as progressive decrease of the water resource, uneconomic pumping conditions, degradation of ground-water quality, and interference with prior water rights.

Ground-water development in parts of the High Plains of Nebraska has caused progressive water-level declines in some areas. These areas are indicated on the potentiometric map of Pettijohn and Chen (1982). Generally, they coincide with areas of intensive ground-water pumpage shown on the above map. The water-level decline per unit volume pumped is related directly to the specific yield of the aquifer. A means of estimating water-level declines in a water-table aquifer from annual pumpage and specific yield is given in the upper graph above. The data in this graph are based on the assumption that there is no recharge to the aquifer or discharge from the aquifer except by pumpage. Therefore, if annual net recharge to the aquifer is known, the water-level decline determined from the graph should be decreased by the volume of annual recharge, expressed in feet.

Most irrigation wells were drilled during the past 25 years. The number of registered irrigation wells in the High Plains of Nebraska on January 1, 1980, was 63,571. The rate at which this number increased from about 1,200 in January 1936 (Pederson and Johnson, 1979, p. 114) to 63,571 is shown in the lower graph. The rate of well installation increased gradually until 1953, when it increased rapidly. The rate decreased markedly from 1958 through 1963, and then increased rapidly again until 1977, when a combination of economic factors discouraged farmers from investing in new well construction. The years of peak well installation, 1956 and 1976, coincided with major drought periods; more than 4,000 new wells were registered in each of these years.

The advent of the center-pivot irrigation-distribution system has increased greatly the number of acres that can be irrigated from the High Plains aquifer system. Prior to 1965, most wells had gravity-type distribution systems, which function most economically on deep, medium-textured soils and land slopes of about 0.5 percent and thus are limited as to the areas where they can be used. However, by 1965, the center-pivot distribution system, which can operate over rolling land and sandy soils and irrigate larger areas than gravity-type systems, became popular. By 1980, nearly 18,000 of these systems, or about 28 percent of the total wells, were in operation in the High Plains aquifer system in Nebraska. Between 1975 and 1980, 67 percent of all new wells were equipped with this type of distribution system. Consequently, about 2.3 million acres, or 35 percent of the land irrigated in 1980 in the High Plains of Nebraska, was irrigated by center-pivot distribution systems.

The volume of water pumped during 1980, by county, for counties that are entirely or mostly underlain by the High Plains aquifer system, is given in the table on the right. A total of 6,703,000 acre-feet of ground water was applied to 5,390,000 acres of cropland. This is an average application rate of about 15 inches per acre of irrigated land. Because of less than normal precipitation during the early part of the 1980 growing season, larger than normal withdrawals of ground water probably were made to irrigate crops. Consequently, the above application rate may be greater than the normal annual average.

The data in the following table were obtained from E. K. Steele (unpublished data, 1981) who compiled data on acres irrigated and on quantities of ground water pumped during 1980 from randomly selected wells in Blaine and Kimball Counties and from the Blue River basin. He computed average application rates and number of acres irrigated by each type of irrigation-distribution system (gravity or center-pivot). These data were then extended by him to most other counties that have similar climate, soil type, crop type, and topography. Exceptions were parts of the Platte River basin where average acres irrigated per well by gravity systems were less than in the rest of the State. The application rates and acres irrigated per well by type of distribution system were then grouped as shown in the following table. Location of basins listed in the table are shown on the small map to the right.

Type of distribution system	Location	Average application rate (inch per (acre)	Average area per well (acre)
Center-pivot	Counties north of the North Platte and Platte River basins--------------------	13.7	130
	All others------------------	10.3	130
Gravity	Counties in the Platte River basin, except Hall and Merrick Counties-----------	15.7	70.0
	Counties in the North and South Platte River basins---------	20.0	70.0
	Counties in the Blue River basin---------------------	15.7	82.5
	Hall and Merrick Counties-----	15.7	50.0
	All others------------------	20.0	82.5

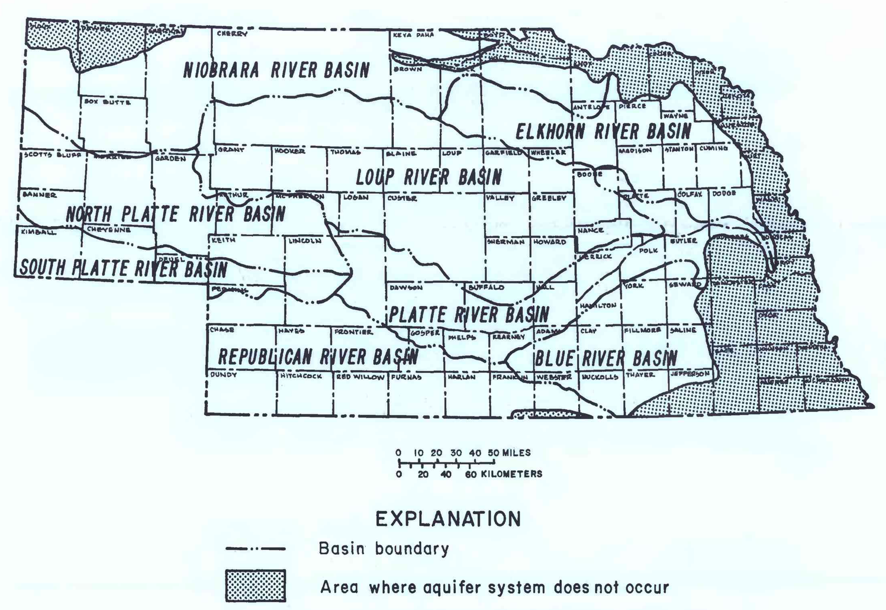
Data from the preceding table and from the 1980 center-pivot map report (University of Nebraska, 1980) and well-registration file, which provide data on number of wells, were used to compute total acres irrigated and volume of water pumped for each of the counties listed in the table on pumpage above. Because the acres irrigated and the volumes pumped change with time, data, such as in the above table, need to be updated periodically. Such data are important in developing models of the aquifer system and plans for management of the system.

SELECTED REFERENCES

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.
Gutentag, E. D., and Weeks, J. B., 1980, Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-642, 2 sheets, scale 1:2,500,000.
Heimes, F. J., and Luckey, R. R., 1980, Evaluating methods for determining water use in the High Plains in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming, 1979: U.S. Geological Survey Water-Resources Investigations 80-111, 118 p.
Johnson, A. I., 1967, Compilation of specific yield for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.
Lappala, E. G., 1978, Quantitative hydrogeology of the Upper Republican Natural Resources District, southwest Nebraska: U.S. Geological Survey Water-Resources Investigations 78-38, 154 p.
Lohman, S. W., and others, 1972, Definitions of selected ground-water terms, revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.
Luckey, R. R., Heimes, F. J., and Gaggiani, N. G., 1980, Calibration and testing of selected portable flowmeters for use on large irrigation systems: U.S. Geological Survey Hydrologic Investigations 80-72, 21 p.
Luckey, R. R., Gutentag, E. D., and Weeks, J. B., 1981, Water-level and saturated-thickness changes, predevelopment to 1980 in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-652, 2 sheets, scale 1:2,500,000.
Olmsted, F. H., and Davis, G. H., 1961, Geologic features and ground-water storage capacity of the Sacramento Valley, California: U.S. Geological Survey Water-Supply Paper 1497, 241 p., 5 pl.
Pederson, D. T., and Johnson, M. S., 1979, Groundwater levels in Nebraska, 1978: University of Nebraska-Lincoln, Conservation and Survey Division, Nebraska Water Survey Paper 49, 116 p.
Pettijohn, R. A., and Chen, H. H., 1982, Geohydrology of the High Plains aquifer system in Nebraska: U.S. Geological Survey Water-Resources Investigations Open-File Report 82-502, 3 sheets.
University of Nebraska, 1980, Center-pivot irrigation systems in Nebraska, 1979: University of Nebraska-Lincoln, Conservation and Survey Division, map with tables, scale 1:1,000,000.
Weeks, J. B., 1978, Plan of study for 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 Water-Resources Investigations 78-70, 28 p.
Weeks, J. B., and Gutentag, E. D., 1981, Bedrock geology, altitude of base, and 1980 saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-648, 2 sheets, scale 1:2,500,000.

PUMPAGE FOR IRRIGATION BY COUNTY, 1980

County	Acres irrigated	Acre-feet pumped	County	Acres irrigated	Acre-feet pumped
Adams	128,000	154,000	Jefferson	44,000	49,000
Antelope	144,000	176,000	Kearney	120,000	140,000
Arthur	6,600	5,700	Keith	68,000	91,000
Banner	20,000	22,000	Keya Paha	17,000	20,500
Blaine	12,000	14,500	Kimball	26,000	30,000
Boone	84,000	127,000	Knox	30,500	37,500
Box Butte	79,000	104,000	Lincoln	135,000	141,000
Brown	52,000	61,000	Logan	12,500	16,500
Buffalo	222,000	270,000	Loup	10,500	15,000
Butler	73,000	87,000	McPherson	9,300	9,000
Cedar	39,000	55,000	Madison	55,500	76,000
Chase	144,000	138,000	Merrick	193,000	241,000
Cherry	41,000	49,500	Morrill	53,500	60,000
Cheyenne	36,500	44,000	Nance	49,500	76,500
Clay	165,000	199,000	Nuckolls	43,500	54,500
Colfax	46,500	62,500	Perkins	89,000	80,500
Cuming	23,000	35,000	Phelps	121,000	146,000
Custer	139,000	206,000	Pierce	78,000	97,000
Dawes	6,600	8,600	Platte	102,000	119,000
Dawson	215,000	274,000	Polk	107,000	133,000
Deuel	21,500	30,000	Red Willow	58,500	89,500
Dodge	74,500	100,000	Rock	63,000	73,500
Dundy	87,000	88,000	Saline	76,000	92,000
Fillmore	153,000	175,000	Scotts Bluff	31,000	50,000
Franklin	63,500	95,000	Seward	92,000	109,000
Frontier	54,000	82,500	Sheridan	45,000	60,000
Furnas	48,500	77,000	Sherman	43,000	60,000
Garden	28,500	31,000	Sioux	18,000	25,500
Garfield	17,000	23,000	Stanton	22,000	33,000
Gosper	47,000	74,500	Thayer	96,000	113,000
Grant	2,300	2,900	Thomas	3,500	4,700
Greeley	50,000	72,500	Valley	46,000	66,000
Hall	170,000	187,000	Wayne	12,000	16,000
Hamilton	204,000	216,000	Webster	38,000	52,000
Harlan	57,000	88,000	Wheeler	40,500	47,500
Hayes	32,500	37,500	York	212,000	263,000
Hitchcock	34,500	54,000			
Holt	240,000	286,000			
Hooker	2,900	3,400			
Howard	65,000	97,000	Totals	5,390,000	6,703,000



MAP SHOWING LOCATION OF RIVER BASINS

Base from U.S. Geological Survey
State base map, 1969

HYDRAULIC CONDUCTIVITY, SPECIFIC YIELD, AND PUMPAGE-HIGH PLAINS AQUIFER SYSTEM, NEBRASKA

By
Robert A. Pettijohn and Hsiu-Hsiung Chen