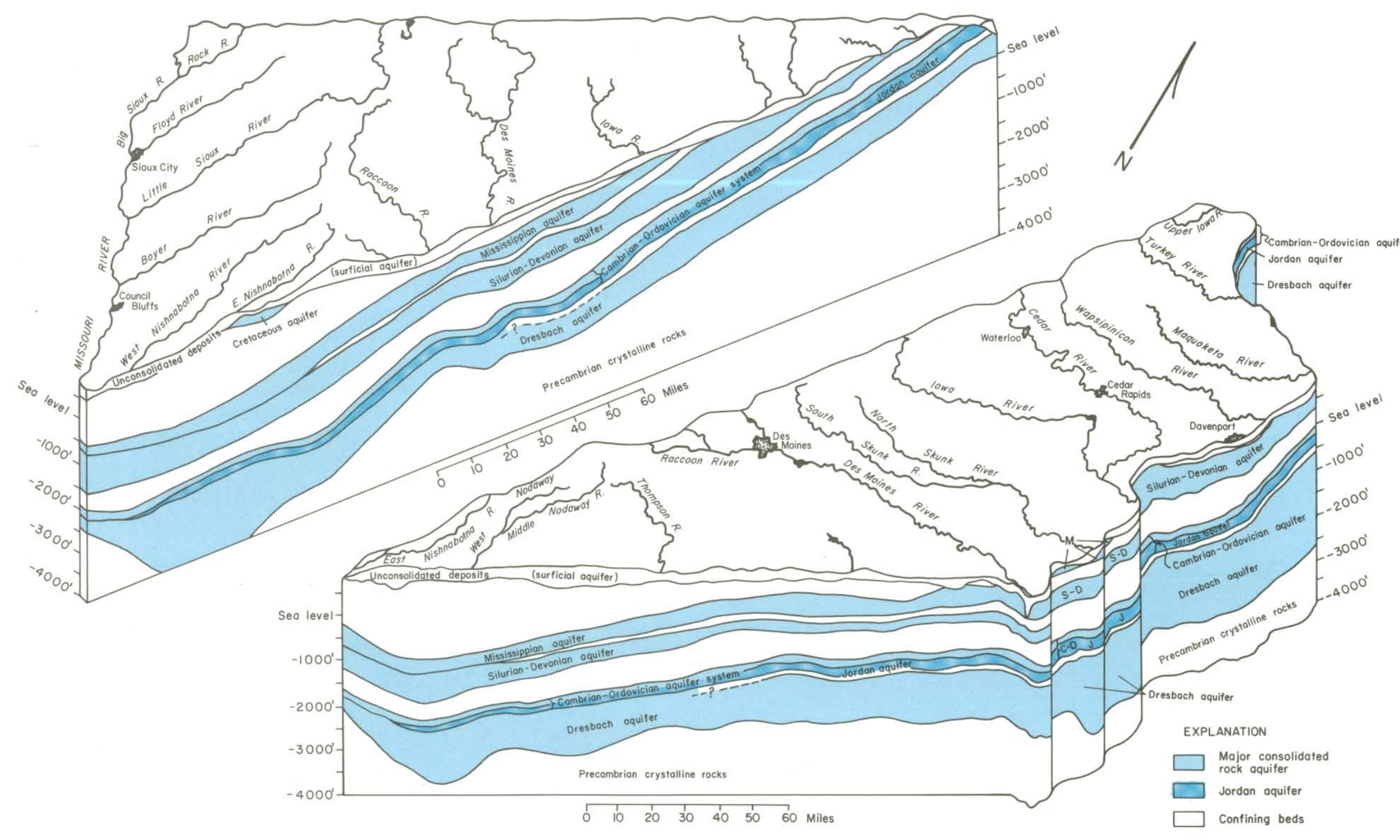
IOWA GEOLOGICAL SURVEY
STANLEY C. GRANT, DIRECTOR

Prepared in cooperation with the
United States Geological Survey

MISCELLANEOUS MAP SERIES 6
SHEET 1 OF 3

INTRODUCTION

Water demand for all uses in Iowa is increasing at an accelerated rate. Demand has increased from about 1,800 million gallons per day in 1955 to 3,500 million gallons per day in 1975 (MacKichan, 1957; Murray and Reeves, 1977). By the year 2020, water demand is expected to be eight times that in 1975 (Barnard and Dent, 1976). Historically, about 75 percent of the demand, excluding that required for power generation, has been met by withdrawals from the water-bearing zones (aquifers) in Iowa's ground-water reservoir. Because this percentage is expected to remain about the same, the anticipated future demands will require extensive withdrawals from the ground-water reservoir. The increasing stress on the ground-water system, which already is severely stressed in several places in the state, will create development and management problems that will require hydrologic information to solve. In order to provide this information, the Iowa Geological Survey in cooperation with the U.S. Geological Survey has instituted a series of investigations to define, describe, and evaluate the major aquifers in Iowa's ground-water reservoir. Information from each investigation will be presented in atlas format.



BLOCK DIAGRAM OF IOWA

IOWA'S GROUND-WATER RESERVOIR CONSISTS OF FIVE PRINCIPAL CONSOLIDATED ROCK AQUIFERS, AND THE UNCONSOLIDATED DEPOSITS OF SAND AND GRAVEL THAT OVERLIE THE BEDROCK. WIDESPREAD CONFINING BEDS RETARD MOVEMENT OF THE WATER BETWEEN THE AQUIFERS.

The bottom of the ground-water reservoir is the Precambrian crystalline complex, which occurs at a depth of about 5,200 feet in southwestern Iowa and rises to the surface in extreme northwestern Iowa and to within 800 feet of the surface in northeastern Iowa. Overlying these basement rocks is a succession of consolidated sedimentary strata of Paleozoic age that are dominantly sandstones and dolomites in the lower part, and shales, dolomites and limestones in the upper part. These strata have been downwarped into a broad trough, known as the Iowa Basin. The surface of the dipping Paleozoic rocks was beveled by erosion, thereby exposing older Paleozoic strata in the northeastern and northwestern parts of the basin. This process created the extensive recharge areas of the Paleozoic aquifers in northeastern Iowa and southern Minnesota. The beveled Paleozoic rocks in northwestern Iowa are unconformably overlain by nearly flat-lying shales and sandstones of Cretaceous age. The surfaces of both the Paleozoic and Cretaceous rocks have been modified considerably by pre-Pleistocene erosion, and nearly everywhere are mantled by glacial drift and loess of variable thicknesses.

The water-yielding consolidated rocks in the ground water reservoir are the porous, permeable sandstones of Cretaceous age and the sandstones and fissured, cavernous carbonates (limestones and dolomites) of Paleozoic age. One of the Paleozoic carbonate units, the Mississippian aquifer, was the subject of the first atlas published (Horick and Steinhilber, 1973). The present atlas is concerned with another Paleozoic unit — the Jordan aquifer, which is the lower and consistently most productive water-yielding unit of the Cambrian-Ordovician aquifer system. The Jordan aquifer is one of the most dependable sources of water supply for large capacity wells in Iowa.

PURPOSE

The purpose of this atlas is to (1) define and describe the spatial relations and physical characteristics of the Jordan aquifer, (2) present information on the occurrence, availability, use, and chemical quality of water in the aquifer, and (3) define and delineate changes in the potentiometric surface of the aquifer. The geohydrologic information has been divided into three subject headings that are presented on separate atlas sheets — geology, hydrology, and chemical quality.

ACKNOWLEDGMENTS

Acknowledgments are due to several people who assisted in acquiring data for this study. James F. Wiegand of the Iowa Natural Resources Council was instrumental in obtaining the cooperation of water superintendents in maintaining water-level and pumpage records. Additional pumpage data of many Jordan aquifer wells were obtained from the Department of Environmental Quality files. The cooperation of several Iowa drillers and engineering consultants, who submitted construction details, sample cuttings, water-level data, and pumping-test information, cannot be stressed enough. The municipal water-plant operators also deserve praise for their cooperative attitude in keeping accurate records. Leon Steele and R. E. Hansen of the U.S. Geological Survey and Greg Ludvigson of the Iowa Geological Survey assisted in the collection of field data. R. J. Schliekelman provided information on radium-226 in Jordan aquifer well water and on treatment processes used for radium removal. Logan Kuiper of the Iowa Geological Survey critically reviewed the water-budget calculations.

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STRATIGRAPHIC AND HYDROLOGIC RELATIONS OF THE JORDAN AQUIFER

System	Rock-Stratigraphic Unit		Maximum Thickness	Physical Characteristics	Hydrologic Units	
ORDOVICIAN		Maquoketa Formation	300'	Mostly shale, grayish green, with dolomite beds in upper and lower part in east-central Iowa; mostly dolomite, brown, with chert in north-central and western Iowa; thin red shale with limonite or hematite pellets (Neda) at top.	Confining bed (locally water bearing in north-central Iowa)	
		Galena Dolomite	230'	Dolomite, minor limestone, minor chert in lower half.	Water Bearing	
		Decorah Formation	170'	Limestone and dolomite, tan to brown; grayish-green and brown shales at top and base.	Confining Bed	
		Platteville Formation		Limestone, gray, and dolomite, brown, fossiliferous; shale, grayish-green at base (Glenwood). Sandstone, fine-to-medium grained above the shale in southeast Iowa only.		
		St. Peter Sandstone	110'	Sandstone, coarse to fine, rounded and frosted grains, loosely cemented, minor green shale stringers.	Water Bearing	Cambrian-Ordovician Aquifer System
	Prairie du Chien Formation	Willow River Dolomite Member	650'	Dolomite, sandy.	Confining Bed	
		Root Valley Sandstone Member		Sandstone, dolomitic	Jordan Aquifer	
		Oneota Dolomite Member		Dolomite, crystalline, contains chert.		
CAMBRIAN	Trempealeau Group	Jordan Sandstone	145'	Sandstone, fine-to medium-grained, well-sorted and frosted grains; contains sandy dolomite beds in upper (Madison) and basal (Lodi) units.		
		St. Lawrence Dolomite	260'	Dolomite, coarsely crystalline, gray, silty, commonly containing glauconite	Confining Bed	
		Franconia Sandstone	280'	Dolomitic siltstone, glauconitic shale, and glauconitic sandstone.		
	Dresbach Group	Galesville Sandstone	200'	Sandstone, medium- to coarse-grained, white to gray.	Water Bearing	Dresbach Aquifer
		Eau Claire Sandstone	260'	Shale, silty, gray, fissile; siltstone, dolomitic; sandstone, fine-grained; some dolomite.	Confining Bed	
		Mt. Simon Sandstone	825'	Sandstone, medium-to coarse-grained with minor shale stringers.	Water Bearing	

The nomenclature and classification of rock units in this report are those of the Iowa Geological Survey and do not necessarily coincide with those accepted by the U.S. Geological Survey.

DEFINITION OF THE AQUIFER

The Jordan aquifer, named for the Jordan Sandstone, is a part of the Cambrian-Ordovician aquifer system[1] and consists of the Cambrian Jordan Sandstone, the principal water-yielding unit, and the Oneota Dolomite and Root Valley Sandstone Members of the overlying Ordovician Prairie du Chien Formation (see stratigraphic chart and geohydrologic section). These two members are included in the Jordan aquifer because they are always left open in "Jordan wells" and contribute substantial quantities of water in some places. Although many "Jordan wells" are extended into the upper part of the underlying St. Lawrence Dolomite, this unit is not included as part of the aquifer because it is not considered to be a major water-bearing unit. The extent, altitude, and thickness of only the Jordan Sandstone is mapped here, because this is the unit that must be penetrated for maximum well yields from the aquifer.

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[1] *The Cambrian-Ordovician aquifer system is defined as consisting of the Cambrian Jordan Sandstone and the Ordovician Prairie du Chien Formation and St. Peter Sandstone (Steinhilber and Horick, 1970).*

PHYSICAL CHARACTERISTICS OF THE AQUIFER

As described above, the Jordan aquifer consists of two sandstone units separated by a dolomite unit. The total thickness of the aquifer ranges from about 400 to 450 feet in east-central and southeastern Iowa to about 150 feet or less in western Iowa. All units wedge out in extreme northwestern Iowa, either because of nondeposition or erosion or both.

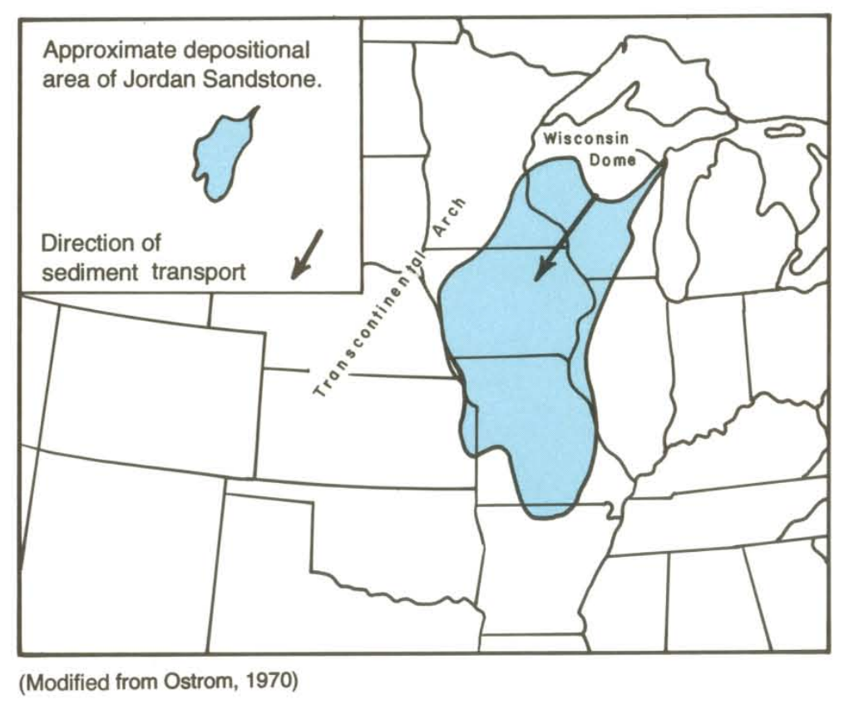
The lithology of the Jordan Sandstone is rather uniform. In the northern part of the state it is a white to buff, fine- to coarse-grained, quartzose sandstone that is loosely cemented. Dolomite beds occur in the upper and lower parts. In the southern part of the state the sandstone is similar but contains an increasing percentage of dolomite and is moderately to tightly cemented. The thickness of the formation ranges from a maximum of about 145 feet in northeastern Iowa to about 30 feet in central and southwestern Iowa, as shown on the map in the lower right hand corner.

The Oneota Member of the Prairie du Chien Formation is a drab-gray to buff, thick-bedded, crystalline, cherty dolomite that is locally vuggy, cavernous, and highly fractured. Its maximum thickness is about 235 feet in southeast Iowa, from where it thins to about 190 feet in northeastern Iowa and to 0 thickness in northwestern Iowa.

The Root Valley Member of the Prairie du Chien Formation is very similar to the Jordan Sandstone, consisting of white to buff, fine- to medium-grained, quartzose sandstone; it is loosely cemented in northern Iowa and becomes increasingly dolomitic and more tightly cemented to the south. The thickness of the Root Valley is extremely variable throughout the state. The maximum thickness occurs in central and southeastern Iowa, where it is as thick as 110 feet; elsewhere it is as thin as 20 feet.

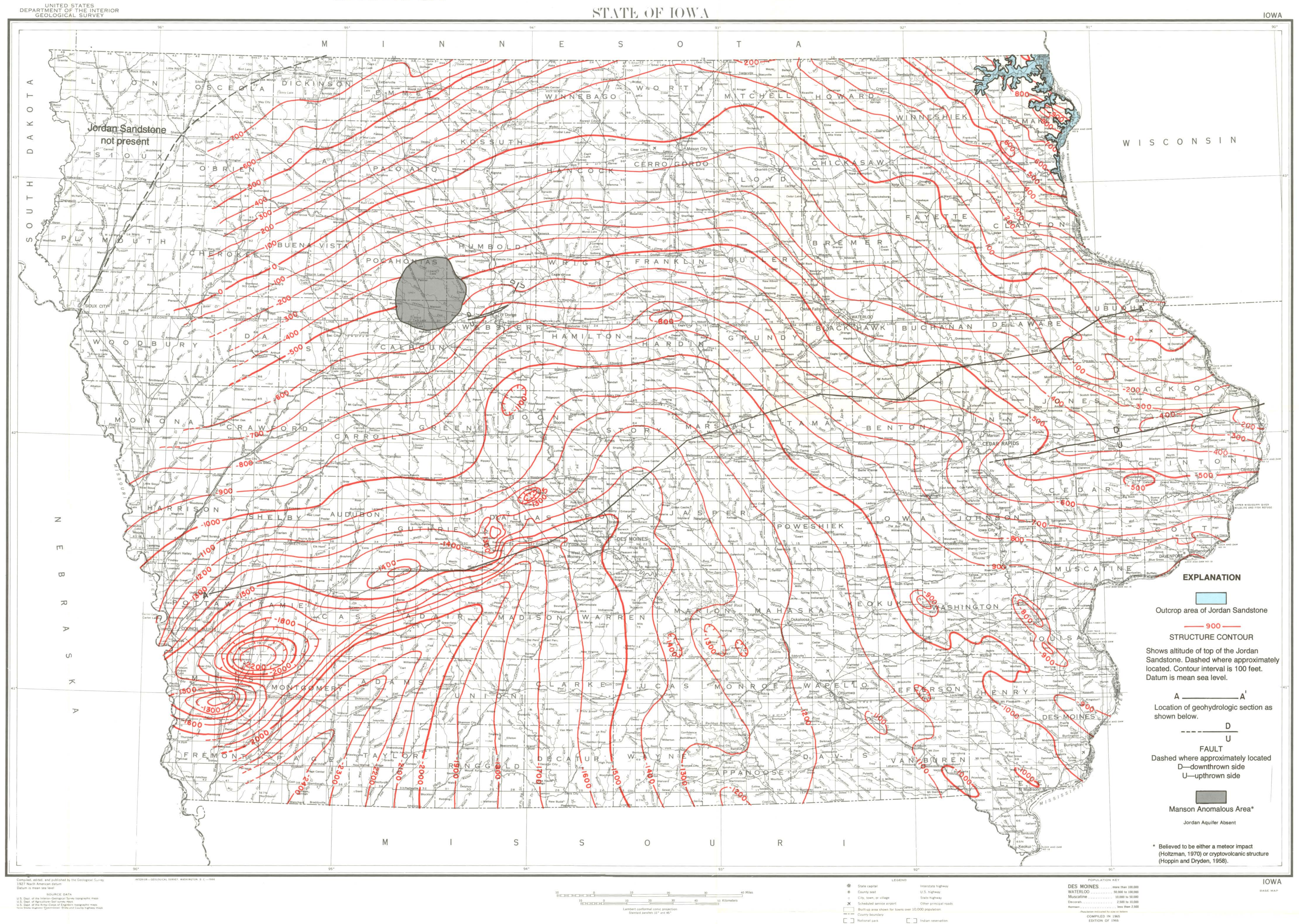
AREAL EXTENT

The lower Paleozoic sedimentary rocks of the Upper Mississippi Valley are considered to be cyclic deposits with each cycle consisting of a basal quartzose sandstone, overlain by reworked quartzose sandstone, clayey sandstone or shale, and capped by dolomite or limestone (Ostrom, 1970). Five cycles or partial cycles are identified in Iowa rocks. The five quartzose sandstones are the Mount Simon, Galesville, and Jordan Sandstones, the Root Valley Member of the Prairie du Chien Formation, and the St. Peter Sandstone. The source of the sediments was the Wisconsin Dome which was periodically uplifted and eroded during Cambrian and Ordovician time. This caused fluctuations of sea level and deposition of the different types of sediment that characterize the cycles. The approximate depositional area of the Jordan Sandstone is shown on the map below. In Iowa the Jordan Sandstone underlies all of the state except the northwest corner and extreme southwest corner. The precise boundary of the formation in these areas is not known because it is covered by thick Cretaceous deposits in the northwest and thick Paleozoic units in the southwest. The only place the Jordan can be observed in surface exposures in Iowa is in Allamakee and Clayton Counties in the bluffs of the Mississippi River and in the valleys of the Upper Iowa River and small tributaries of the Mississippi River. From this outcrop area, where its altitude is about 700 to 1000 feet above sea level, the formation dips southwesterly beneath younger Paleozoic strata to the deepest part of the Iowa Basin where it is at an altitude of 2,400 feet below sea level. In the northwest part of the Iowa Basin the Jordan rises to 700 feet above sea level beneath the Cretaceous rocks in O'Brien and Dickinson Counties.



(Modified from Ostrom, 1970)

GEOLOGY



EXPLANATION

Outcrop area of Jordan Sandstone

—900— STRUCTURE CONTOUR

Shows altitude of top of the Jordan Sandstone. Dashed where approximately located. Contour interval is 100 feet. Datum is mean sea level.

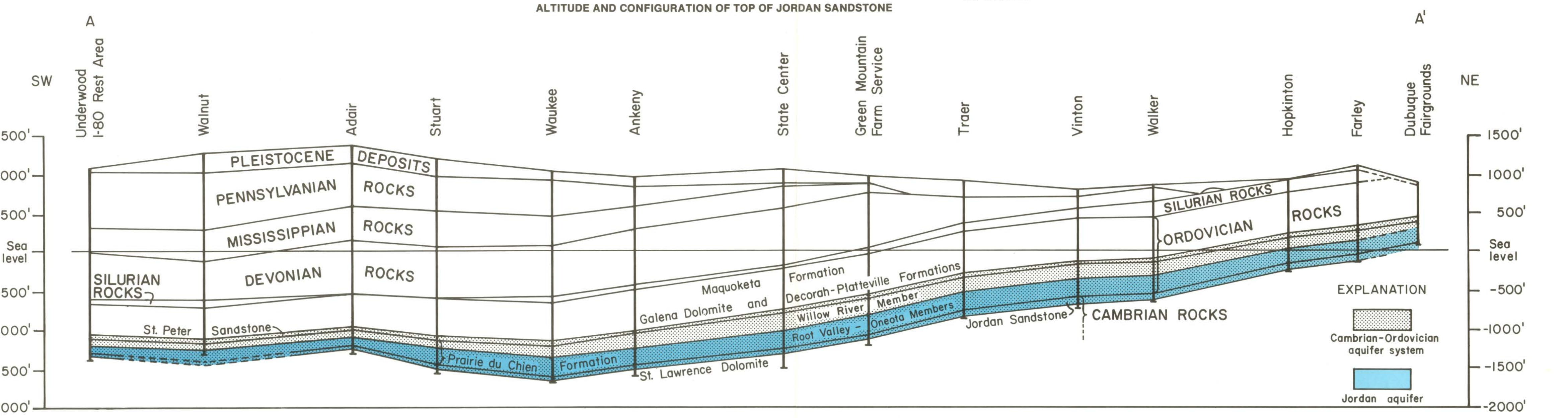
A ——— A' Location of geohydrologic section as shown below.

FAULT
Dashed where approximately located
D—downthrown side
U—upthrown side

Manson Anomalous Area*
Jordan Aquifer Absent

* Believed to be either a meteor impact (Holtzman, 1970) or cryptovolcanic structure (Hoppin and Dryden, 1958).

ALTITUDE AND CONFIGURATION OF TOP OF JORDAN SANDSTONE

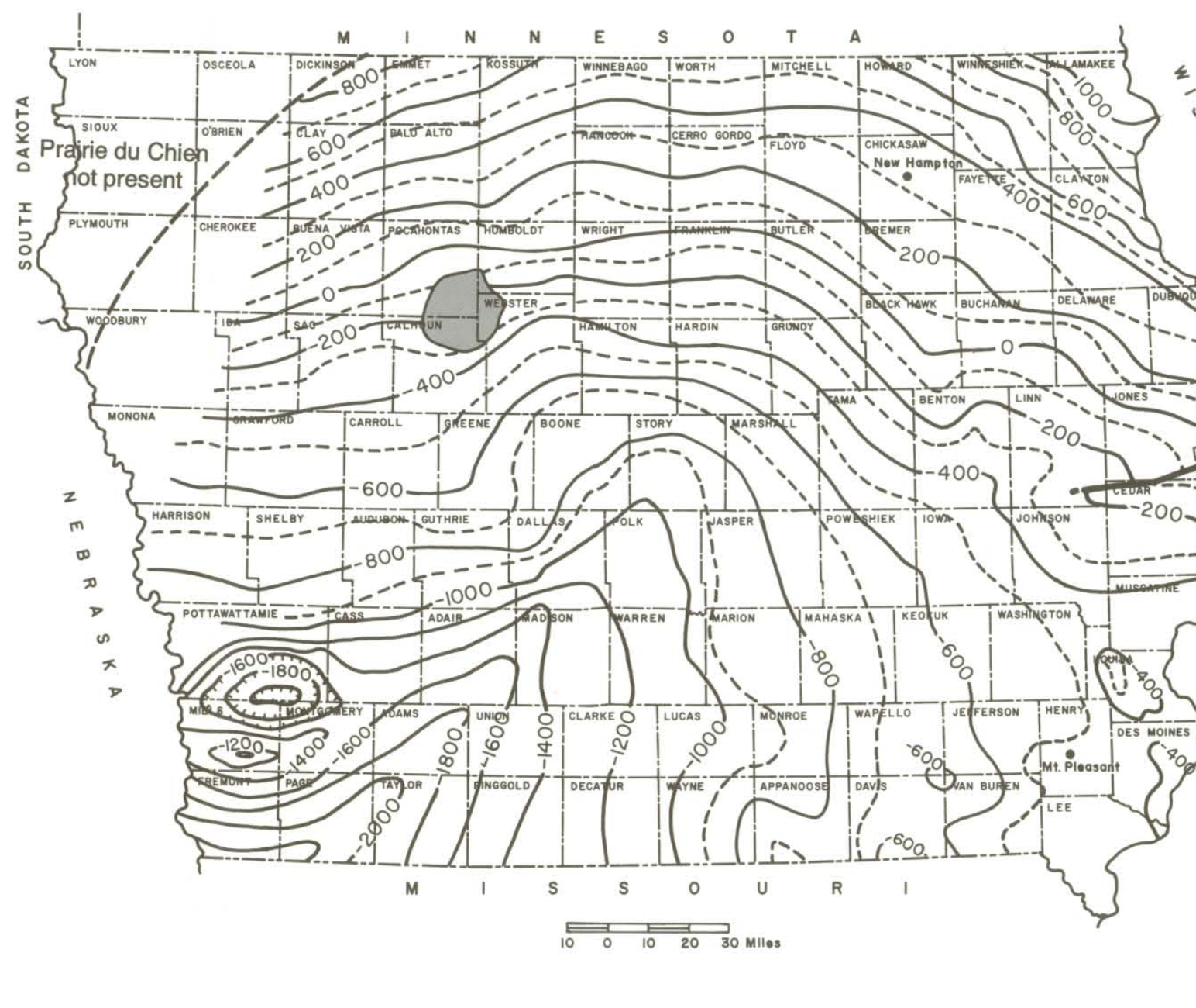


GEOHYDROLOGIC SECTION

HOW TO CALCULATE WELL AND CASING DEPTHS

Useful information for predicting drilling depths and casing needs for Jordan aquifer wells can be obtained from the large map above showing the altitude of the top of the Jordan Sandstone, and the smaller maps opposite showing the altitude of the top of the Prairie du Chien Formation and the thickness of the Jordan Sandstone. Most modern Jordan aquifer wells are designed to be drilled about 25 feet into the St. Lawrence Dolomite and to be cased and grouted from the surface into the upper 50 to 100 feet of the Prairie du Chien to exclude all overlying water zones. Therefore, depending on whether the altitudes of the Prairie du Chien Formation and Jordan Sandstone are above or below sea level datum at a contemplated drilling site, the altitude from the maps can be subtracted or added to the surface altitude at the drilling location to obtain a reasonable estimate of the formation depths in feet below ground level. For example, at New Hampton, in Chickasaw County, the maps indicate the top of the Prairie du Chien lies at about 325 feet above sea level and the top of the Jordan Sandstone at about 25 feet below sea level. The thickness of the Jordan Sandstone is shown to be about 115 feet. With this information and assuming a surface altitude of 1,150 feet above sea level, the top of the Prairie du Chien would be expected at approximately 825 feet below ground level and the top of the Jordan Sandstone at about 1,175 feet below ground level. Thus, the bottom of the casing string probably would be set at about 875 feet, while the final well depth probably would be about 1300 feet.

At Mt. Pleasant, in Henry County, based on a surface altitude of 730 feet above sea level and the information from the maps, a Jordan aquifer well should be about 1,840 feet deep, with the bottom of the casing set at about 1,265 feet. All depth estimates obtained by using these maps are subject to some adjustment because of local structural and thickness variation of the strata.



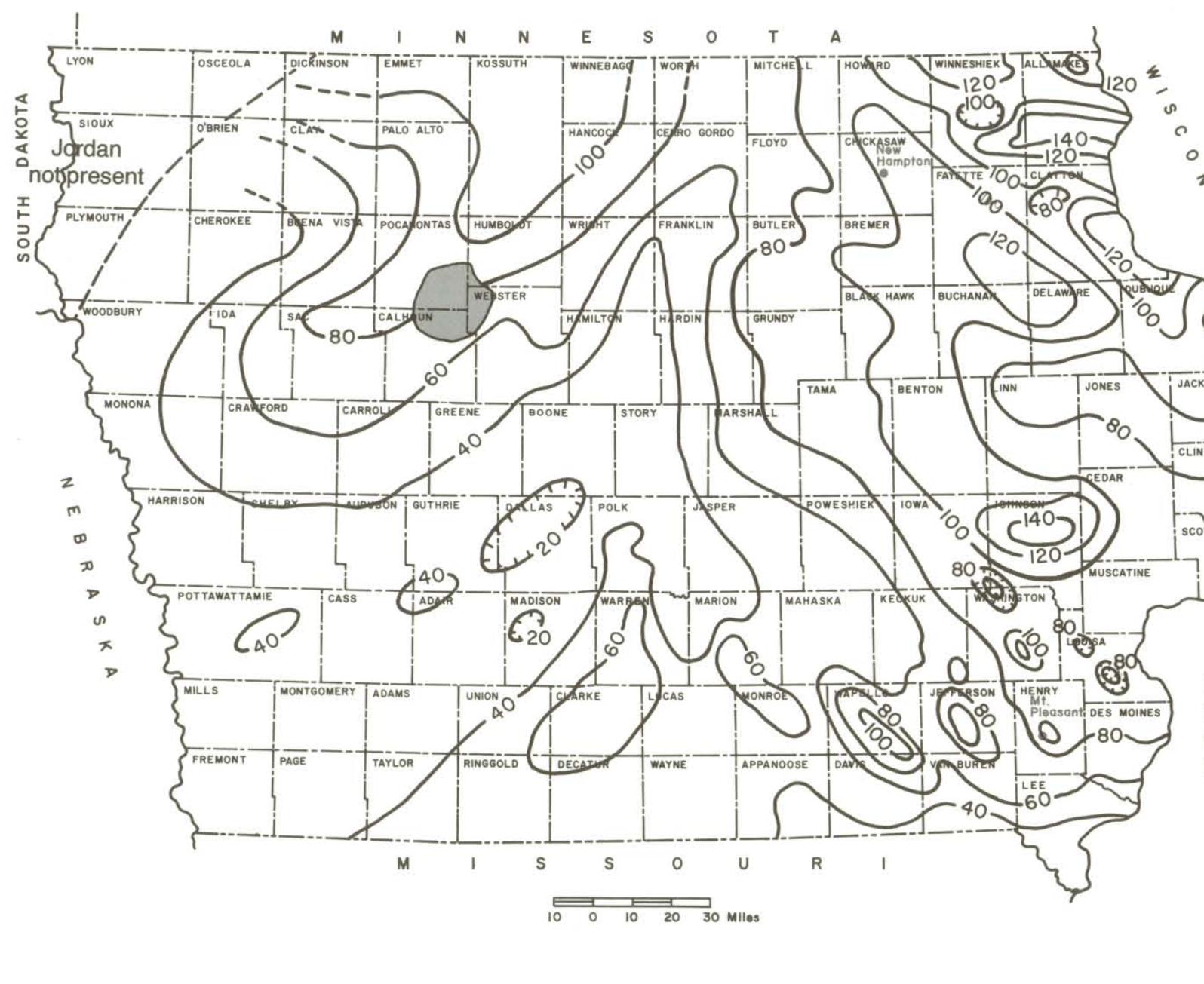
EXPLANATION

—200— Structure contour interval is 200 feet. Supplemental 100-foot contours shown by dashed lines. Datum is mean sea level.

Plum River Fault
D—downthrown side
U—upthrown side

Manson Anomalous Area
Jordan Aquifer Absent

ALTITUDE OF TOP OF PRAIRIE DU CHIEN FORMATION



EXPLANATION

—80— Line of equal thickness of Jordan Sandstone. Dashed where approximately located. Interval is 20 feet.

Manson Anomalous Area
Jordan Aquifer Absent

THICKNESS OF JORDAN SANDSTONE

JORDAN AQUIFER OF IOWA

by

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United States Geological Survey

Published by the
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1978

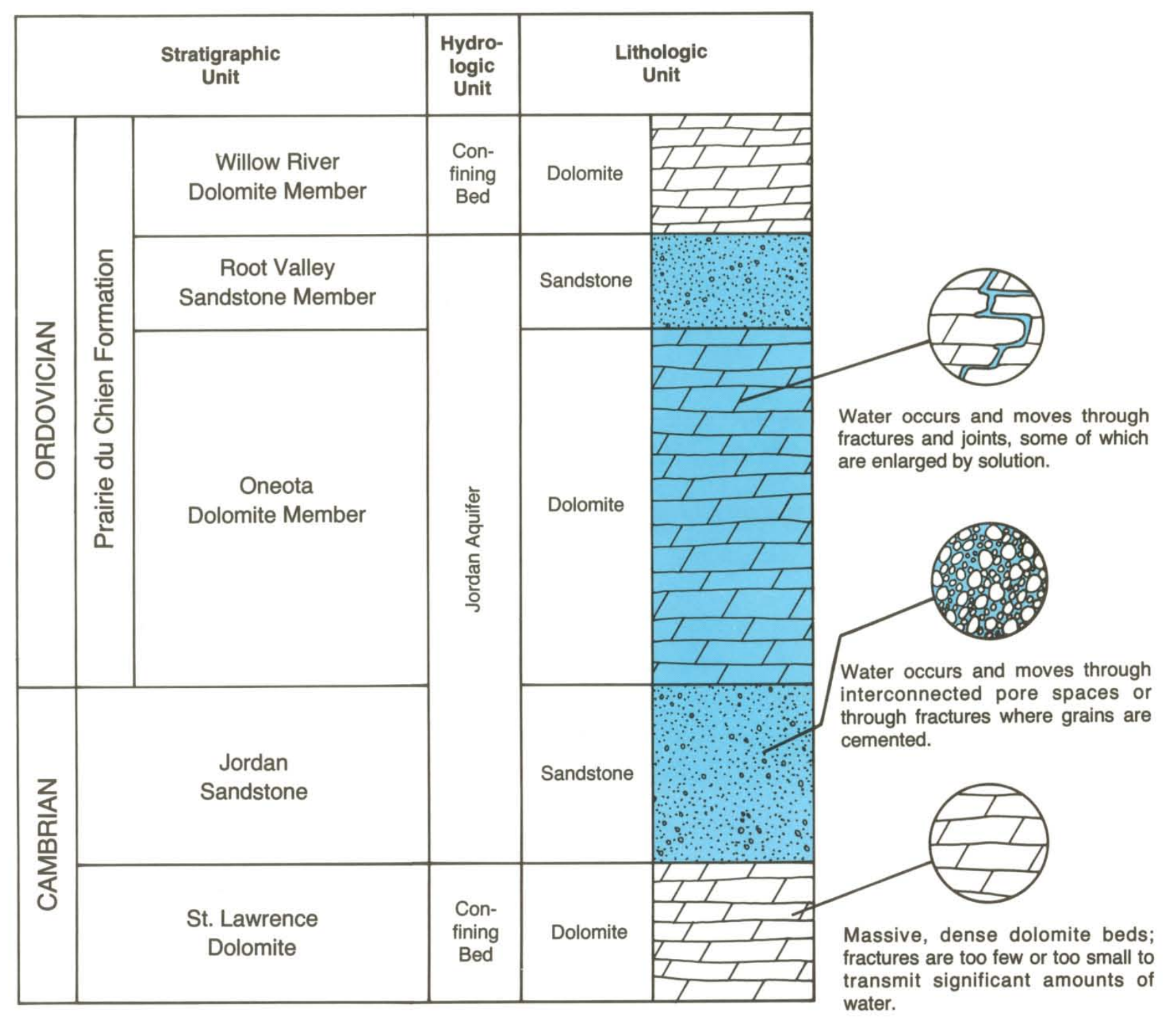
Prepared in cooperation with the
United States Geological Survey

HYDROLOGY

HOW WATER OCCURS IN THE JORDAN AQUIFER

WATER OCCURS IN THE JORDAN AQUIFER IN SANDSTONES AND CARBONATE ROCKS THAT HAVE BOTH PRIMARY AND SECONDARY POROSITY. From the time of deposition the sandstones had primary porosity except where the intergranular pore spaces later became filled with natural cementing substances. Secondary porosity was subsequently developed in some of the cemented zones by fracturing. The carbonate rocks, which are dense, crystalline dolomite, originally had a very low porosity. But as the sediments hardened and underwent structural stresses, openings developed along horizontal bedding planes and vertical fractures and joints. Groundwater containing dissolved carbon dioxide infiltrated these openings and dissolved some of the dolomite, thus enlarging the openings. Although the jointing in the dolomite probably follows a systematic pattern, the other openings generally are very irregular in distribution and size because of the variable solubility of the dolomite and the composition of the overlying materials through which the water percolates. The sandstones probably have greater storage and transmission capabilities than do the dolomites, but locally the dolomites contain large fractures or solution caverns and will yield more water than the sandstones.

THE WATER IN THE JORDAN AQUIFER IS UNDER ARTESIAN CONDITIONS; THAT IS, THE WATER IS UNDER PRESSURE AND RISES IN WELLS ABOVE THE TOP OF THE AQUIFER OR ABOVE THE LEVEL AT WHICH WATER WAS FIRST ENCOUNTERED IN THE AQUIFER. Originally the pressure was sufficient to cause natural flows from wells in the valleys of the large rivers of eastern and central Iowa. The pressure surface has declined gradually over the years as more and more wells have tapped the aquifer for water supply. At major pumping centers the withdrawal rates are so high that water is being withdrawn from the aquifer more rapidly than it is being recharged, for example, at Des Moines, Ft. Dodge, and Cedar Rapids.



ESTIMATED WATER BUDGET FOR THE REGIONAL FLOW SYSTEM OF THE AQUIFER

Water enters the Jordan aquifer principally by infiltration of the precipitation that falls on the intake area of northern Iowa and southern Minnesota. The infiltrating water moves through Pleistocene drift directly into the aquifer in the northernmost part of the intake area. In the rest of the intake area the water moves through Pleistocene drift, sandstones and shales of Cretaceous age, and carbonate rocks of Devonian and Ordovician age before entering the aquifer. From the intake or recharge area, the water moves laterally southeastward by subsurface flow toward Illinois and Missouri. Discharge is into the Mississippi River north of the Jackson-Clinton County line and into the Illinois Basin via western Illinois and northern Missouri south of the line. During its movement from recharge to discharge areas, large quantities of water are extracted from the system by pumping wells, and significant amounts are added to the system by leakage from overlying aquifers in central and eastern Iowa. The amounts of water added to and removed from the system — a water budget of the system — have been calculated and the results portrayed on the map below.

The budget of the regional flow system of the aquifer can be expressed by the following equation (Lohman, 1972, p. 63).

$$R + \Delta R = D + \Delta D + q + S\frac{\Delta h}{\Delta t}$$

where the parameters, per unit area, are:

R = recharge rate,
ΔR = change in recharge rate; in this example $\Delta R = \Delta R_1 + \Delta R_2$, where ΔR_1 is leakage from overlying or underlying aquifers, and ΔR_2 is increased underflow from recharge area by gradient steepening,
D = natural discharge rate,
ΔD = change in natural discharge rate,
q = rate of withdrawal from wells,
$S\frac{\Delta h}{\Delta t}$ = rate of change in storage.

In this example, leakage (ΔR_1) will be left as the residual, because data are available to estimate the other parameters.

Recharge (R) and discharge (D) — Prior to withdrawals by wells, the system was in dynamic equilibrium. Recharge equaled discharge, and interaquifer leakage was minimal. Both recharge and discharge can be determined from the predevelopment potentiometric and transmissivity maps by using Darcy's Law to calculate the flow between two adjacent contour lines. The calculated values for recharge and discharge are about 6.5 to 7.5 billion gallons per year.

Change in discharge (ΔD) — An estimated 1 to 1.5 billion gallons per year of water that formerly discharged into northern Missouri has been diverted to the pumpage centers in the central part of the state. The gradient in most of eastern Iowa has been decreased approximately 20 percent, so that the present discharge along the eastern Iowa border is believed to be about 1 to 1.5 billion gallons per year less than during predevelopment time in that area. Thus, the total ΔD is about 2 to 3 billion gallons per year.

Change in recharge (ΔR_2) — The gradient in the recharge area of northern Iowa, shown on the 1974-75 potentiometric map, has increased since predevelopment time by about 42 percent. Thus, the underflow from the main recharge area, which is proportional to the gradient, has been increased 42 percent or 2.7 to 3.2 billion gallons per year.

Total pumpage (q) in the area of the regional flow system in Iowa equals 16.5 to 17.5 billion gallons per year.

Change in storage $(S\frac{\Delta h}{\Delta t})$ — The change in state-wide aquifer storage since pumping began is about 175 to 200 billion gallons, which was determined from the potentiometric-change map and by assuming a state-wide storage coefficient of 2.5×10^{-4}. Because about 30 percent of the change in the storage is attributed to withdrawals during the last 10 years (as indicated on the historical pumpage table), the annual average change (decrease) in storage attributed to pumping is about 5.3 to 6 billion gallons per year. This amount is approximately equivalent to an average state-wide head loss of about 1.8 to 2.4 feet per year as shown in the adjacent hydrographs.

Therefore, the average leakage to the aquifer, which is attributed to increased interaquifer head differentials, is estimated as:

$$\Delta R_1 = D - \Delta D + q - S\frac{\Delta h}{\Delta t} - R - \Delta R_2$$

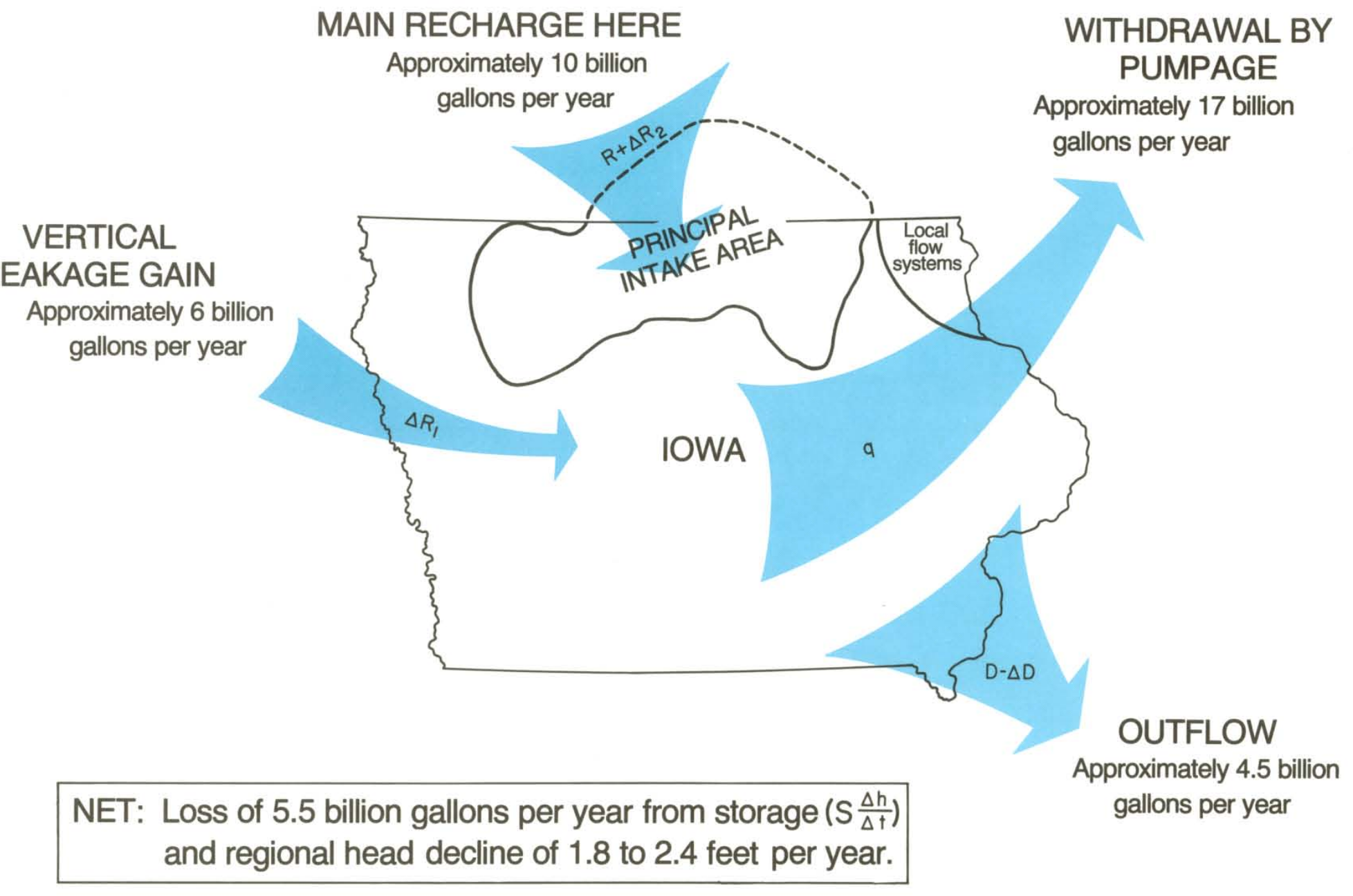
$\Delta R_1 = 7 - 2.5 + 17 - 5.5 - 7 - 3 = 6$ billion gallons per year

and: $R + \Delta R_1 + \Delta R_2 = D + \Delta D + q - S\frac{\Delta h}{\Delta t}$

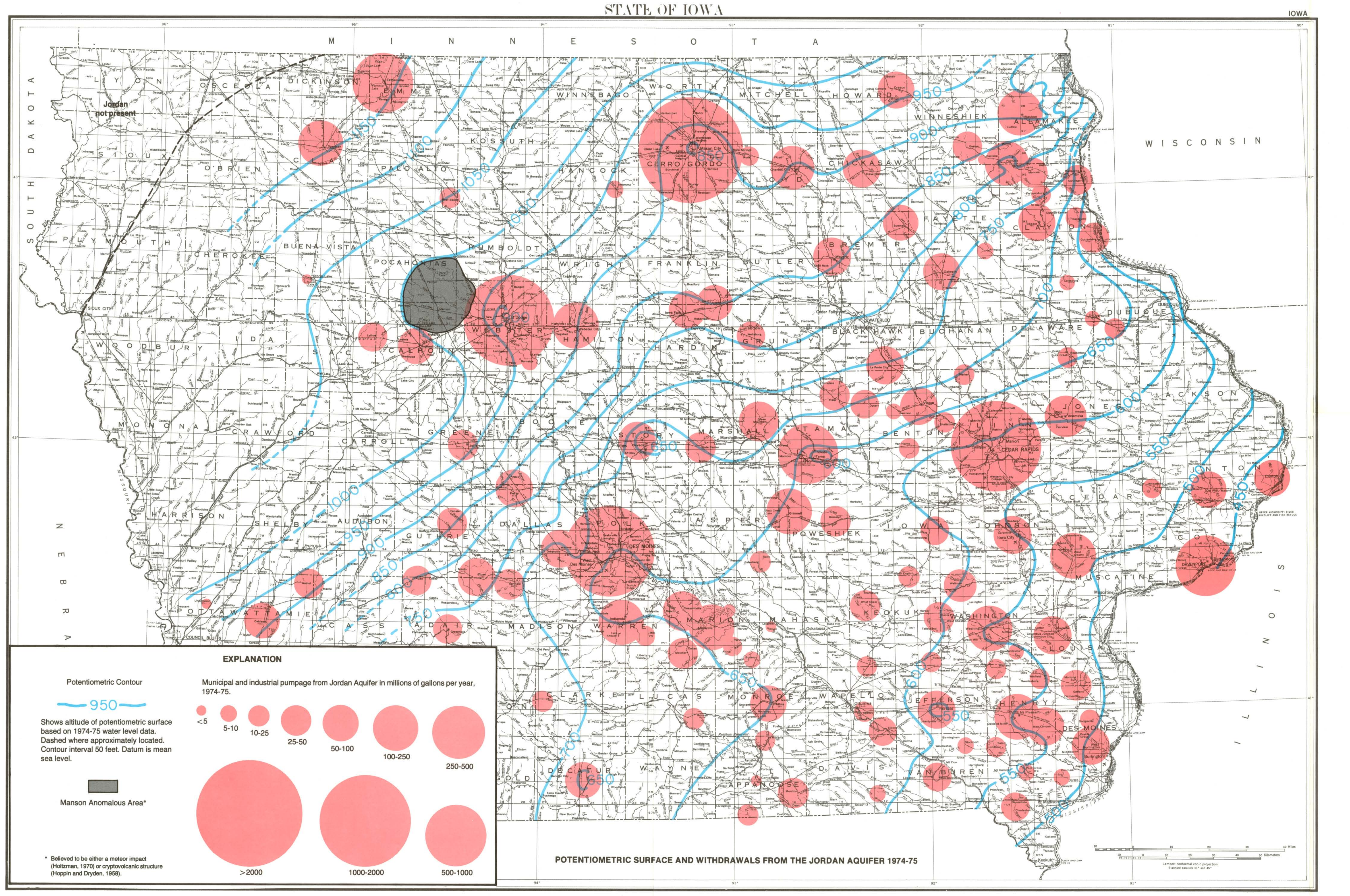
$$\underbrace{7 + 6 + 3}_{16} = \underbrace{7 - 2.5 + 17}_{21.5} \underbrace{- 5.5}_{5.5}$$

thus: (recharge) = (discharge) – (storage loss)

Because storage is being depleted, it is important to estimate the amount of water stored in the aquifer. Storage can be considered either as **artesian** storage — the amount of water that is released when the potentiometric surface is lowered by pumping, or as **total** storage — the amount of water contained in the aquifer openings (the porosity of the aquifer). The former is a more practical measure, because, except for some northeastern counties, dewatering of this deeply buried aquifer isn't likely in the foreseeable future. A meaningful value for artesian storage is the amount of water stored per foot of artesian head, which is about 2.4 billion gallons. Thus, if the potentiometric surface were lowered 100 feet throughout the State, excluding western and southwestern Iowa, the amount of water derived from artesian storage would be about 240 billion gallons.



STATE OF IOWA



EXPLANATION

Potentiometric Contour

— 950 —

Shows altitude of potentiometric surface based on 1974-75 water level data. Dashed where approximately located. Contour interval 50 feet. Datum is mean sea level.

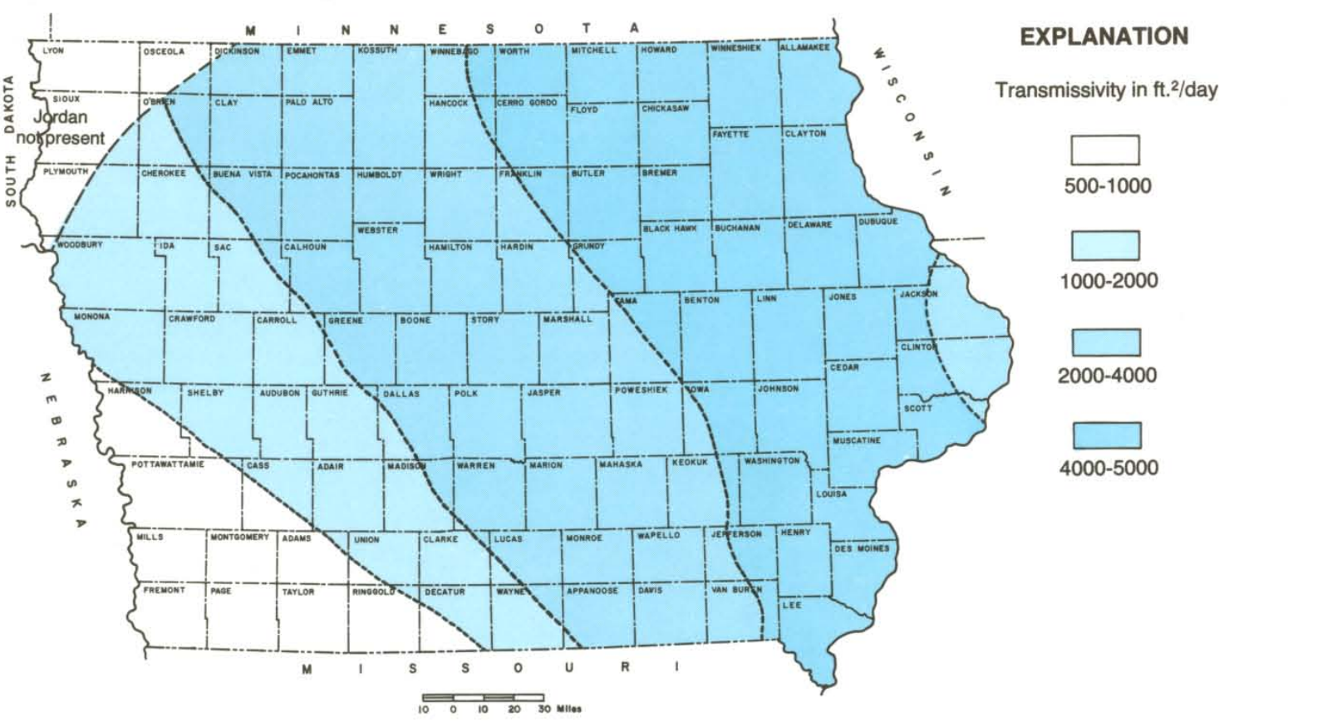
Manson Anomalous Area*

Municipal and industrial pumpage from Jordan Aquifer in millions of gallons per year, 1974-75.

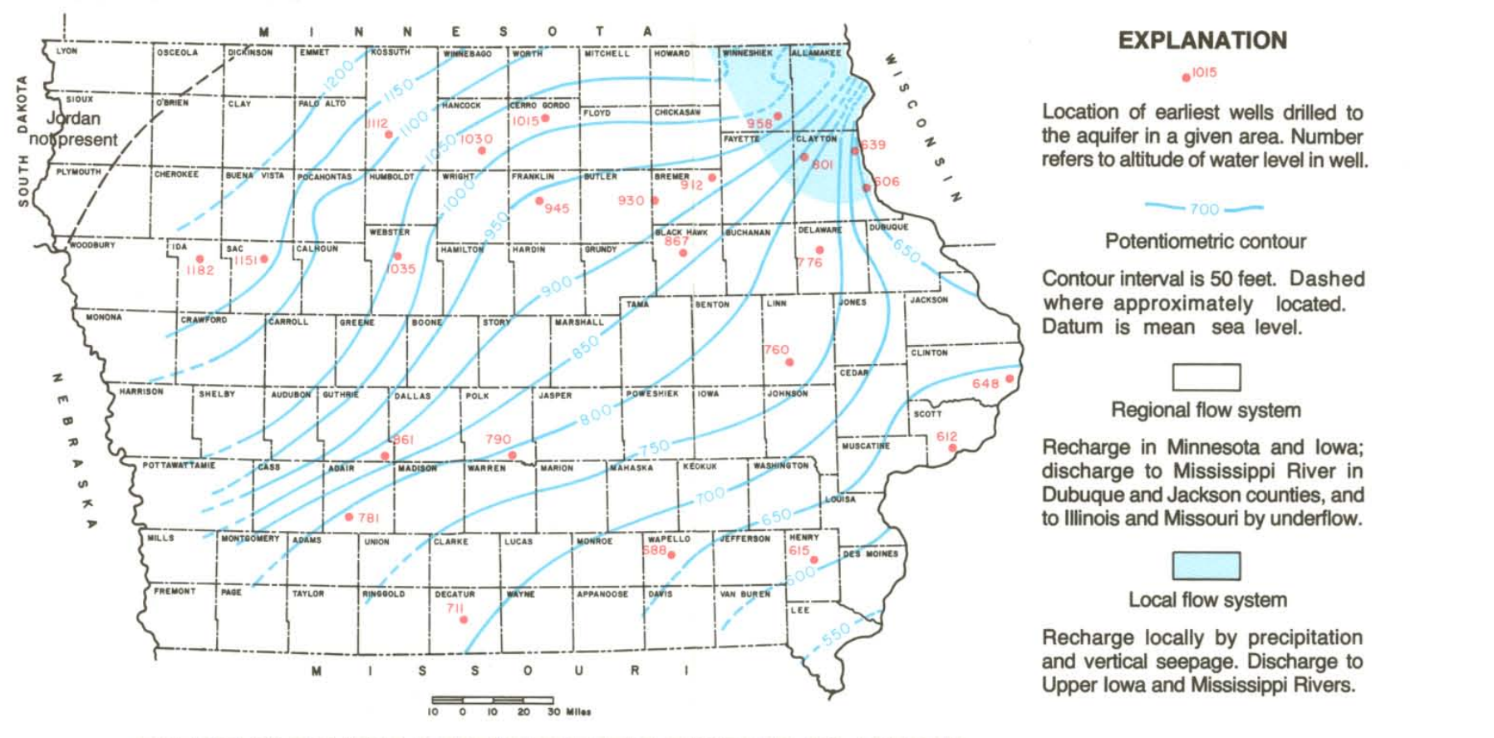
<5, 5-10, 10-25, 25-50, 50-100, 100-250, 250-500, >2000, 1000-2000, 500-1000

* Believed to be either a meteor impact (Holtzman, 1970) or cryptovolcanic structure (Hoppin and Dryden, 1958).

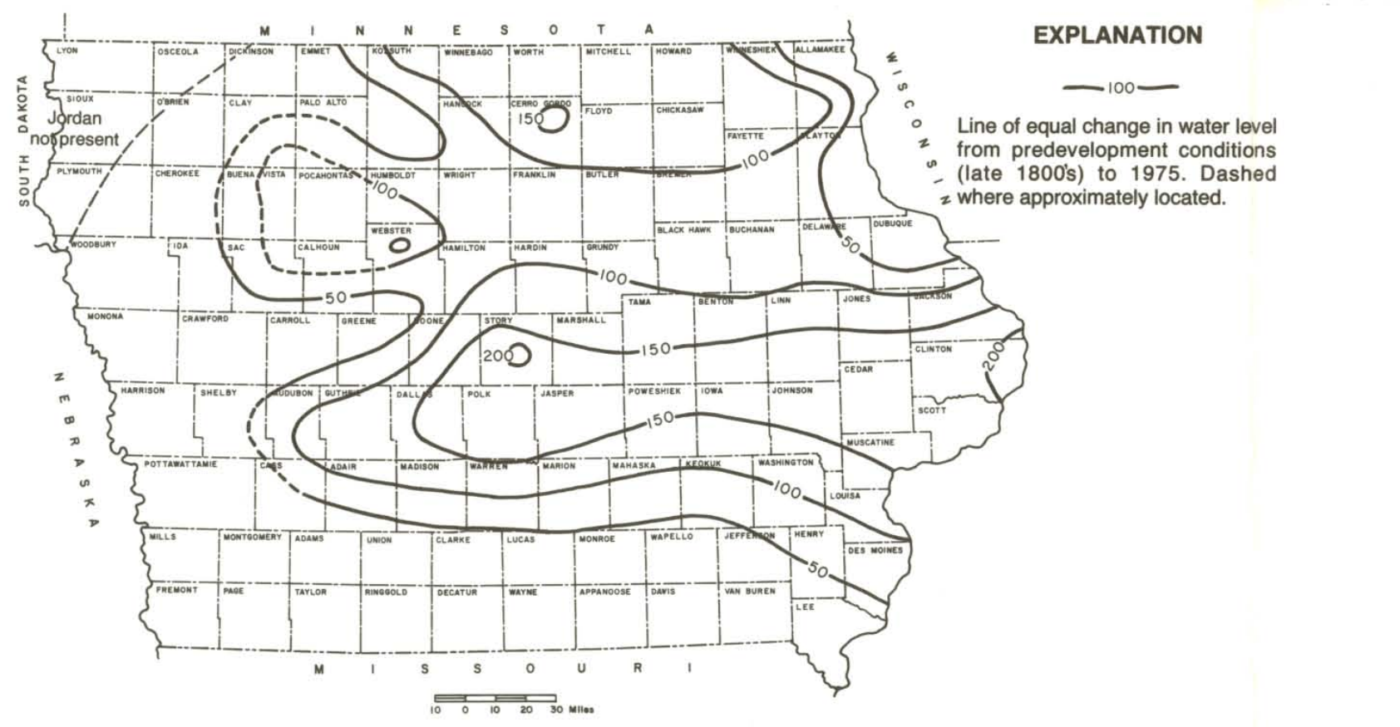
POTENTIOMETRIC SURFACE AND WITHDRAWALS FROM THE JORDAN AQUIFER 1974-75



THE TRANSMISSIVITY OF THE JORDAN AQUIFER IS THE RATE AT WHICH WATER IS TRANSMITTED THROUGH A UNIT WIDTH OF THE AQUIFER UNDER A UNIT HYDRAULIC GRADIENT. It is expressed in square feet per day.



PRE-DEVELOPMENT POTENTIOMETRIC SURFACE OF JORDAN AQUIFER BASED ON EARLIEST WATER LEVEL RECORDS AVAILABLE FROM DEEP WELLS DATING BACK TO 1896 (NORTON, 1912). This map may be compared with the latest potentiometric map above prepared from 1974-75 data to estimate the head loss that has occurred in the intervening years and as shown on the map at right.



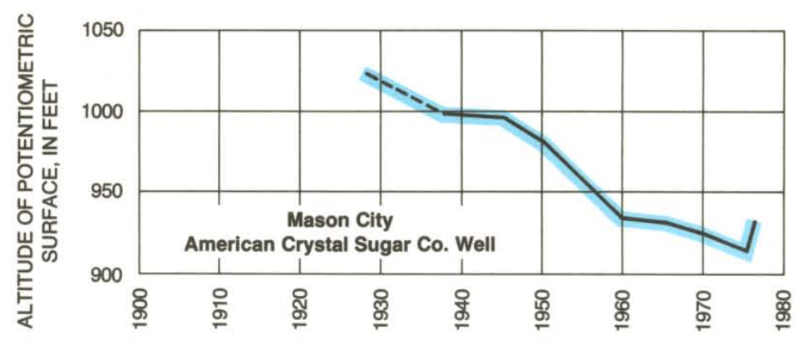
AREAL RECESSION OF POTENTIOMETRIC SURFACE OF JORDAN AQUIFER. This map shows the regional decline. At the pumping centers the head loss is somewhat greater.

HYDRAULIC CHARACTERISTICS OF THE AQUIFER

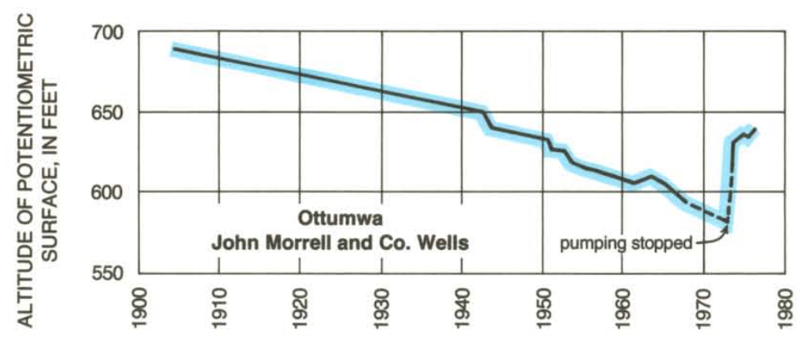
The transmissivity of the aquifer, shown on the above map, is estimated to range from about 500 ft²/day in the western part of the state to about 5000 ft²/day in the northeastern part. The boundaries shown are highly generalized. These regional estimates are based on state-wide specific capacity data and on several aquifer tests in the eastern part of the state (Hansen, 1970; and Hershey and others, 1970). At a few localities in southeastern Iowa and in Polk County, where unusually high specific capacities occur, the transmissivities may be somewhat higher than shown on the map. The storage coefficient of the aquifer, based on a few aquifer tests in the northern and eastern parts of the state, is estimated to average about 2.5×10^{-4} (the value in the southwestern part may be somewhat lower). The value of 2.5×10^{-4} was used in calculating artesian storage in the aquifer and in calculating storage losses.

THE POTENTIOMETRIC SURFACE — a record of decline

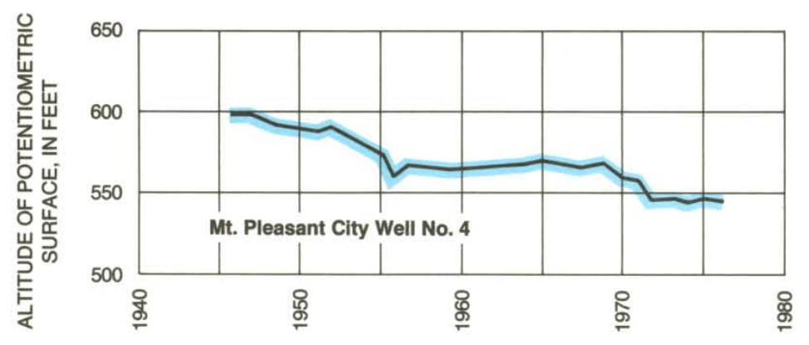
SINCE THE FIRST WELLS DRILLED TO THE JORDAN AQUIFER BEGAN WITHDRAWING WATER IN THE LATE 1800's, THE POTENTIOMETRIC SURFACE IN IOWA HAS DECLINED ABOUT 50 TO 150 FEET REGIONALLY AND AS MUCH AS 175 TO 200 FEET AT THE MAJOR PUMPING CENTERS. These recessions are shown on the small map above, which shows the changes between the predevelopment and 1975 potentiometric maps. Water-level trends at some pumping centers, shown on the hydrographs, indicate that the water levels are declining at an average rate of 1.8 to 2.4 feet per year. These declines will increase as long as the pumpage rates increase as indicated by the adjacent historical pumpage table. The water-level declines at most major pumping centers are about 4 to 6 feet per year. The large and deep drawdown cones created by these heavy withdrawals can be mitigated somewhat by spacing new wells farther apart in order to reduce mutual interference effects. A tool to calculate interference effects and thereby determine optimum well spacing is the distance-drawdown graph shown below.



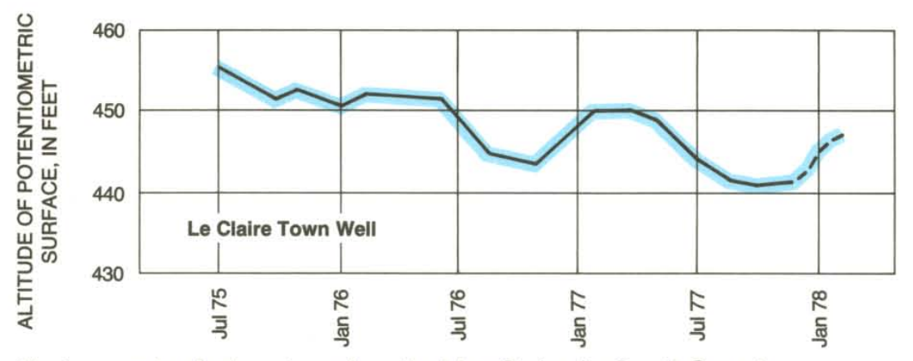
The effect of industrial and municipal pumpage on the static head of the water level is shown in the hydrograph of a well penetrating the Jordan aquifer at Mason City in Cerro Gordo County. The sharp recovery in the period 1975-76 is attributed to shutdown of one of the major industrial consumers tapping this source.



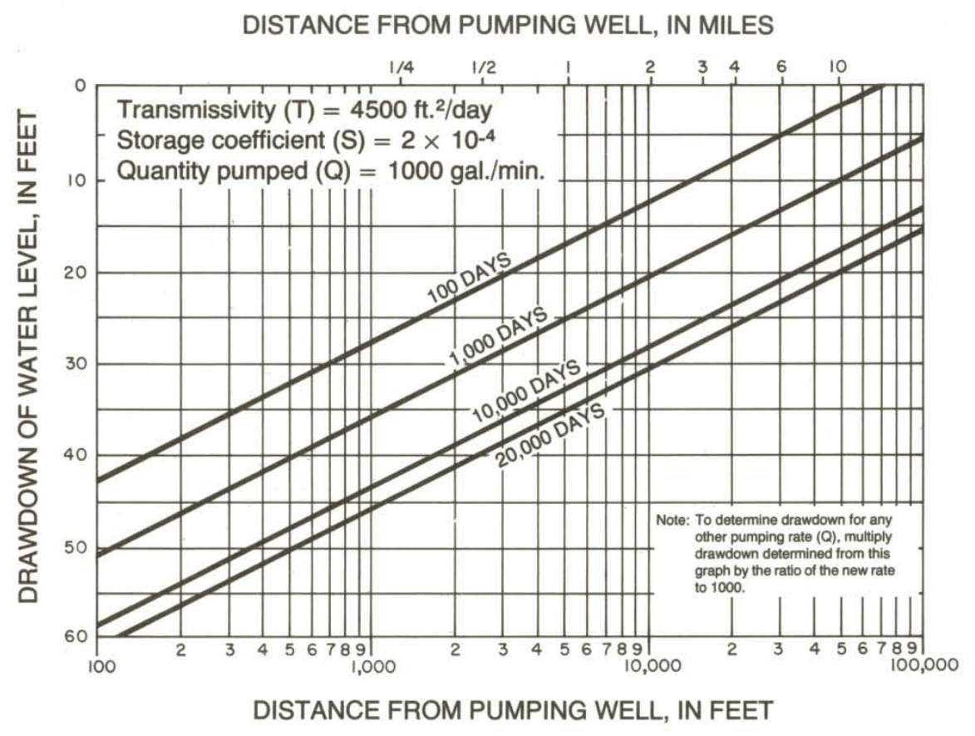
Hydrograph of well tapping the Jordan aquifer at Ottumwa in Wapello County, showing head loss over the years resulting from industrial pumpage. Observe the sharp recovery beginning in 1973 when pumping was stopped.



Hydrograph indicating general decline of the water level in the Jordan aquifer at Mt. Pleasant in Henry County. For the 30-year period of record, the total head loss is about 54 feet.



Hydrograph of abandoned well at Le Claire in Scott County, showing a regional decline of the potentiometric surface and annual fluctuations caused by industrial withdrawals from wells in the Quad Cities area. Note that subsequent recoveries during the winter months do not regain the previous year's water level.



(Modified from Hershey and others, 1970)

A USEFUL TOOL IN DETERMINATION OF THE WATER LEVEL DRAWDOWNS THAT WILL OCCUR AT SPECIFIC DISTANCES FROM A PUMPING WELL FOR VARIOUS PERIODS OF TIME IS THE DISTANCE-DRAWDOWN GRAPH. A reproduction of one such graph is shown above (Hershey and others, 1970). The graph will assist in selecting the optimum spacing between Jordan aquifer wells to prevent serious interference effects. Drawdowns determined for new wells must be superimposed on the existing potentiometric map. The graph is considered valid for localities in the eastern half of the State based on pumping tests at Mason City and Cedar Rapids. Other graphs based on different transmissivities will have to be constructed for other localities.

WITHDRAWALS FROM THE AQUIFER

ANNUAL WITHDRAWAL OF WATER FROM THE JORDAN AQUIFER IN IOWA DURING 1974-75 WAS ABOUT 18 TO 19 BILLION GALLONS. OF THIS QUANTITY, ABOUT 12 TO 13 BILLION GALLONS OR ABOUT 66 PERCENT WAS WITHDRAWN BY MUNICIPALITIES AND ABOUT 6 BILLION GALLONS OR ABOUT 34 PERCENT WAS WITHDRAWN BY INDUSTRIES. All known pumping centers are shown on the adjacent map; the principal pumping centers, where about 85 percent of the water was withdrawn, are itemized in the table below. Industrial pumpage is itemized in the other table below. An unknown, but probably small amount of domestic pumpage occurs in and near the outcrop area in northeastern Iowa.

Withdrawals from the Jordan aquifer are expected to increase in the future. Limited historical pumpage records, shown on the bottommost table, indicate an increase in withdrawals by many municipalities; this trend is expected to continue or even to accelerate.

QUANTITY OF WATER WITHDRAWN BY MUNICIPALITIES AND INDUSTRIES IN MILLION GALLONS PER YEAR AT MAJOR PUMPING CENTERS, 1974-75[a]

City or Area	Quantity Pumped (M gal/yr)
Mason City	2,560
Cedar Rapids-Marion	1,686
Des Moines	1,653
Fort Dodge	1,642
Tama-Toledo	722
Estherville	706
Davenport	506
Webster City	485
Spencer	410
Grinnell	392
Charles City	385
Knoxville	337
Indianola	332
West Liberty	300 E
Washington	292
Mt. Pleasant	291
Postville	281
Waukon	270
Waverly	241
Coralville-Iowa City	239
Oelwein	223
New Hampton	209
Cresco	206
Nevada	204
Perry	193
DeWitt	175
Clinton	160
Albia	156
Columbus Jct.	150
Green Mountain	150
Vinton	125
Fairfield	117
Anamosa	108
Oakland	100
	15,996[b]

E = Estimate
[a] Includes industrial pumpage, which is shown in adjacent table.
[b] Represents about 85% of total withdrawal from Jordan aquifer.

QUANTITY OF WATER ANNUALLY PUMPED BY INDUSTRIES FROM THE JORDAN AQUIFER, 1974-75

Company and Location	Quantity Pumped (M gal/yr)
Wilson & Company, Cedar Rapids	604
Lehigh Portland Cement, Mason City	570
Packaging Corp. of America, Tama	512
Oscar Mayer Co., Davenport	506
Farmland Foods, Inc., Fort Dodge	486
Spencer Packing Co., Spencer	410
Quaker Oats, Cedar Rapids	270
Louis Rich Foods, West Liberty	216
Cresco Creamery Co., Cresco	200 E
Oscar Mayer Co., Perry	193
Penick & Ford, Inc., Cedar Rapids	190
Allied Mills, Inc., Mason City	180 E
Swift & Co., Inc., Clinton	160
St. Olaf Creamery, St. Olaf	157 E
Rath Packing Co., Columbus Jct.	150
Farm Service Co., Green Mountain	150
Meadowland Dairy, Waukon	140
Iowa Beef Processors, Inc., Fort Dodge	133
Tama Packing Co., Tama	117
Armour Packing Co., Mason City	108[c]
American Beef Packers, Oakland	100
Hubbard Ice & Fuel, Cedar Rapids	85
Hygrade Foods, Postville	77
Farmland Foods, Iowa Falls	75
Northwest States Portland Cement, Mason City	72
Cedar Rapids Gazette, Cedar Rapids	50
Iowa Turkey Products, Postville	49
Georgia-Pacific Co., Fort Dodge	35
Celotex Corp., Fort Dodge	32
U.S. Gypsum, Sperry	22
	6,070

E = Estimate
[c] = 1976 data
Some of these industries have additional sources of water, thus, the figures shown do not necessarily indicate total water use by the industry.

YIELDS, SPECIFIC CAPACITIES, AND DEVELOPMENT TECHNIQUES

THE JORDAN AQUIFER IS ONE OF THE MOST DEPENDABLE GROUND-WATER SOURCES FOR LARGE CAPACITY WELLS IN IOWA. Generally yields from the Jordan aquifer range from several hundred gallons a minute (gal/min) to 1,000 gal/min, and occasionally 2,000 gal/min in the northeastern two-thirds of the State. However, yields vary somewhat dependent upon the amount of cementation of the sandstones and the presence or absence of fractures in the dolomites. The construction method and the extent and technique of well development also have a bearing on the yield. The Jordan Sandstone is the principal water-yielding unit, but some unusually high capacity wells in south-central Iowa (Polk, Dallas, Marion, Warren, Madison, and Guthrie Counties) and parts of southeastern Iowa (Ottumwa-Eldon, Donnellson, and the Tama-Grinnell areas) may obtain most, or at least much, of their water from fractures in the dolomites of the lower part of the Prairie du Chien Formation. The specific capacities of these wells may range as high as 20 to 40 (gal/min)/ft. of drawdown. Elsewhere in the eastern half of the State and parts of northwestern Iowa (Rockwell City-Ft. Dodge-Webster City, Spencer-Estherville, and Storm Lake-Odebolt areas) the aquifer generally will produce at least 4 to 5 (gal/min)/ft. of drawdown and range up to as much as 10 to 15 (gal/min)/ft. In southwestern Iowa, where the sandstone is thin and the aquifer is deeply buried, specific capacities generally are less than 3 (gal/min)/ft. of drawdown.

Proper well construction and development are important in obtaining maximum yields from wells that tap the Jordan aquifer. The most successful wells usually have a bottom hole diameter of at least 8 inches and are cased from the surface into the upper part of the Prairie du Chien Formation with the pipe grouted in place with neat cement for its full length.

Development methods consist of treating the well with large quantities (4,000-8,000 gallons is common) of concentrated, inhibited hydrochloric acid, usually 20° Baume, in one or two stages, using a large volume of water to force the acid into the formation. The acid-water mixture may also be surged with a pressure pump. Some contractors use explosives to blow the acid out into the formation. Dynamiting the water-bearing interval or shooting with shaped charges are other development methods less often used.

These development methods exhibit a wide range of success. Increases of as much as 1,000 percent in specific capacity have been obtained, but the average increase in 23 wells from which data on development were collected was about 375 percent. In six of the wells the increase in specific capacity was less than 100 percent. This information indicates that the added expense of development usually is justified. The comparatively poor improvement in some wells is attributed to several factors such as failure to clean the hole before placement of the acid, insufficient acid used or acid of insufficient strength, acidizing without pressure, using only one treatment when two or three stages may be needed, failure to clean out the sand accumulated in the well from the development work, and shooting or blasting the well at the wrong depth, or with weak charges.

A technique of drilling and developing the Jordan Sandstone by injection of air under high pressure with a large volume of water holds considerable promise for constructing high capacity Jordan aquifer wells. With this method the well can be completed in one step without going back into the hole with the more conventional acid or blasting treatment. Very good results have been obtained with this method in the few places it has been used.

HISTORICAL DATA ON PUMPAGE FROM JORDAN AQUIFER, IN MILLIONS OF GALLONS

COUNTY	CITY, TOWN, or INDUSTRY	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Allamakee	Postville	84	78	60	54	49	44	53	66	59	66	67	69	79	81	87
Appanoose	Moulton										36	39	39	42	37	29
Bremer	Waverly									212	181	245	220	209	239	241
Cerro Gordo	Mason City	1,410	1,392	1,374	1,368	1,366	1,378	1,404	1,420	1,438	1,456E	1,477E	1,500	1,553	1,593	1,623
Clay	Spencer	462	409	287	221	293	290	227	327	333	335	333	323	Abandoned		
Clayton	Elkader						54	54	55	55	56	57	57	57	58	58
Clinton	DeWitt											127	159	173	214	175
Clinton	Wheatland		13	12	13	14	14	15	15	16	16	19	22	25	20	21
Dallas	Perry, Oscar Mayer & Co.											310	323	276	243	193
Dallas	Waukee, Des Moines C.C.								26	38	13	42	42	29	24	50
Dallas	Waukee, I-80 Rest Stop										1.7	2.5	1.8	1.3	1.1	1.1
Delaware	Hopkinton									22	29	32	28	29	30	25
Des Moines	West Burlington					45	48	50	53	56	63	76	79	80	83	85
Emmet	Estherville										682	758	785	879	837	706
Fayette	Oelwein										210	171	190	188	222	222
Grundy	Wellsburg			13				15		15	23	30	21	32	29	
Guthrie	Stuart				26	20	24	23	28	40	40	45	49	56	59	56
Hamilton	Webster City					355	361	389	391	355	387	492	463	486	507	435
Henry	Mt. Pleasant										255	273	270	315	275	266
Henry	New London			47	43	44	44	50	50	52	51	52	51	57	62	59
Jefferson	Fairfield			3	153	252	95	109	212	281	106	minor	97	108	38	minor
Johnson	Coralville							103	136	151	161	176	215	208	228	229
Johnson	Iowa City, State Security Medical Facility										11	13	12	11	14	10
Johnson	Iowa City, Univ. of Iowa, Oakdale Campus											33	51	57	44	41
Lee	Donnellson											28	30	31	41	39
Linn	Marion										358	388	400	419	461	481
Louisa	Morning Sun											25	27	39		31
Mahaska	Leighton										2	2	2	3	3	3
Marion	Knoxville										241	326	328	319	324	337
Polk	Altoona				57					90	86	96	112	116	143	163
Polk	Ankeny										210	240	223	312	357	361
Polk	Runnells Southeast Polk School									4	4	2	6	6	5	7
Polk	West Des Moines								136	500	432	484	485	587	591	764
Poweshiek	Brooklyn				40	36	34	34	38	35	38	37	38	39	41	41
Tama	Tama, Packaging Corp. of America		500	509	389	482	529	511	430	421	481	435	490	526	539	512
Tama	Toledo									81	81	92	88	88	79	93
Wapello	Agency										11	10	12	12	13	13
Wapello	Eldon										38	39	35	38	30	34
Warren	Indianola					147	229	251	262	280	268	277	327	368	326	332
Webster	Fort Dodge									911	726	789	678	1,039	954	949
Webster	Fort Dodge, Farmland Industries, Inc.							173	471	466	450	478	443	462	513	436
Webster	Fort Dodge, Iowa Beef Processing, Inc.					259					100	85	119	231	143	133
	TOTAL (in billions of gallons)	2.0	2.4	2.3	2.4	3.4	3.1	3.5	4.1	5.9	7.7	8.7	9.5	9.6	9.5	9.4

E = Estimate

SUMMARY OF HYDROLOGY

The Jordan aquifer, which is widespread across Iowa, is the principal source for large quantities of water (1,000-2,000 gal/min) for municipal and industrial use from wells penetrating the consolidated rocks. The aquifer occurs at a depth of about 1,000 to 1,500 feet in the northern and northeastern counties and at about 2,500 to 3,000 feet in the central and south-central counties. The artesian head of the aquifer has lowered as much as 175 to 200 feet in the major pumping centers, causing steep and extensive drawdown cones since the original wells were drilled 75 to 85 years ago. The annual head loss in most of the State caused by the current imbalance between recharge and discharge is about 1.8 to 2.4 feet. Mining of water from the Jordan aquifer is expected to continue for the foreseeable future. However, there is no immediate danger of dewatering the aquifer, because of the large amount of water stored in the aquifer and because leakage from overlying rocks supplies a large percentage of the water withdrawn. Problems of local overdevelopment and serious interference may occur at the major pumping centers unless new wells are properly spaced.

JORDAN AQUIFER OF IOWA

by

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QUALITY OF WATER

SIGNIFICANCE OF CHEMICAL CONSTITUENTS AND PROPERTIES OF WATER

The chemical constituents and properties shown in the table below are the ones that are usually determined in routine inorganic and radiochemical water analyses. They form the basis for the chemical characteristics maps and text on this atlas sheet. The contaminant levels indicated and comments regarding the significance and acceptability of water are based on the U.S. Environmental Protection Agency's National Interim Primary Drinking Water Regulations and on the proposed Secondary Drinking Water Regulations. The primary regulations, which became effective in June 1977, established maximum contaminant levels for chemical constituents and other properties of public water supplies that affect the health of consumers. Because Iowa has accepted the primary regulations, these are now enforced by the Iowa Department of Environmental Quality (DEQ). The proposed secondary regulations will establish maximum contaminant levels for constituents that affect the esthetic quality of water. When promulgated, these secondary regulations will be accepted by the DEQ as Iowa's esthetic quality standard for public water supplies.

The maximum contaminant level of some constituents that affect the esthetic quality of water are exceeded in many public supplies withdrawn from the Jordan aquifer. Many of these supplies have been used for many years without obvious ill effects. Some of these supplies are the best that are locally available to the community; any improvement in quality would require demineralization of the water.

Standards for uses other than drinking water are usually different than those listed below. The quality requirements for industries, for example, would depend on how the water was used and therefore are quite varied. The concentrations of some constituents and properties of water from the aquifer are shown on maps so the users can decide if the water meets their particular requirements.

The nonradioactive chemical constituents discussed in this atlas are expressed as ions in concentrations of milligrams per liter (mg/L). One mg/L is 1/1000th of a gram (milligram) of an ion in a volume of 1000 cubic centimeters (one liter) of water. An approximate weight to weight ratio would be one gram of the ion in 1,000,000 grams of water, or one part per million (ppm). Radium concentration and gross alpha activity are reported in picocuries per liter (pCi/L). One picocurie is the quantity of radioactive material producing 2.22 nuclear transformations per minute.

Constituent or property	Maximum contaminant levels in community water supplies[1]		Significance and comments
	Primary regulations	Proposed secondary regulations	
Iron (Fe)		0.3 mg/L	Iron concentrations of 0.3 mg/L or more are likely to be troublesome as iron can cause red-water staining of plumbing fixtures and clothing and plug well screens and water pipes. High concentrations affect the color and taste of beverages.
Silica (SiO_2)	NA[2]		Silica contributes to formation of boiler scale, forms deposits on blades of steam turbines, but is not physiologically or agriculturally significant. Most water from the Jordan aquifer has concentrations of 5 to 30 mg/L.
pH	NA		The pH expresses the negative logarithm of the hydrogen-ion concentration and indicates whether water is acid or alkaline. A pH of 7.0 indicates a neutral solution, less than 7.0 is acid, more than 7.0 is alkaline. Most supplies from the Jordan aquifer have pH values ranging between 7.1 and 7.9 and, therefore, are slightly alkaline.
Specific conductance (micromhos/cm. at 25° C)	NA		Specific conductance refers to the ability of the water to conduct an electric current and generally increases in a direct proportion to the presence of ionic species in solution. There is a consistent enough relationship between the dissolved solids and specific conductance of water from the Jordan aquifer that the dissolved solids can be estimated by multiplying the specific conductance by 0.67.
Dissolved solids (residue on evaporation at 180° F)		500 mg/L	Dissolved solids indicate the concentration of dissolved minerals in the water and is a measure of the water's suitability for many uses. Concentrations of over 2,000 mg/L, which in Iowa implies a high concentration of sulfate, may have a detectable taste and a laxative effect on people not acclimated to the water. Many water supplies, particularly in western and southern Iowa, contain more than 1,000 mg/L dissolved solids; these supplies are used with no obvious ill effects.
Alkalinity (as $CaCO_3$)	NA		Alkalinity is a measure of the concentration of bicarbonate and carbonate ions in water and refers to the water's ability to neutralize acid. In moderate amounts alkalinity does not affect most uses of water. Its significance is usually dependent on the nature of the cations (Ca, Mg, Na, K) associated with it.
Hardness (as $CaCO_3$)	NA		Hardness is caused almost entirely by compounds of calcium and magnesium and is commonly recognized by the increased quantity of soap required to produce lather. Hard water is also objectionable because it causes the formation of scale in boilers, water heaters, radiators, and pipes. Total hardness can be expressed as carbonate and noncarbonate hardness. Carbonate hardness is equivalent to the concentration of bicarbonate and carbonate in the water (that is, the alkalinity); any hardness in excess of this amount is called the noncarbonate hardness.
Sodium (Na) and potassium (K)	NA		Sodium and potassium in moderate quantities have little affect on the usefulness of the water. Water that contains more than 100 mg/L of sodium and potassium combined may cause foaming in boilers. High concentrations of sodium may be objectionable for people on a low sodium diet.
Calcium (Ca) and magnesium (Mg)	NA		Calcium and magnesium in addition to being the main causes of hardness in water are responsible for the formation of boiler scale and deposits in hot water heaters and pipes. They reduce the lathering or sudsing ability of soaps. They combine with soap to form scum deposits.
Manganese (Mn)		0.05 mg/L	Manganese in concentrations as low as 0.01-0.02 mg/L causes dark brown or black stains on fabrics and porcelains and impairs the taste of coffee, tea, and other beverages.
Nitrate (as NO_3) (as N)	45 mg/L 10 mg/L[3]		Serious and occasionally fatal poisonings have occurred when water high in nitrate has been used by infants. It is the cause of methemoglobinemia, or cyanosis, a sickness that gives a baby's skin a bluish tinge. Nitrate concentrations greater than 5 mg/L as NO_3 may indicate pollution.
Fluoride (F)	2.0 mg/L[4]		Fluoride is desirable in water supplies in concentrations that range from 0.8 to 1.2 mg/L, because it reduces tooth decay. However, mottling of tooth enamel of growing children in Iowa may occur when fluoride concentrations exceed 2 mg/L.
Chloride (Cl)		250 mg/L	Chloride concentrations less than 150 mg/L generally are satisfactory for most purposes. More than 250 mg/L generally is objectionable for public supplies because chloride may combine with other ions to give a noticeable taste. Large amounts of chloride in water high in calcium and magnesium increases water's corrosiveness.
Sulfate (SO_4)		250 mg/L	Sulfate may cause detectable taste at concentrations of 300-400 mg/L. It commonly has a laxative effect when the concentration is above 600 mg/L, particularly when combined with magnesium or sodium. This laxative effect is commonly noted by new and casual users of the water but some become acclimated to it in a short time. The effect is noticeable in almost all persons when concentrations exceed 750 mg/L. Sulfate combined with calcium forms a hard scale in boilers and water heaters.
Bicarbonate (HCO_3) and Carbonate (CO_3)	NA		Bicarbonate and carbonate contribute to alkalinity of water. Bicarbonate is formed when carbon dioxide in water reacts with carbonate rocks such as limestone and dolomite. Small amounts of carbon dioxide are present in rainwater; more is picked up by water percolating through decaying organic matter. Bicarbonate is the principal anion in much of the earth's natural fresh water and ranges from about 150 to 500 mg/L in supplies from the Jordan aquifer. Carbonate is seldom present in natural fresh water.
Trace Metals Arsenic (As) Barium (Ba) Cadmium (Cd) Chromium (Cr) Lead (Pb) Mercury (Hg) Selenium (Se) Silver (Ag) Copper (Cu) Zinc (Zn)	 0.05 mg/L 1.0 mg/L .010 mg/L .05 mg/L .05 mg/L .002 mg/L .01 mg/L .05 mg/L	 1.0 mg/L 5.0 mg/L	Extremely small amounts of trace elements occur in water. Some of these trace metals are toxic to man. Others are essential to life, but in high concentrations can be toxic or esthetically unpleasing. The full significance of these minor elements in human metabolism isn't understood in spite of much research. Regulations of the amounts that can be present in drinking water supplies have been set by the EPA. As of this writing the water from the Jordan aquifer does not seem to have objectionable concentrations of any trace metals.
Radionuclides Radium (radium-226 and radium-228 combined) Gross alpha activity	 5 pCi/L[5] 15 pCi/L		The effect and significance of low concentrations of radium in public water supplies isn't fully known. However, the EPA takes the position that any dose of ionizing radiation has a potential to produce deleterious effects on human health and that the effect will be proportional to the dose received. Therefore, the maximum contaminant levels established for radium concentration and gross alpha activity in community water supplies is based on the effects on human health that have been observed at higher doses and dose rates. The monitoring of radioactivity in community water supplies is a screening process: when gross alpha activity exceeds 5 pCi/L, the same or equivalent sample shall be analyzed for radium-226; if the concentration of radium-226 exceeds 3 pCi/L, the same or equivalent sample shall be analyzed for radium-228. The combined radium-226 and radium-228 should not exceed 5 pCi/L. Also, the gross alpha activity (including radium-226, but excluding radon and uranium) should not exceed 15 pCi/L. Many communities with water supplies obtained from the Jordan aquifer have concentrations above these limits, but by zeolite, reverse osmosis, or lime-soda ash softening treatment the radioactivity is readily removed — as much as 90 percent removal is possible (Schliekelman, 1976).
Temperature	NA		Temperature is a major consideration in use of water for industrial cooling and air conditioning purposes.

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[1] The usage of contaminant level in this atlas follows the U.S. Environmental Protection Agency's (EPA) usage in the National Interim Primary Drinking Water Regulations (Federal Register, v. 40, no. 248 and v. 41, no. 133) and in the Proposed Secondary Drinking Water Regulations (Federal Register, v. 42, no. 62).

[2] NA — Not applicable.

[3] The maximum contaminant level for nitrate applies also to noncommunity public water supplies.

[4] The maximum contaminant level of fluoride, which is based on average maximum daily air temperatures, is 2 mg/L for about 95 percent of the State it is 1.8 mg/L for a few communities in extreme southeastern and southwestern Iowa, and is 2.2 mg/L for a few communities in northeastern Iowa.

[5] The State may require annual monitoring of supplies that exceed 3 pCi/L radium-226.

DATA NOT SHOWN ON MAPS

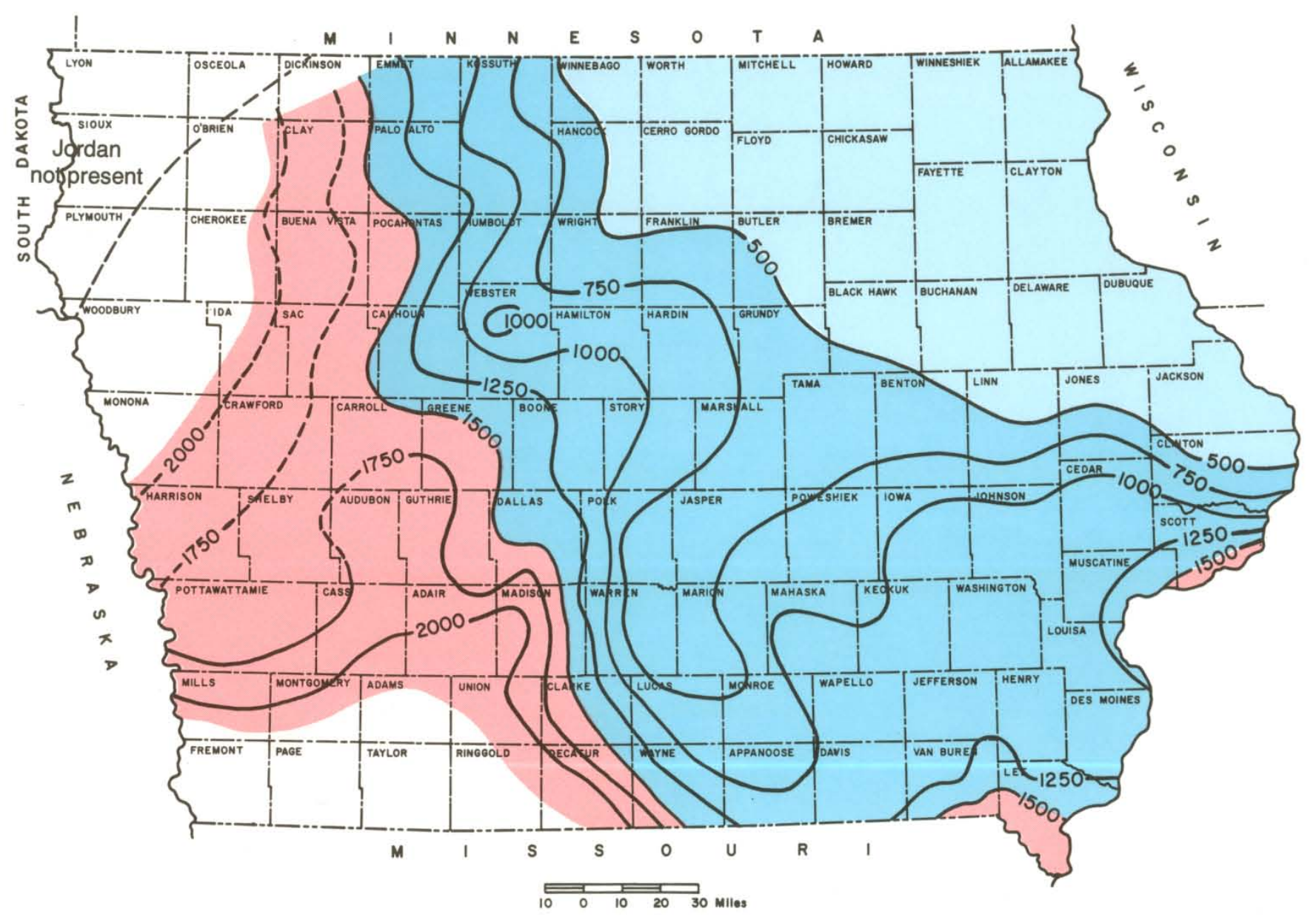
IRON concentrations in water samples from the Jordan aquifer vary considerably, both areally and temporally. It should be noted that iron concentration in a water supply can be affected by a number of factors, some of which tend to raise the concentration and some of which tend to lower the concentration. (A discussion of these is not within the scope of this report.) The analyses on hand indicate that the concentration of iron ranges from 0.0 to 5.6 mg/L with a mean value of 1.08 mg/L and a median value of 0.65 mg/L. Of these analyses, 70 percent exceeded the proposed secondary drinking water standard of 0.3 mg/L. The iron, however, can be easily stabilized or removed by aeration and filtration.

MANGANESE concentrations range from 0.0 to 0.36 mg/L with a mean value of 0.02 mg/L. The proposed maximum level of 0.05 mg/L was exceeded in only about 15 percent of the water supplies. Objectionable manganese concentrations can be lowered to about 0.05 mg/L by aeration and filtration.

NITRATE concentration in water from the Jordan aquifer throughout the State is very low. The concentration ranges from 0.0 to 5.5 mg/L with a mean value of 1.4 mg/L. There may be some exceptions where the Jordan aquifer is close to the surface in northeast Iowa and, thus, subject to contamination from surface sources.

CHLORIDE concentration in water from the Jordan aquifer ranges from about 50 to 100 mg/L in most of the State except in the southwest quarter, the southern two tiers of counties in the southeast quarter, and in the Scott County region where concentrations range from 300 to 680 mg/L. The area where the chloride concentration exceeds 250 mg/L is shown on the sodium distribution map.

HYDROGEN SULFIDE is an objectionable constituent of Jordan aquifer water supplies in some places, as at Marion, Toledo, and Fort Dodge. Aeration treatment is used to remove the odor before the water goes to the consumer. Quantitative data on concentrations of hydrogen sulfide are not available at this time.



EXPLANATION

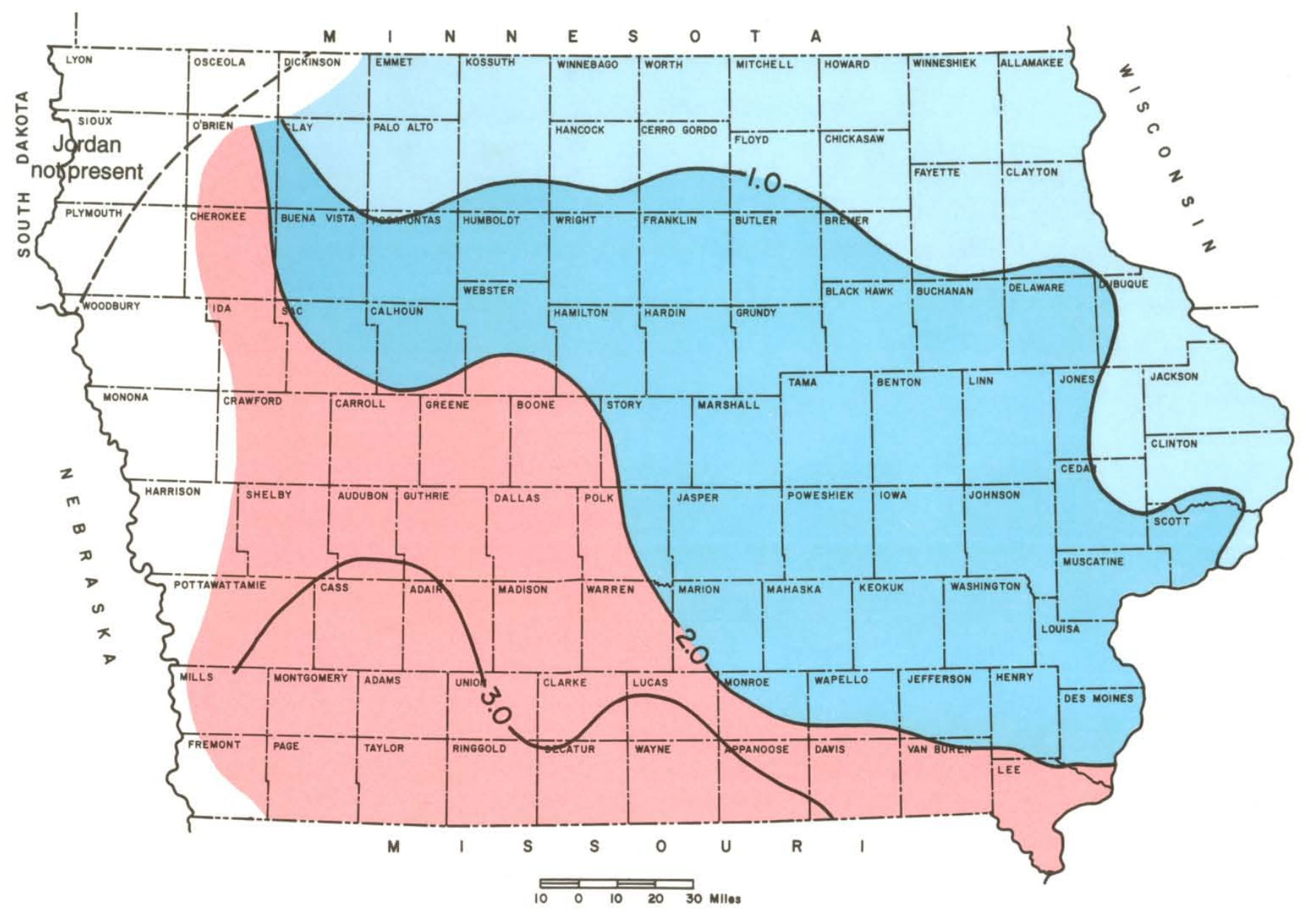
—500— Line of equal concentration of dissolved solids. Interval is 250 mg/L.

▭ Area where dissolved solids are less than the maximum level proposed for community water supplies.

▭ Area where water from the aquifer may be considered acceptable for most uses, except in those areas where the fluoride concentration exceeds 2 mg/L and (or) the sulfate concentration exceeds 600 mg/L.

▭ Area where water is of objectionable quality for most uses.

ALTHOUGH THE CONCENTRATION OF DISSOLVED SOLIDS MEETS THE SECONDARY DRINKING WATER REGULATIONS IN ONLY THE NORTHEASTERN PART OF THE STATE, WATER FROM THE AQUIFER IS CONSIDERED ACCEPTABLE FOR MOST USES OVER A MUCH BROADER AREA IN SOUTHEASTERN, CENTRAL, AND NORTH-CENTRAL IOWA. If large quantities of water are needed it generally is necessary to drill to the Jordan aquifer, especially in central and southeastern Iowa because only low yields and (or) highly mineralized waters are available from the upper or intermediate aquifers. Only locally in these areas is better quality water available from the upper or intermediate aquifers.



EXPLANATION

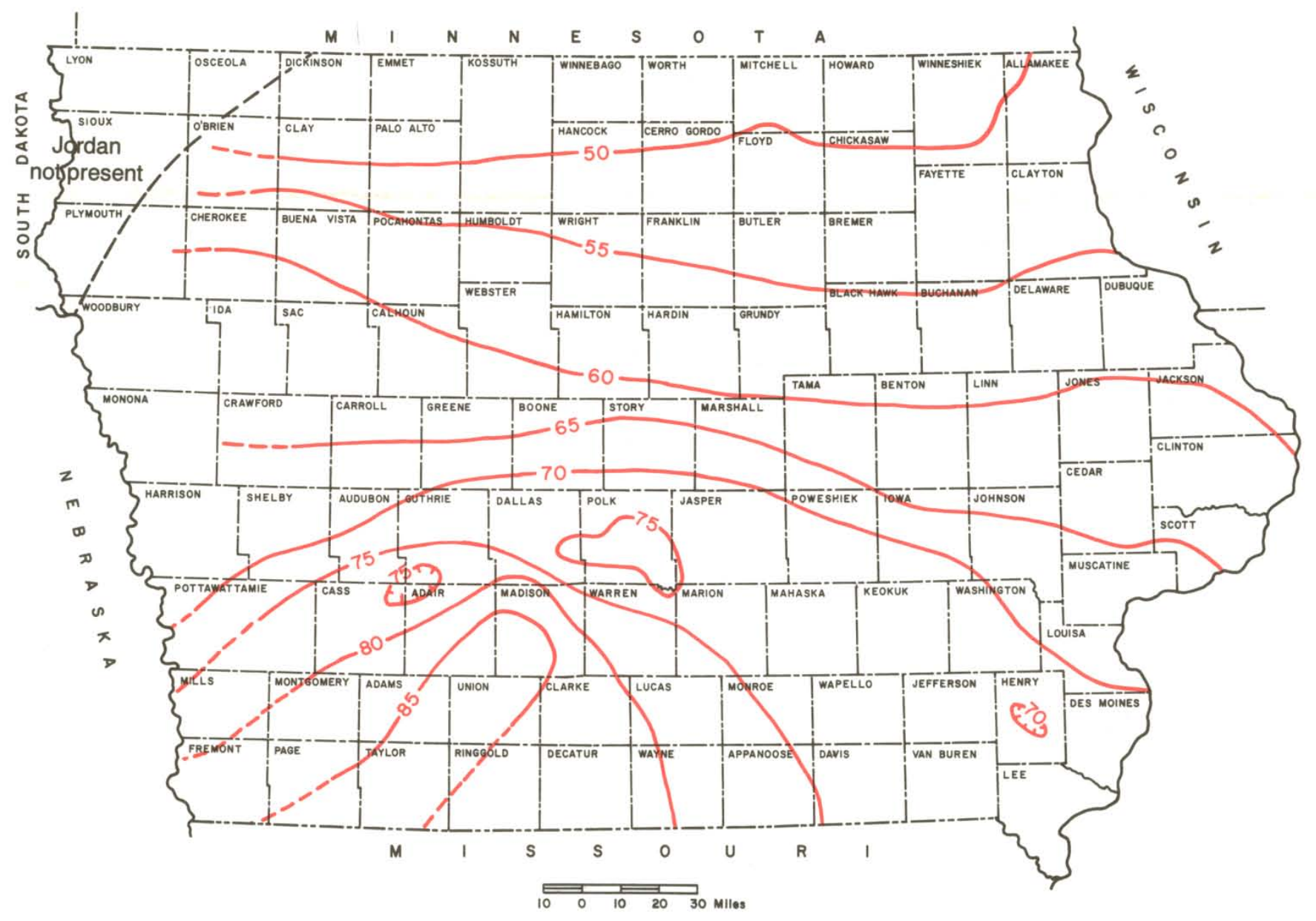
—2.0— Line of equal fluoride concentration. Interval is 1.0 mg/L.

▭ Area where fluoridation of water may be considered in order to increase fluoride concentration to more desirable levels.

▭ Area where fluoride concentration is less than the maximum level established for community water supplies.

▭ Area where fluoride concentration is greater than the maximum level.

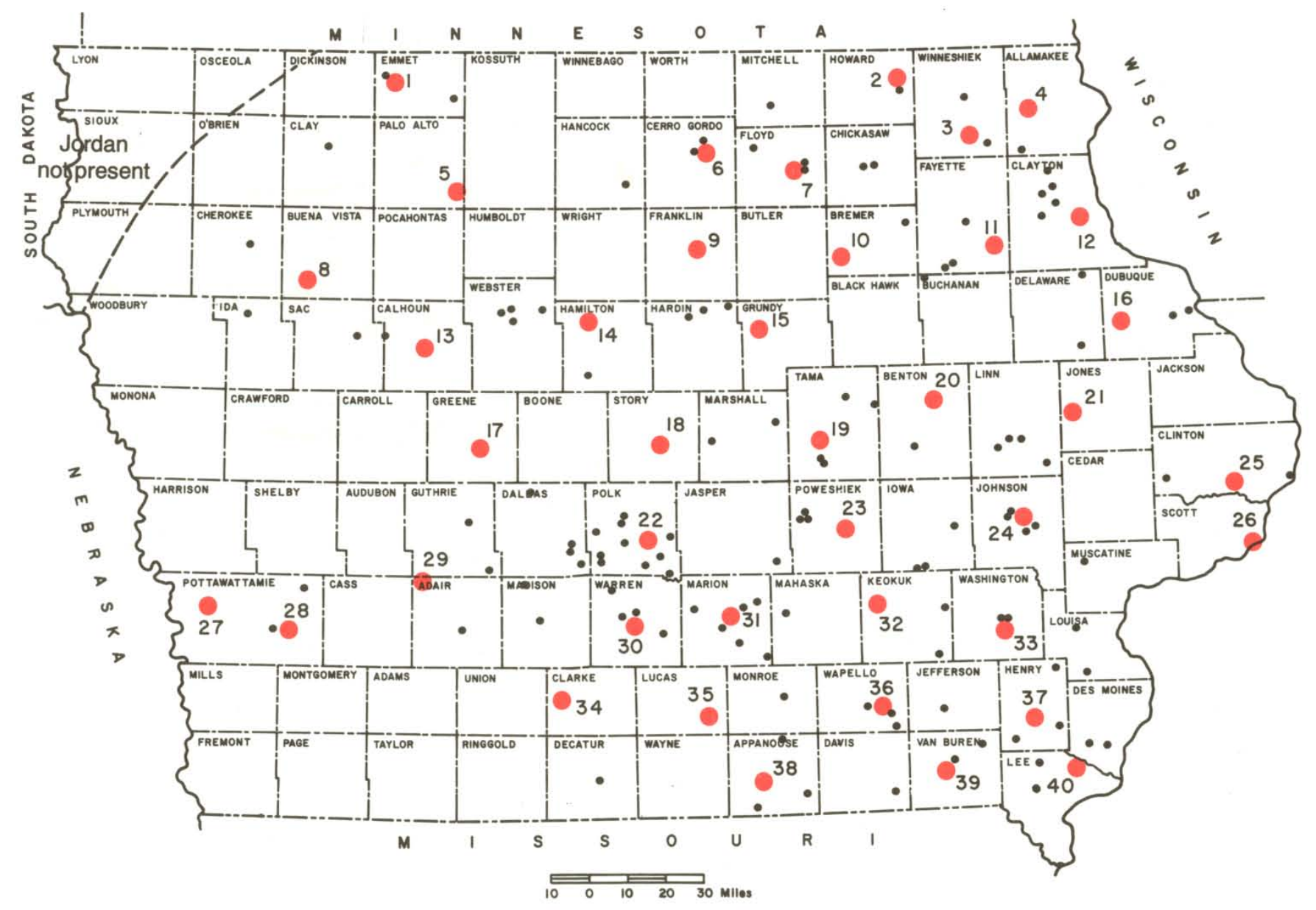
THE FLUORIDE CONCENTRATION IN WATER FROM THE JORDAN AQUIFER IS ACCEPTABLE FOR COMMUNITY WATER SUPPLIES IN A LARGE AREA OF THE STATE. Excess concentrations occur in much of the southern and western parts of the State.



EXPLANATION

—50— Line of equal temperature. Interval is 5°F.

The temperature of the water obtained from the Jordan aquifer in Iowa depends on the location of the wells and the depth of the aquifer, and ranges from about 50°F across the northern part of the State to about 85°F in the southwestern part.

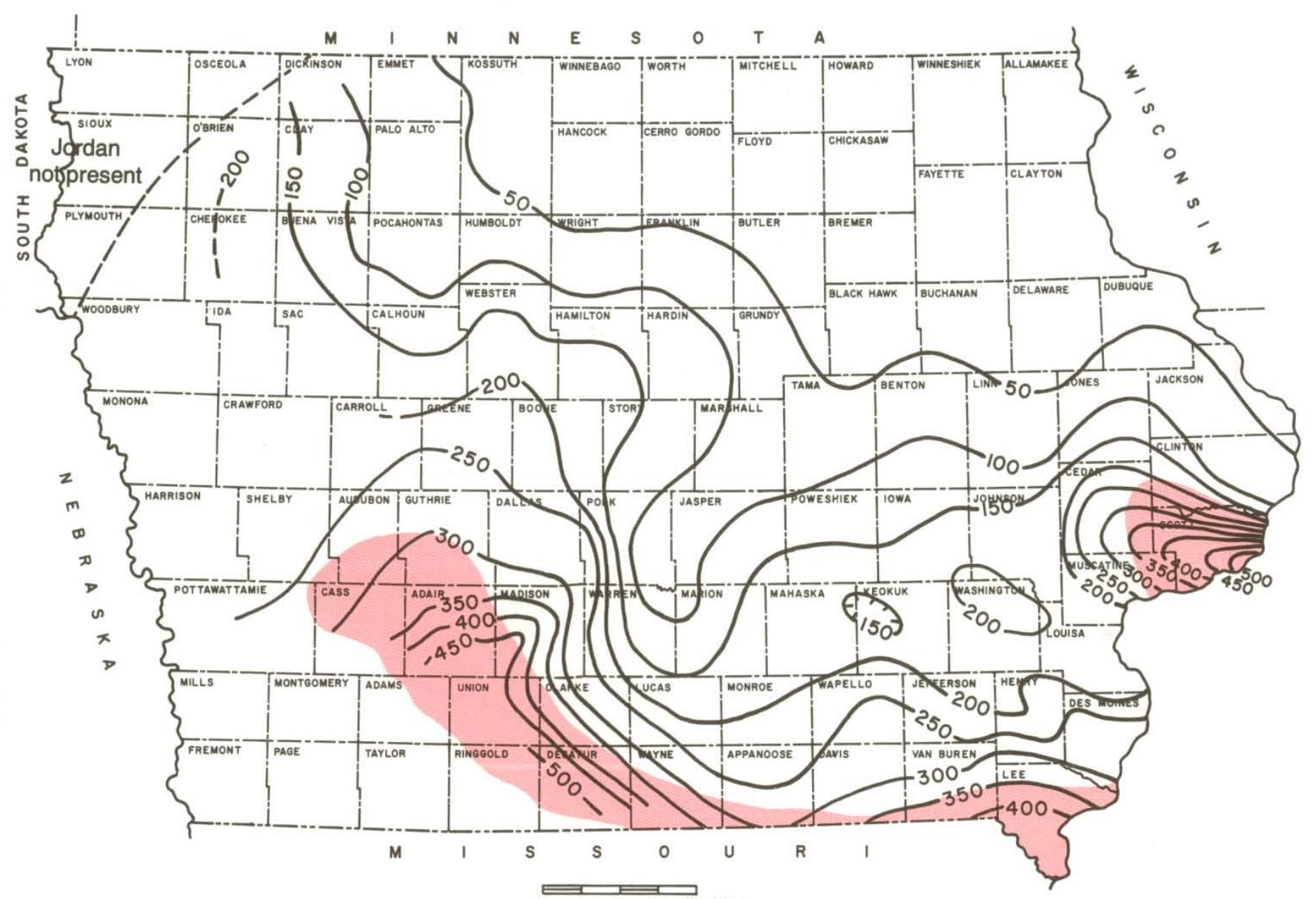


EXPLANATION

● 2 Location of water-quality sampling site. Analyses shown in adjacent table. Number refers to well number in table.

• Location of additional sampling sites. Analyses are on file at Iowa Geological Survey.

The chemical-quality data, other than radium, presented on this sheet are based on about 250 analyses of water from 185 wells that tap the Jordan aquifer. The radium-226 data are based on about 240 analyses of water from 72 municipal wells that tap the aquifer. Some of the wells are open to other water-bearing units, but the Jordan Sandstone is considered the principal water-yielding unit. Hence, if these wells are pumped several hours or longer, the water sample is considered to be representative of the Jordan aquifer. Nevertheless, the emphasis in drawing the chemical characteristic maps was placed on those analyses of water from wells that are cased from the surface into the upper part of the Prairie du Chien Formation.

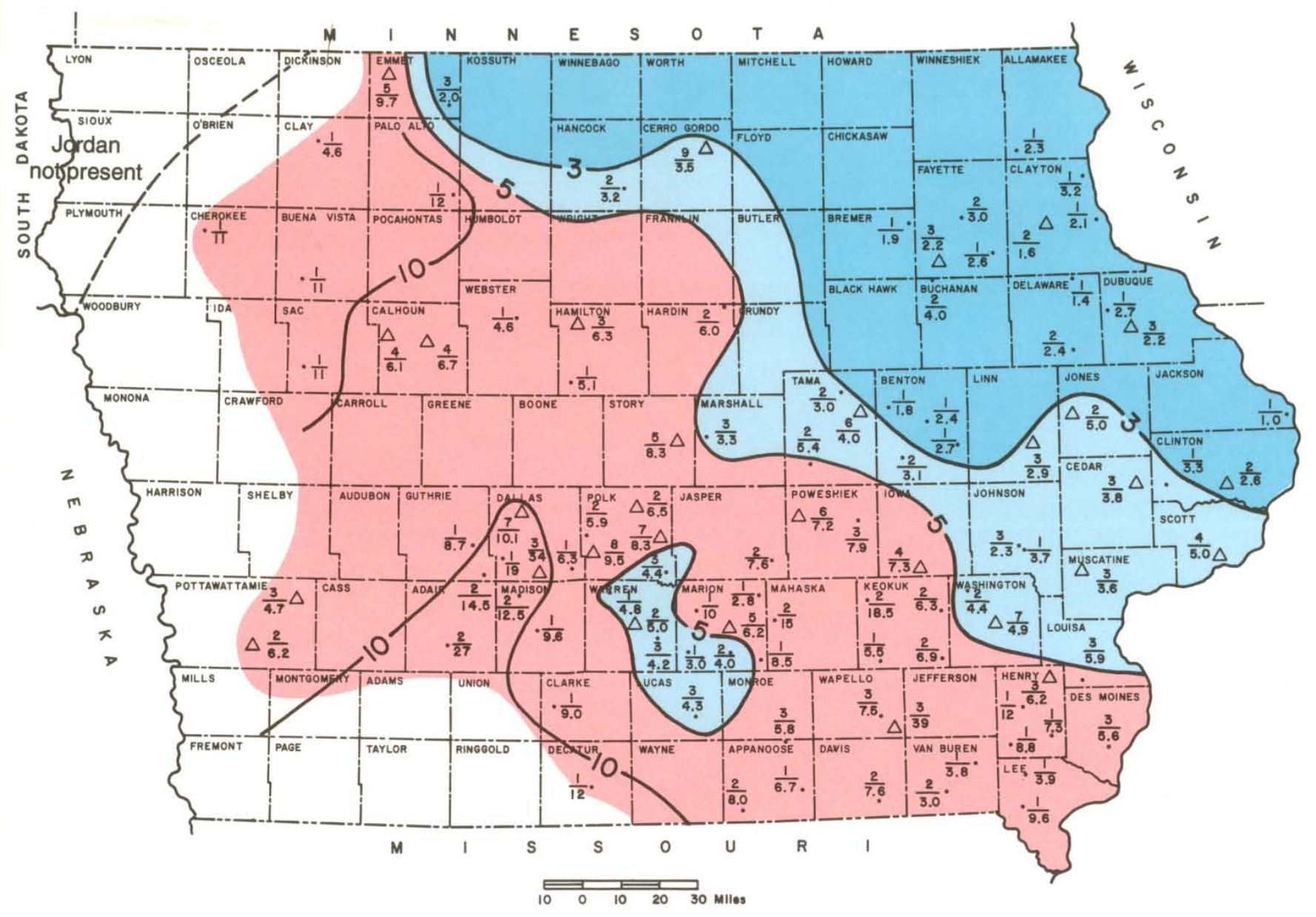


EXPLANATION

—50— Line of equal concentration of sodium. Interval is 50 mg/L.

▭ Area where the chloride concentration in supplies from the Jordan aquifer exceeds 250 mg/L. High sodium concentrations in this area may impart a noticeably salty taste to the water.

PEOPLE ON A SODIUM-RESTRICTIVE DIET SHOULD BE AWARE THAT WATER FROM THE JORDAN AQUIFER IN A LARGE PART OF THE STATE CONTAINS MODERATELY HIGH TO HIGH CONCENTRATIONS OF SODIUM. The Environmental Protection Agency had considered establishing a maximum contaminant level for sodium, but concluded that "existing data did not support the establishment of a Maximum Contaminant Level for sodium in Interim Primary Drinking-Water Regulations. It is recommended that the States institute programs for regular monitoring of the sodium content of drinking water served to the public, and for informing physicians and consumers of the sodium concentrations in drinking water. By this means, those affected by high sodium concentrations can make adjustments to their diets, or seek alternative sources of water to be used for drinking and food preparation" (U.S. Environmental Protection Agency, March 31, 1977).



EXPLANATION

• $\frac{2}{2.7}$ Location of a single well tapping Jordan aquifer, for which Ra-226 analysis is available. Upper number refers to number of analyses; lower number is mean concentration of Ra-226 in pCi/L.

△ $\frac{3}{6.3}$ Location of 2 or more wells tapping the Jordan aquifer, for which Ra-226 analyses are available. Upper number refers to number of analyses available; lower number is the mean concentration of Ra-226 in pCi/L.

▭ Area where the concentration of Ra-226 generally is less than 3 pCi/L.

▭ Area where the concentration of Ra-226 generally is greater than 3 pCi/L but less than 5 pCi/L.

▭ Area where the concentration of Ra-226 generally is greater than 5 pCi/L and in many localities is greater than 10 pCi/L. Concentrations of between 3 and 5 pCi/L occur at a few localities.

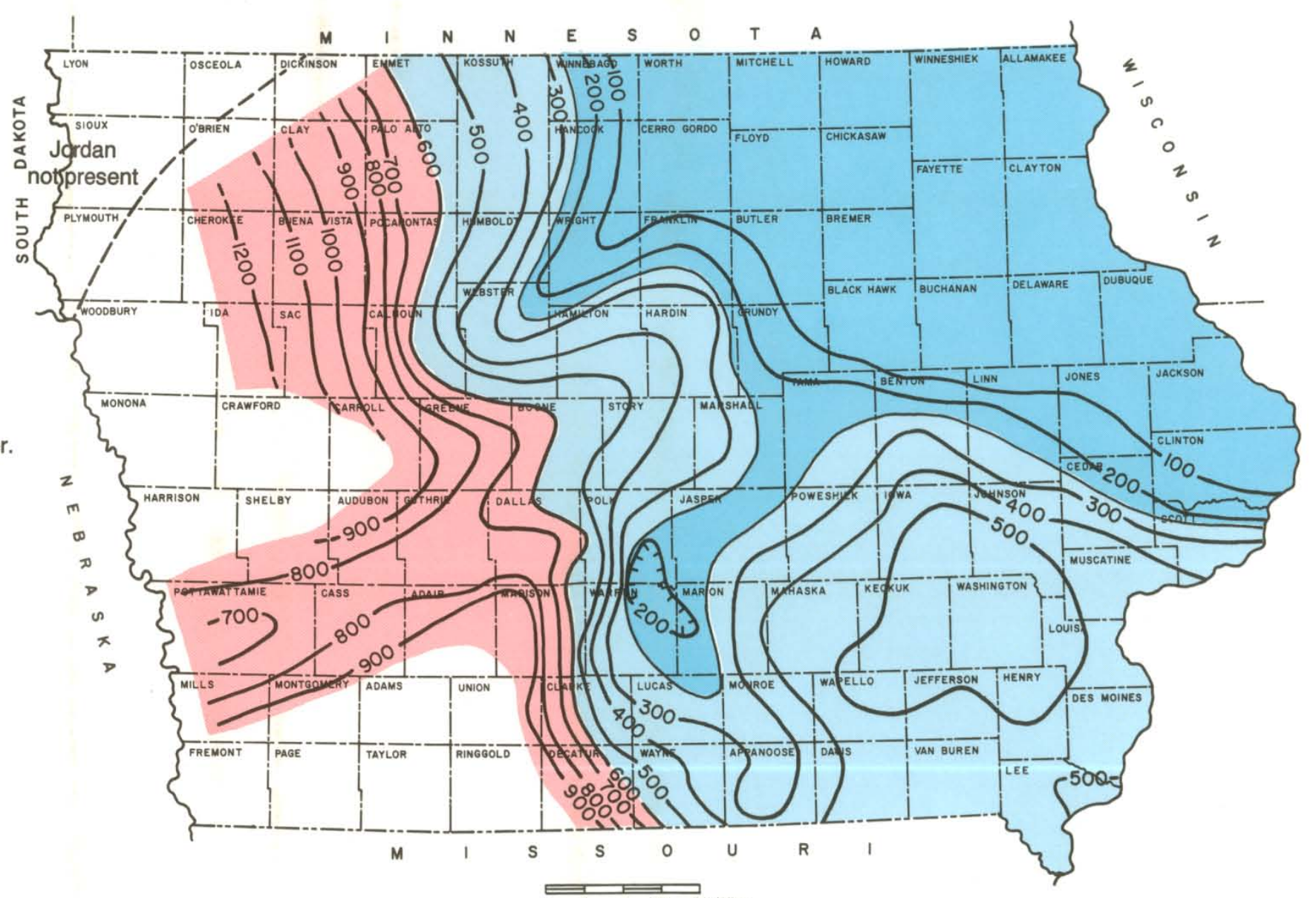
OBJECTIONABLE CONCENTRATIONS OF RADIUM OCCUR IN WATER FROM THE JORDAN AQUIFER IN A WIDE AREA IN SOUTHEASTERN, CENTRAL, AND WESTERN IOWA AND POSE A POTENTIAL HEALTH PROBLEM. The map above reflects the *minimum* concentration of radium, because only radium-226 concentrations are shown. Although the State Hygienic Laboratory has determined the radium-228 concentrations in many "finished" public-water supplies, not enough analyses have been made on "raw" water samples to use for mapping purposes. The limited data on hand indicate that radium-228 concentrations range from less than 0.68 to about 5 pCi/L or more. Consequently, the total radium concentration in water from the Jordan will likely be somewhat higher than this map indicates. Fortunately, however, high radium concentrations can be brought to acceptable levels by softening treatment methods.

CHEMICAL ANALYSES OF WATER FROM SELECTED JORDAN WELLS

Dissolved constituents and hardness in milligrams per liter.

Analyses made by the Iowa State Hygienic Laboratory, The University of Iowa

Well Number	Well Name	Well Location	Year Drilled	Principal Source of Water	Date of Collection	Depth (feet)	Temperature (°F)	Dissolved solids	Iron	Manganese	Calcium	Magnesium	Potassium	Sodium	Carbonate	Bicarbonate	Sulfate	Chloride	Fluoride	Nitrate (as NO_3)	Hardness (as $CaCO_3$)			pH	Conductivity Micromhos at 25°C	Radium-226 (picocuries/liter)
																					Total	Carbonate	Noncarbonate			
1	Estherville No. 9	Emmet County SW sec. 11, T. 99N., R. 34W.	1965	St. Peter through Jordan	12-16-69	750	48	1270	1.7	.23	236	71	6.7	56	0	499	560	1.5	0.5	0.9	880	409	471	6.8	1600	6.9
2	Cresco	Howard County NW sec. 23,T.99N.,R. 11W.	1965	Prairie du Chien-Jordan	10-21-69	1145	48	271	.24	<.05	72	20	1.3	2.0	0	288	38	3.0	0.9	0.4	264	236	28	7.0	470	—
3	Ossian No. 2	Winneshiek County NE SE sec. 10, T. 96N., R. 8W.	1962	Prairie du Chien-Jordan	9-26-74	1017	50	266	.36	<.01	58	26	2.5	3.0	0	281	41	1.0	.25	<0.1	240	230	10	7.6	460	—
4	Waukon No. 4	Allamakee County SW NE sec. 30, T. 98N., R. 5W.	1957	Prairie du Chien-Jordan	3-10-60	662	52	304	.04	<.05	87	18	1.1	1.8	0	334	19	2.0	.05	0.8	292	274	18	7.4	530	—
5	West Bend	Palo Alto County SW NE sec. 13, T. 94N., R. 31W.	1959	Prairie du Chien-Jordan	6-4-62	1360	54	1306	2.3	<.05	206	65	22	94	0	434	593	18	1.0	<0.1	784	356	428	7.2	1670	—
6	Mason City No. 14	Cerro Gordo County NE NE sec. 15, T. 96N., R. 20W.	1957	Prairie du Chien-Jordan	5-11-70	1297	50	473	.24	<.05	104	34	5.8	16	0	420	83	17	0.8	0.2	400	344	56	7.1	780	2.2
7	Charles City No. 6	Floyd County NE NW sec. 12, T. 95N., R. 16W.	1955	Prairie du Chien-Jordan	6-10-55	1355	52	244	.9	0	53	23	4.0	5.5	—	243	17	2.0	1.0	0	227	227	0	8.3	429	—
8	Storm Lake	Buena Vista County NE NE sec. 5, T. 90N., R. 37W.	1959	Prairie du Chien-Jordan	7-17-75	1690	—	1970	1.7	.03	290	74	45	160	0	323	1100	30	1.6	1.3	1010	265	745	7.2	2300	11.0
9	Hampton No. 3	Franklin County SE NW sec. 34, T. 92N., R. 20W.	1952	Prairie du Chien-Jordan	8-30-68	1763	52	612	.83	<.05	96	32	21	68	0	386	200	11	1.1	0.5	372	316	56	7.0	960	—
10	Waverly No. 2	Bremer County NE NW sec. 2, T. 91N., R. 14W.	1930	Prairie du Chien-Jordan	10-1-73	1263	—	407	2.4	<.01	65	33	10	30	0	356	68	2	1.4	<0.1	282	282	0	7.1	650	—
11	Arlington No. 2	Fayette County NW SW sec. 27, T. 92N., R. 7W.	1955	Prairie du Chien-Jordan	9-19-66	1312	—	285	.28	<.05	54	25	6.8	11	0	275	55	1.5	.55	0.1	240	225	15	7.6	510	—
12	Garnavillo No. 2	Clayton County NW NW sec. 19, T. 93N., R. 3W.	1956	Prairie du Chien-Jordan	12-1-70	815	52	290	.48	<.05	70	25	1.0	3.4	0	332	27	1.0	0.2	0.4	280	272	8	7.2	520	2.1
13	Rockwell City No. 4	Calhoun County SE NE sec. 36, T. 88N., R. 33W.	1970	Prairie du Chien-Jordan	2-7-72	1970	63	1190	1.3	.03	170	60	30	100	0	375	570	10	1.3	0.4	671	307	364	6.8	1600	11.0
14	Webster City No. 5	Hamilton County SE SE sec. 32, T. 89N., R. 25W.	1954	St. Peter through St. Lawrence	3-31-71	2005	59	960	.68	<.05	116	41	20	130	0	356	370	65	1.2	1.1	460	292	168	6.9	1400	—
15	Wellsburg No. 1	Grundy County SW NW sec. 14, T. 88N., R. 18W.	1959	Prairie du Chien-Jordan	8-6-75	2050	—	601	1.0	.01	81	38	22	71	0	382	200	13	1.3	0.4	344	313	31	7.4	950	6.2
16	Farley No. 3	Dubuque County NW SE sec. 7, T. 88N., R. 1W.	1972	Prairie du Chien-Jordan	1-10-77	1330	57	418	.58	.01	50	26	12	69	0	310	85	23	1.0	<0.1	233	233	0	7.6	690	2.3
17	Jefferson	Greene County NW SW sec. 8, T. 83N., R. 30W.	1951	Prairie du Chien-Jordan	8-3-51	2307	—	1650	0.3	0	157	63	269		0	259	838	107	2.8	0	651	212	439	7.5	2020	—
18	Nevada No. 2	Story County SW SE sec. 6, T. 83N., R. 22W.	1928	Prairie du Chien-Jordan	12-14-60	2791	68	954	3.0	<.05	102	58	19	144	0	364	475	39	1.8	<0.1	496	298	198	7.5	1470	6.8
19	Toledo	Tama County SE SW sec. 15, T. 83N., R. 15W.	1961	Prairie du Chien-Jordan	2-3-72	2016	—	704	2.2	.02	96	45	19	79	0	378	260	8	1.1	<0.1	420	310	110	6.9	1000	5.2
20	Vinton No. 2	Benton County SE SW sec. 16, T. 85N., R. 10W.	1932	Prairie du Chien-Jordan	5-6-68	1505	—	568	.80	<.05	74	38	15	70	0	364	180	7	1.1	0.2	340	298	42	7.2	880	2.4
21	Anamosa	Jones County NE NW sec. 2, T. 84N., R. 4W.	1970	Prairie du Chien-Jordan	4-21-71	1640	63	575	.32	.05	70	28	15	80	0	339	160	11	1.2	0.5	292	278	14	7.0	830	4.6
22	Altoona No. 2	Polk County NE SE sec. 13, T. 79N., R. 23W.	1968	Prairie du Chien-Jordan	10-25-71	2505	—	594	5.6	.07	70	29	15	82	0	305	220	20	1.7	<0.1	296	250	46	7.5	910	6.4
23	Brooklyn No. 5	Poweshiek County NW SW sec. 23, T. 80N., R. 14W.	1961	Prairie du Chien-Jordan	8-14-72	2040	70	899	3.2	.03	97	48	19	110	0	364	380	20	1.2	0.2	450	298	152	7.1	1300	4.8
24	Coralville	Johnson County SW SW sec. 32, T. 80N., R. 6W.	1965	Prairie du Chien-Jordan	7-21-72	1677	—	1170	.96	.02	100	50	19	170	0	293	570	42	1.4	<0.1	460	240	220	7.2	1600	2.4
25	DeWitt No. 5	Clinton County SE SW sec. 18, T. 81N., R. 4E.	1948	Galena through St. Lawrence	10-12-70	1421	—	529	.10	<.05	54	20	13	100	0	320	92	85	1.0	1.4	220	220	0	7.1	910	1.9
26	LeClaire No. 3	Scott County NE NE sec. 3, T. 78N., R. 5E.	1966	Prairie du Chien-Jordan	12-3-68	1607	63	1790	.40	<.05	96	39	28	500	0	329	340	650	1.0	1.8	400	270	130	7.3	3100	—
27	D.O.T. I-80 Reststop	Pottawattamie County NE NE sec. 10, T. 76N., R. 42W.	1969	Prairie du Chien-Jordan	11-19-69	2520	70	1610	2.0	.10	216	54	40	220	0	200	740	210	2.4	3.2	760	164	596	7.2	2200	—
28	American Beef Packers No. 2	Pottawattamie County NW NE sec. 1, T. 75N., R. 40W.	1971	Prairie du Chien-Jordan	10-7-71	2925	76	1680	.84	.02	196	61	38	240	0	203	740	220	3.0	3.9	742	166	576	7.3	2300	—
29	Adair	Adair County NW NE sec. 4, T. 77N., R. 33W.	1968	Prairie du Chien-Jordan	5-26-69	2700	72	1870	4.4	.06	184	58	51	330	0	207	770	320	3.1	0.5	700	170	530	7.3	2700	—
30	Indianola No. 10	Warren County NW NE sec. 30, T. 76N., R. 23W.	1965	Prairie du Chien-Jordan	9-16-74	2590	79	624	.39	<.01	56	25	16	130	0	317	230	32	1.9	<0.1	236	236	0	7.4	1000	4.7
31	Knoxville No. 2	Marion County SE NW sec. 31, T. 76N., R. 19W.	1968	Prairie du Chien-Jordan	9-24-75	2280	72	747	.59	<.01	67	31	15	130	0	322	250	56	1.5	0.5	296	264	32	7.7	1100	5.9
32	What Cheer	Keokuk County NW SW sec. 10, T. 76N., R. 13W.	1964	Prairie du Chien-Jordan	12-19-74	1925	—	974	2.5	<.01	100	53	21	140	0	339	450	33	1.5	1.0	440	278	162	7.4	1400	20
31	Washington No. 7	Washington County SE NW sec. 17, T. 75N., R. 7W.	1969	Prairie du Chien-Jordan	6-19-72	1825	—	1200	.27	.01	110	47	22	180	0	290	580	60	1.3	<0.1	480	238	242	7.2	1700	3.5
34	Murray	Clarke County SE SW sec. 10, T. 72N., R. 27W.	1968	Prairie du Chien-Jordan	10-1-69	3060	82	1680	4.5	<.05	140	41	27	340	0	257	760	220	2.4	0.5	520	211	309	7.3	2500	9.0
35	Russell	Lucas County NW NE sec. 6, T. 71N., R. 20W.	1956	Prairie du Chien-Jordan	7-14-75	2519	77	863	1.4	<.01	61	26	19	200	0	267	300	98	3.4	5.5	256	219	37	8.0	1400	5.7
36	Agency	Wapello County NW SE sec. 36, T. 72N., R. 13W.	1968	Prairie du Chien-Jordan	10-21-74	2108	—	1160	2.5	<.01	86	39	20	240	0	310	500	120	1.7	1.2	382	254	128	7.8	1700	9.0
37	Mt. Pleasant No. 4	Henry County NW NE sec. 9, T. 71N., R. 6W.	1946	Prairie du Chien-Jordan	5-4-67	1860	70	1120	.15	<.05	108	39	17	190	0	327	470	90	1.6	5.3	431	268	163	7.6	1700	—
38	Centerville	Appanoose County NE SE sec. 2, T. 68N., R. 18W.	1968	Prairie du Chien-Jordan	8-1-68	2372	79	942	.74	<.05	66	25	22	240	0	405	270	160	3.1	1.8	269	269	0	7.3	1600	—
39	Keosauqua	Van Buren County SE NW sec. 36, T. 69N., R. 10W.	1954	St. Peter through Jordan	12-17-73	1831	—	1240	1.8	<.01	69	32	16	320	0	320	430	240	2.4	3.0	296	262	34	7.6	2000	2.3
40	Denmark	Lee County NW SE sec. 29, T. 69N., R. 4W.	1971	Prairie du Chien-Jordan	4-30-73	1765	—	1330	43	<.01	74	33	18	320	0	298	500	220	2.8	0.8	308	244	64	7.6	2100	3.2



EXPLANATION

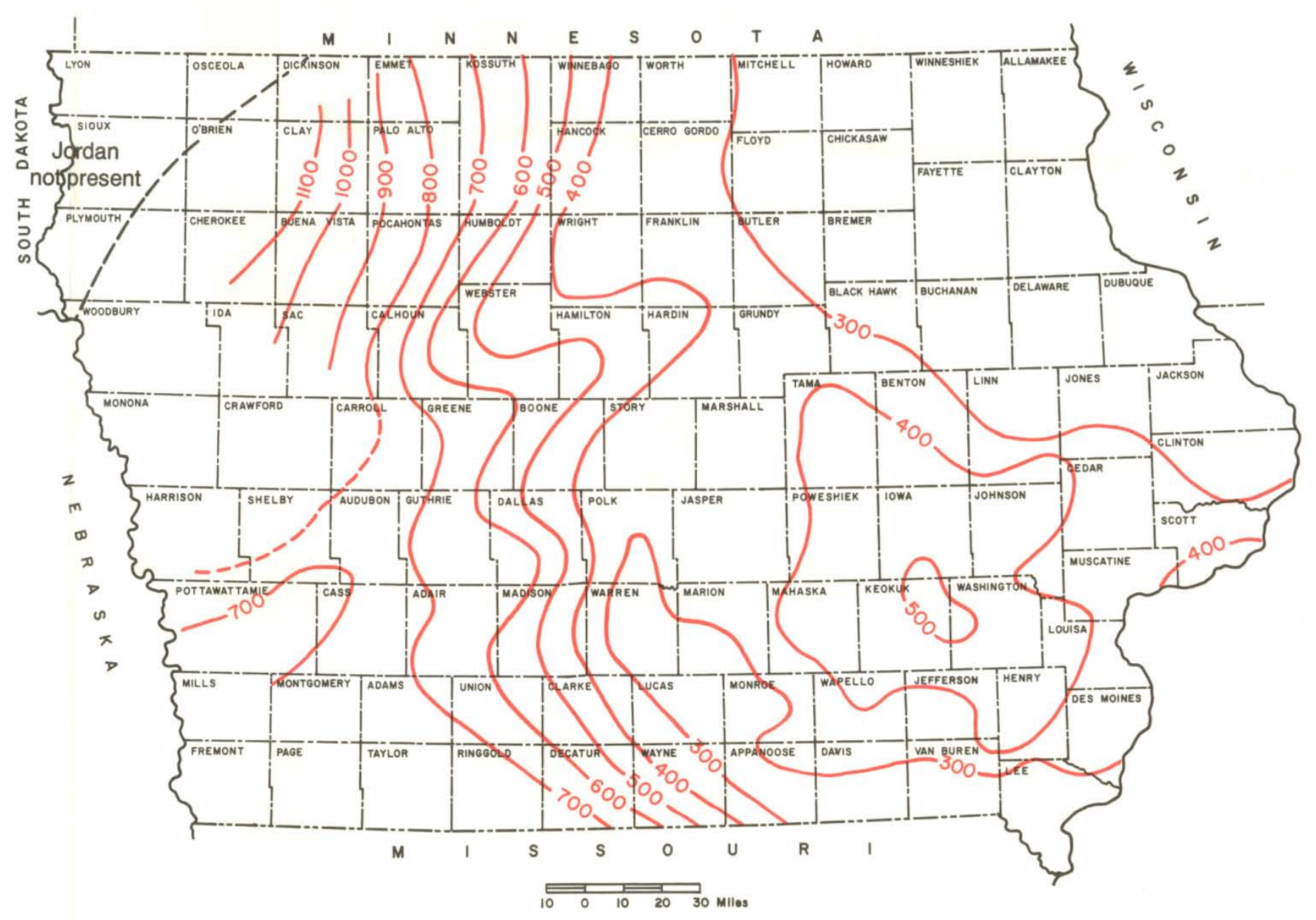
—200— Line of equal sulfate concentration. Interval is 100 mg/L.

▭ Area where the sulfate concentration is less than the maximum level proposed for community water supplies.

▭ Area where sulfate concentration is more than the maximum recommended level but may be considered acceptable because most users can adjust to it.

▭ Area where sulfate concentration is high enough to affect the taste of water and also to have a laxative effect.

THE SULFATE CONCENTRATION IS LESS THAN THE PROPOSED MAXIMUM LEVEL FOR COMMUNITY WATER SUPPLIES IN ONLY ABOUT 30 PERCENT OF THE STATE. However, because most users become acclimated to higher sulfate concentrations, the water is considered acceptable in an additional 30 percent of the State. Note that the distribution of sulfate in the aquifer closely parallels the dissolved-solids distribution; the major exception is in Scott County where chloride is the principal anion.



EXPLANATION

—300— Line of equal hardness. Interval is 100 mg/L.

WATER FROM THE JORDAN AQUIFER RANGES FROM LESS THAN 300 TO MORE THAN 1000 MG/L HARDNESS. THE LOWEST CONCENTRATIONS ARE FOUND IN THE EASTERN HALF OF THE STATE AND THE HIGHEST IN THE WESTERN HALF. The hardness of the water can be reduced by softening methods. However, it should be noted that the sodium content will increase perceptibly when an ion exchange method of softening is used.

WATER TREATMENT

ONLY A FEW OF THE JORDAN SUPPLIES ARE NOT TREATED IN SOME WAY. The majority of the Jordan aquifer well water supplies used for municipal purposes contain excess iron and require treatment for iron removal. A typical treatment system consists of aeration, filtration, and disinfection, in that order. The aerators generally are forced draft, pressure, overflow trays or other splash units. Filtration is through sand by pressure or rapid gravity flow. Chlorine gas or hypochlorine solutions are the usual disinfecting agents. About 75 to 80 percent of all municipal wells that tap the Jordan aquifer are treated in this fashion.

A relatively small number of Jordan aquifer supplies are softened as a part of their treatment process. Most of the softened supplies are located in the southeast quarter of the State. The most common softening method is the zeolite or base exchange treatment. This method is preferred for community supplies where radioactivity concentrations exceed 5.0 pCi/L radium-226 and radium-228 combined or the gross alpha concentration is more than 15 pCi/L. A few large plants use the lime-soda ash softening process and one or two the reverse osmosis method.

Fluoridation is included in several treatment systems in the northern part of the State where the natural fluoride concentration of the Jordan aquifer water is less than 1.0 mg/L.

In about 25 percent of the Jordan aquifer municipal supplies polyphosphate or alkali chemicals are added to the water for stabilization, to adjust the pH, for corrosion control, and to hold iron in solution.

A few communities aerate the water to remove hydrogen sulfide odor.

SUMMARY OF QUALITY

THE CHEMICAL-QUALITY CHARACTERISTICS OF WATER IN THE JORDAN AQUIFER ARE A FUNCTION OF THE MINERAL COMPOSITION OF THE ROCKS THROUGH WHICH THE WATER PERCOLATES IN THE INTAKE AREA AND WHERE IN THE FLOW SYSTEM THE WATER OCCURS. The best quality water occurs in northeast Iowa, where the concentration of dissolved solids is less than 500 mg/L. The water is a calcium-magnesium-bicarbonate type that is typical of flush-through systems in predominantly carbonate terrains. The aquifer is recharged in northeastern Iowa and southeastern Minnesota by vertical leakage through drift and carbonate rocks. From there, the water moves toward and discharges into the Mississippi River north of the Jackson-Clinton County line (approximately where the Ordovician Maquoketa Shale crops out in the river channel). The chemical composition of the water remains essentially the same from recharge to discharge areas, indicating the system has been thoroughly flushed.

The mineralization of the water increases markedly southwest of a line running from Hancock to Clinton Counties. Water that is classed as good-to-fair quality and containing dissolved-solids concentrations of 500 to 1500 mg/L is found in a broad belt through the central and southeastern parts of the State. From east to west in the northern half of this area, the water changes from a calcium-magnesium bicarbonate type to a calcium-magnesium sulfate-bicarbonate type. In the southern half of the area — the down-gradient direction — the sodium and chloride concentrations increase perceptibly until near the southern and southeastern borders of the State the water is a sodium-calcium-magnesium sulfate-chloride-bicarbonate type. This central part of the flow system is being flushed more slowly than in northeastern Iowa as the water discharges by underflow toward the Illinois Basin via northern Missouri and western Illinois.

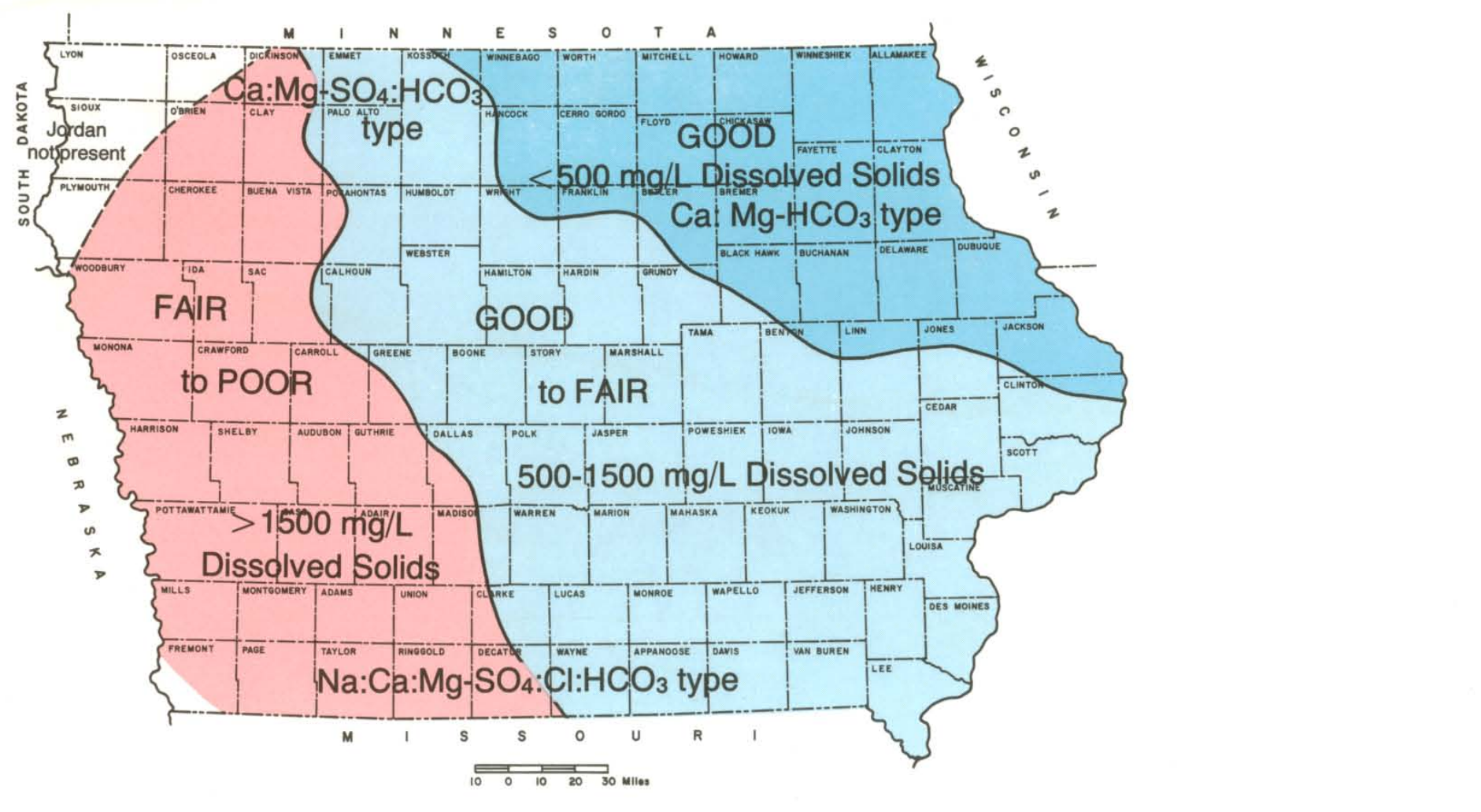
West and southwest of this central belt, the water generally is so highly mineralized as to be a poor to objectionable source for most uses. The water is a calcium-magnesium sulfate-bicarbonate type in the northern part of this area and gradually changes to a calcium-magnesium-sodium sulfate-chloride-bicarbonate type in the southern part. In this western part of the flow system where the transmissivity of the aquifer is lowest, the aquifer is flushed very slowly as the water discharges by underflow into northern Missouri.

The increasing sulfate concentrations from east to west in the western and central belt are attributed to recharge to the aquifer by vertical leakage through the Cretaceous shales and sandstones that locally contain water with high sulfate concentrations in northwestern Iowa and south-central Minnesota.

The radium concentration also has an important bearing on the general acceptance of Jordan aquifer water supplies. The data seem to indicate a correlation between the concentration of radioactive isotopes in the Jordan aquifer and the extent to which the aquifer has been flushed. Low radium values occur in northeast Iowa and higher values in central and western Iowa.

The map below illustrates the general quality of the water in the Jordan aquifer.

FUTURE CHEMICAL-QUALITY CHANGES CAN BE EXPECTED IN THE CENTRAL PART OF THE STATE. Poor-quality water from the western part of the flow system is being diverted toward the major pumping centers as evidenced by the potentiometric map. Because the flow velocities are extremely slow, the change will be gradual. Significant chemical quality changes are not expected in the northeastern part of the State, although the Allamakee-Clayton-Winneshiek County area is susceptible to nitrate and bacterial pollution from surface-water infiltration.



JORDAN AQUIFER OF IOWA

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