Iowa Geological Survey Water Atlas No. 7

WATER RESOURCES OF NORTH - CENTRAL IOWA

Iowa Geological Survey Water Atlas Number 7

Water Resources of North-Central Iowa

by
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This atlas presents information on the occurrence, availability, quality, and utilization of water in north-central Iowa.

Prepared by the U.S. Geological Survey
in cooperation with the Iowa Geological Survey

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FOREWORD

Water is one of mankind's fundamental needs. If we are to exist at our present cultural and industrial level we must have an adequate and safe water supply. In addition, this natural resource needs to be used wisely and managed to the optimum benefit of all consumers. Managing water resources for rational development and environmental protection requires a thorough understanding of the physical and chemical characteristics of the area and the earth materials supplying the water.

This water atlas presents a summary of the hydrology and geology of north-central Iowa. The information should provide the necessary tools for the long-range planner, developer and individual water-user to optimize the use of these resources. Planners and developers are provided with the information needed to locate acceptable water supplies and to make fundamental decisions about activities which affect water quality and quantity. Individual water-users are provided with the information they need to evaluate the water-yielding potential of their property.

Information presently available through the U.S. Geological Survey and the Iowa Geological Survey is presented in this report. These two agencies, however, have a continuing data-collection program and new data accumulate daily. Persons requiring water-resource and geologic data can use this report for a thorough, concise summary of information available as of the publication date. If more or later information is needed, inquiry directed to the Surveys is welcome.

Donald L. Koch
State Geologist and Director
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Iowa City, Iowa
June, 1985

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COVER PHOTO:
View to the northwest of the Rice Lake area near Lake Mills, Winnebago Co., Iowa. The landscape of rounded knobs and basins shown in the photo was constructed by Pleistocene-age glaciers.

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GLOSSARY

Abbreviations

ft^3/s - cubic feet per second; 1 ft^3/s equals 449 gallons per minute or about 0.65 million gallons per day.

$(ft^3/s)/mi^2$ - cubic feet per second per square mile.

gal/min - gallons per minute.

Mgal/d - million gallons per day.

Mgal/y - million gallons per year.

mg/L - milligram per liter; equals approximately 1 part per million.

Micromhos - micromhos per centimeter at 25° Celsius.

Alluvium - Clay, sand, gravel, boulders, and other matter deposited by streams.

Aquifer - Rocks and sediments that contain and transmit water in sufficient quantity to be considered a source for water supplies.

Artesian water - Groundwater that is under sufficient pressure to rise above the top of the formation in which it is penetrated by a well; does not necessarily rise to or above the land surface.

Average discharge - The arithmetic average of the streamflow or discharge of all the complete water years of record, whether consecutive or not. It represents the long-term total quantity of water that a stream produces per unit of time.

Basement complex - A complex of igneous and metamorphic rocks that lie beneath the sedimentary rocks in Iowa.

Climatic year - In U.S. Geological Survey reports describing surface-water supply, the 12 months beginning April 1 and ending the following March 31. The climatic year is designated by the calendar year in which it begins. It is used especially for low-flow studies.

Confining bed - Rocks or sediments that will not transmit water fast enough to provide an appreciable supply for a well or spring.

Contour - A line used to connect points of equal altitude, whether they be points on the land surface, on the bedrock surface, on the surface of a particular rock layer, on the water table, or on a potentiometric surface.

Contour interval - The difference in values between two adjacent contours.

Conversion factors - For those readers who may prefer to use metric units rather than English units; the conversion factors for the terms used in this report are listed at the top of the next column:

Multiply English unit	By	To obtain metric unit
inches	2.54×10	millimeters
feet	3.048×10^{-1}	meters
mile	1.609	kilometers
acre	4.047×10^{-3}	square kilometers
acre-feet	1.233×10^{3}	cubic meters
square mile	2.590	square kilometers
cubic feet per second	2.832×10^{-2}	cubic meters per second
gallon	3.785	liters
gallon	3.785×10^{-3}	cubic meters
gallons per minute	6.309×10^{-2}	liters per second
gallons per day	3.785×10^{-3}	cubic meters per day
million gallons per day	3.785×10^{3}	cubic meters per day
tons per square mile	3.503×10^{-1}	metric tons per square kilometer

Discharge - The volume of water (more broadly, total fluids), that passes a given point within a given time. Groundwater discharge is the volume of fluids leaving the zone of saturation.

Dissolved solids - The total concentration of dissolved material, ordinarily determined from the weight of the dry residue remaining after evaporation at 105° Celsius of the volatile portion of an aliquot of the water sample.

Drawdown - The lowering of the water table or potentiometric surface due to the pumping of a well.

Evapotranspiration - A term referring to water returned as vapor to the air through direct evaporation from water surfaces or moist soil and by transpiration from vegetation; no attempt is made to distinguish between the two.

Gaging station - A particular site on a stream where a continuous record of discharge is obtained.

Glacial drift - A mixture of rocks, such as boulders, gravel, sand, or clay, transported by glaciers and deposited by or from the ice, or deposited by or in water from the melting of the ice.

Glacial till - Nonsorted, nonstratified sediments, carried or deposited by a glacier, which are composed of material of all size fractions, from clays to boulders.

Hydraulic-head potential - The energy to move a fluid resulting from the difference in altitude of the fluid between two points. Usually expressed in feet.

Hydrostatic head - The height of a vertical column of water, the weight of which, if of unit cross section, is equal to the hydrostatic pressure at a point.

Hydrostatic pressure - The pressure exerted by the water at any given point in a body of water at rest. Hydrostatic pressure of groundwater generally is due to the weight of water at higher levels in the zone of saturation.

Igneous rocks - Rocks formed by solidification of hot molten rock matter or magma.

Infiltration - The movement of water through the soil surface into the ground.

Karstification - The enlargement of openings in carbonate rocks by solution and mechanical activity of water. The process by which caverns are formed and an important source of secondary permeability in the carbonate aquifers.

Karst topography - Landforms that have been formed by the solution and collapse of underlying carbonate rocks.

Kettle - A depression in glacial drift, made by the melting of a detached mass of glacial ice that had been either wholly or partly buried in the drift.

Knob and kettle topography - An irregular belt of knolls and basins formed by the oscillatory recession of a glacier.

Mean discharge - The arithmetic average of a stream's discharge for a unit of time, such as a day, month, or year.

Metamorphic rocks - Rocks that have formed in the solid state by recrystallization and reactions between rock matter in response to pronounced changes of temperature, pressure, and chemical environment.

Natural storage - Water naturally detained in a drainage basin in the stream channels, lakes, reservoirs, natural depressions, and the groundwater reservoir.

Normal annual air temperature - The arithmetic average of air temperature values for 30 years ending in even 10-year multiples.

Normal annual precipitation - The arithmetic average of annual quantities of precipitation for 30 years ending in even 10-year multiples.

Partial-record station - A particular site where limited streamflow or water-quality data are collected systematically for a number of years for use in hydrologic analyses.

Percolation - Movement, by gravity, of water through the interstices of rock or soil.

Permeable rocks - Rocks having a texture that permits water to move through them perceptibly under the hydraulic-head difference ordinarily found in groundwater systems.

Potentiometric surface - The surface to which the water from an aquifer will rise in properly constructed wells.

Recharge - The processes by which water is added to the zone of saturation.

Runoff - That part of precipitation that appears in surface streams.

Sea level - Elevations referenced to the National Geodetic Vertical Datum (NGVD) of 1929, a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level."

Sedimentary rocks - Rocks formed by the consolidation of loose particles in a stratified fashion, layer upon layer.

Structural deformation - Warping and/or faulting of the Earth's crust by forces within the Earth.

Suspended sediment - Fragmental material such as clay, mud, silt, sand, and small rocks that is transported in suspension by moving water.

Terrace - Flat, horizontal or slightly inclined surfaces usually found along the edge of a stream valley or in isolated sections within the valley, which are at perceptibly higher altitudes than the flood-plain surface.

Water stage - Height of a water surface above any chosen datum plane, commonly above an established low-water plane.

Water table - The upper surface of the zone of saturation in an aquifer that is unconfined and open to direct recharge and atmospheric pressure.

Water year - In U.S. Geological Survey reports describing surface-water supply, the 12 months beginning October 1 and ending the following September 30. The water year is designated by the calendar year in which it ends.

Zone of saturation - The zone in which all pores in rocks and soils are saturated with water.

ACKNOWLEDGEMENTS

The cooperation and help given by city water superintendents and plant engineers in north-central Iowa is greatly appreciated. The information they supplied about water withdrawal and uses made sections of this report possible. Additional municipal and industrial water-use data were supplied by the Iowa Natural Resources Council and the Iowa Department of Environmental Quality (now merged into the Iowa Department of Water, Air and Waste Management).

Most of the chemical analyses used in this report were made by personnel of the University Hygienic Laboratory. Supplemental water analyses data were obtained from the U.S. Environmental Protection Agency's "STORET" computer file.

Much of the credit for this report must be given to the past and present personnel of the Iowa Geological Survey who, through the years, have analyzed many thousands of drill-cuttings samples and have accumulated and stored a large volume of geologic and groundwater data. Their work was the basis upon which the aquifers in this study were defined. In addition, the cooperation of the well drillers in north-central Iowa was appreciated. Their efforts in carefully collecting these drill cuttings and recording water data made this report possible.

INTRODUCTION

One of man's fundamental needs is water. Modern man needs both a safe and dependable supply of water to maintain his present economic, industrial, and cultural level. In order to use this natural resource in the most efficient and beneficial manner, a basic knowledge and understanding of water sources, and of the occurrence and potential of each source, needs to be gained. To provide this information, the U.S. Geological Survey, in cooperation with the Iowa Geological Survey, has compiled this atlas. It describes the water resources available for development in an 11-county area in north-central Iowa. The report contains information on the quantity, quality, and use of water from all known sources of water. This information is presented to aid water users and developers who are searching for and evaluating sources of water for specific sites. It also will be an aid to water planners and managers who must develop the available water resources on a regional basis.

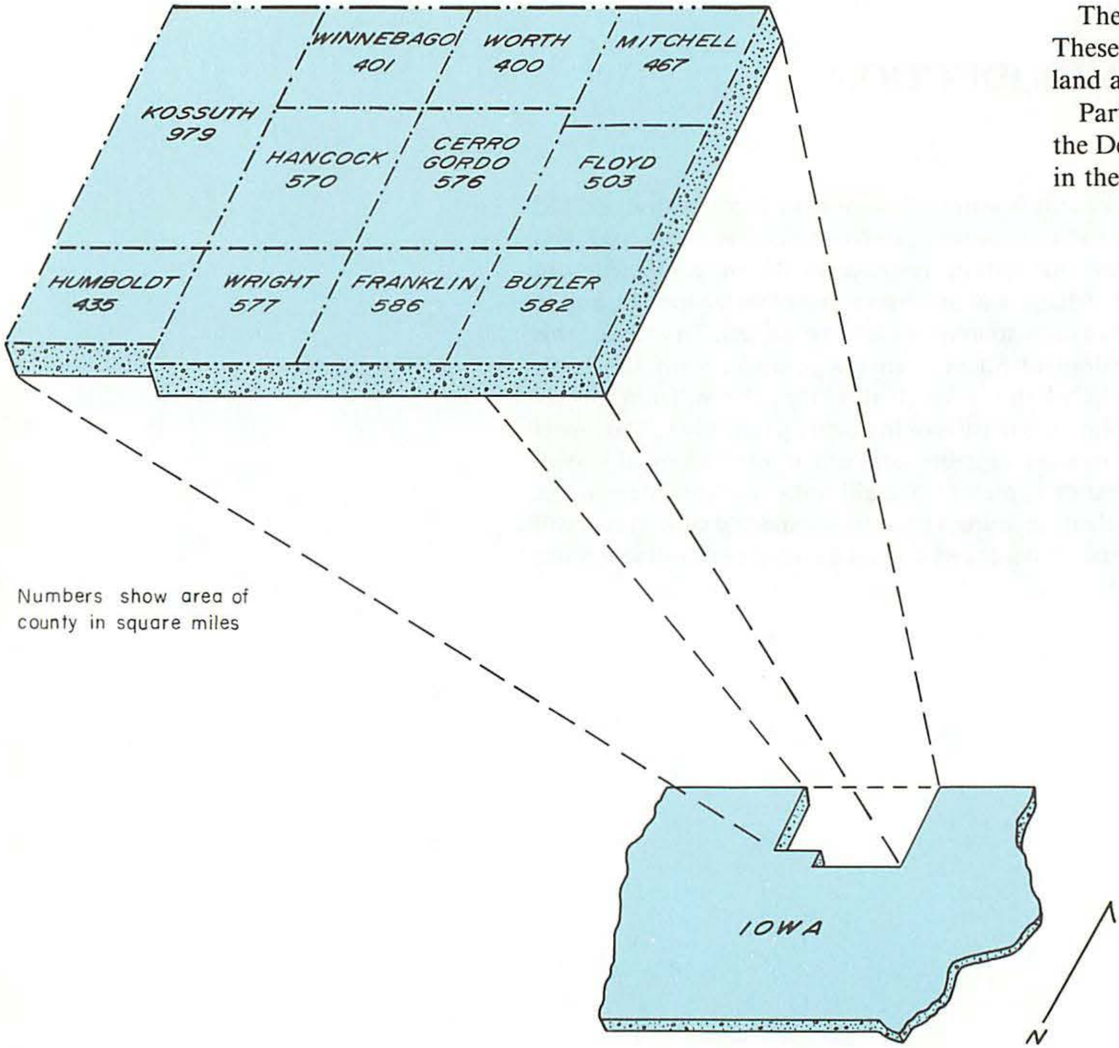


Figure 1. The 11 counties in north-central Iowa

NORTH-CENTRAL IOWA

The report area consists of 11 counties in the north-central section of the State. These 11 counties have an area of 6,076 square miles or about 11 percent of the land area of Iowa (figure 1).

Parts of five large drainage basins are located within the area: the Blue Earth, the Des Moines, the Iowa, the Cedar and the Wapsipinicon (figure 2). The rivers in these basins eventually flow into the Mississippi River.

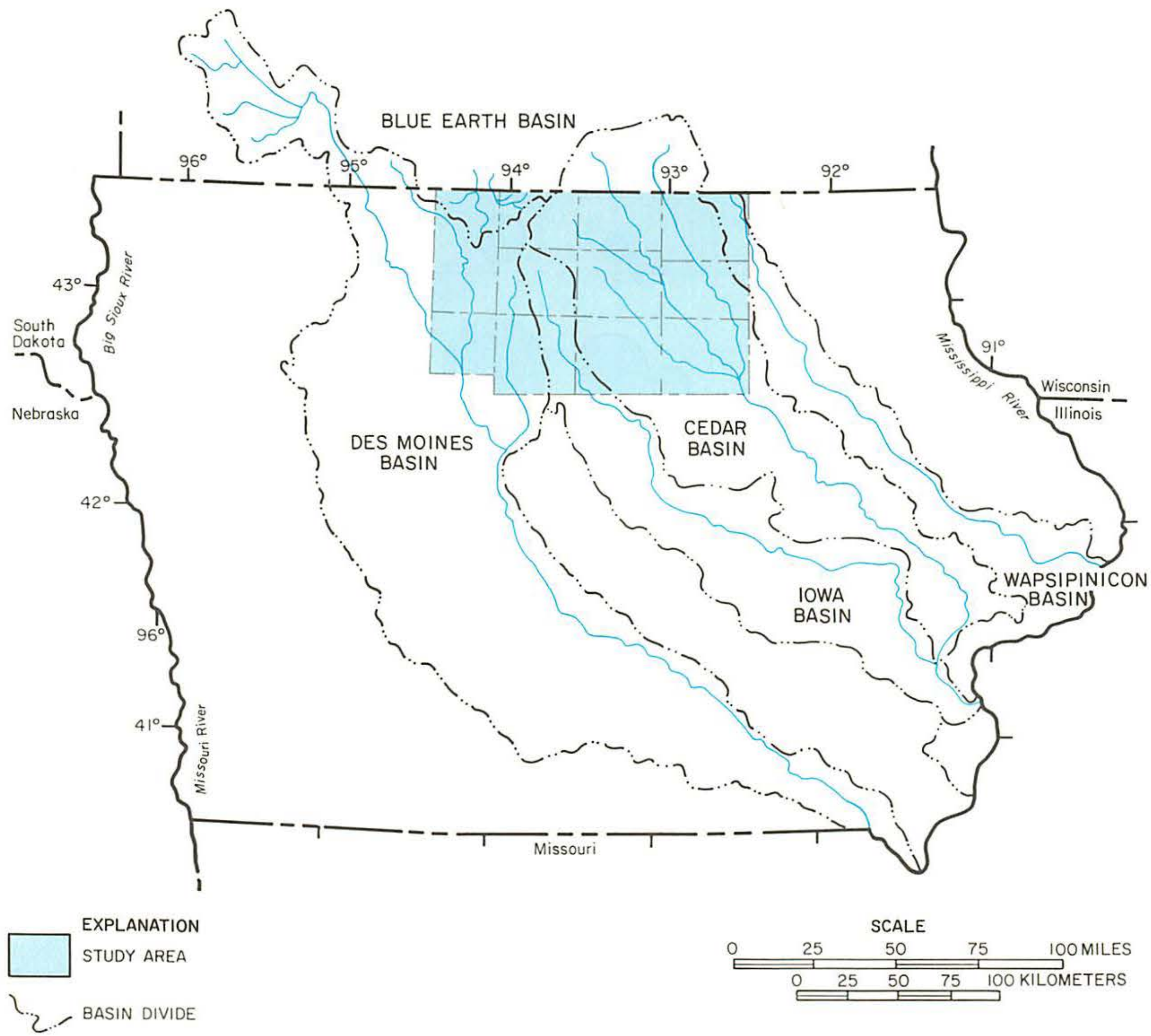


Figure 2. Drainage basins in north-central Iowa

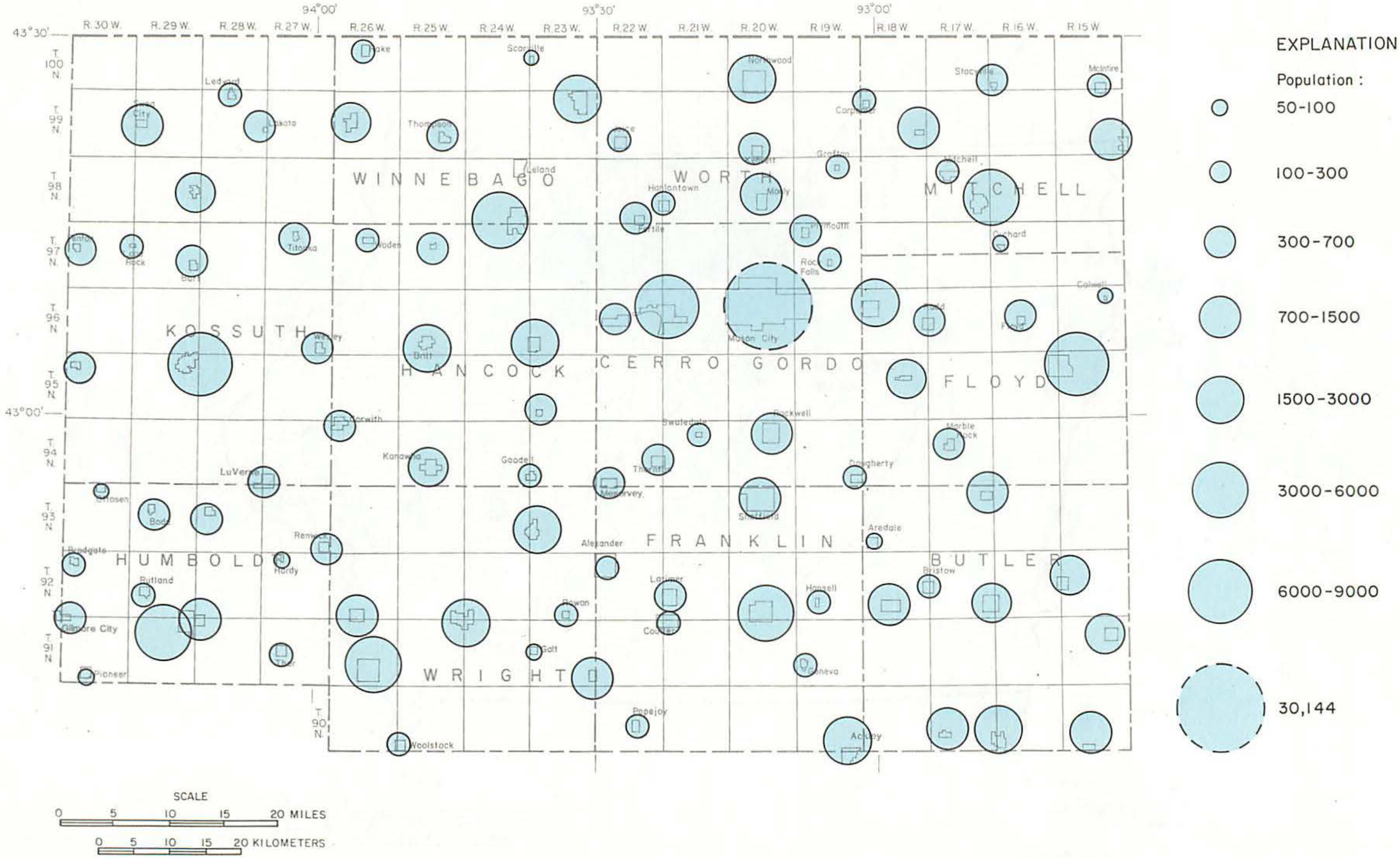


Figure 3. Population centers in north-central Iowa in 1980

POPULATION

The 1980 population of the 11 counties of north-central Iowa was 197,462 or approximately 7 percent of the State's inhabitants. Urban population (communities with more than 2,500 people) accounts for 42 percent of this total, with rural population accounting for 58 percent. The relative populations of cities and towns for this area are depicted in figure 3. There are 12 cities in the 11 counties that have more than 2,500 people. These are: Mason City with 30,144 people; Charles City with 8,778 people; Clear Lake with 7,458 people; Algona with 6,289 people; Humboldt with 4,794 people; Hampton with 4,630 people; Eagle Grove with 4,324 people; Forest City with 4,270 people; Osage with 3,718 people; Clarion with 3,060 people; Garner with 2,908 people; and Belmond with 2,505 people.

The distribution of population is important in the planning, management, and use of water resources. The national trend away from rural areas and toward urban centers places greater and greater demands on municipal water supplies. The increase of industries in these areas adds to the increased water demands.

The population in north-central Iowa has been shifting from rural to urban centers, but the total population of the area has remained quite stable (figure 4). By the year 2000 total population should increase to slightly more than 200,000, with the urban and rural fractions being about equal.

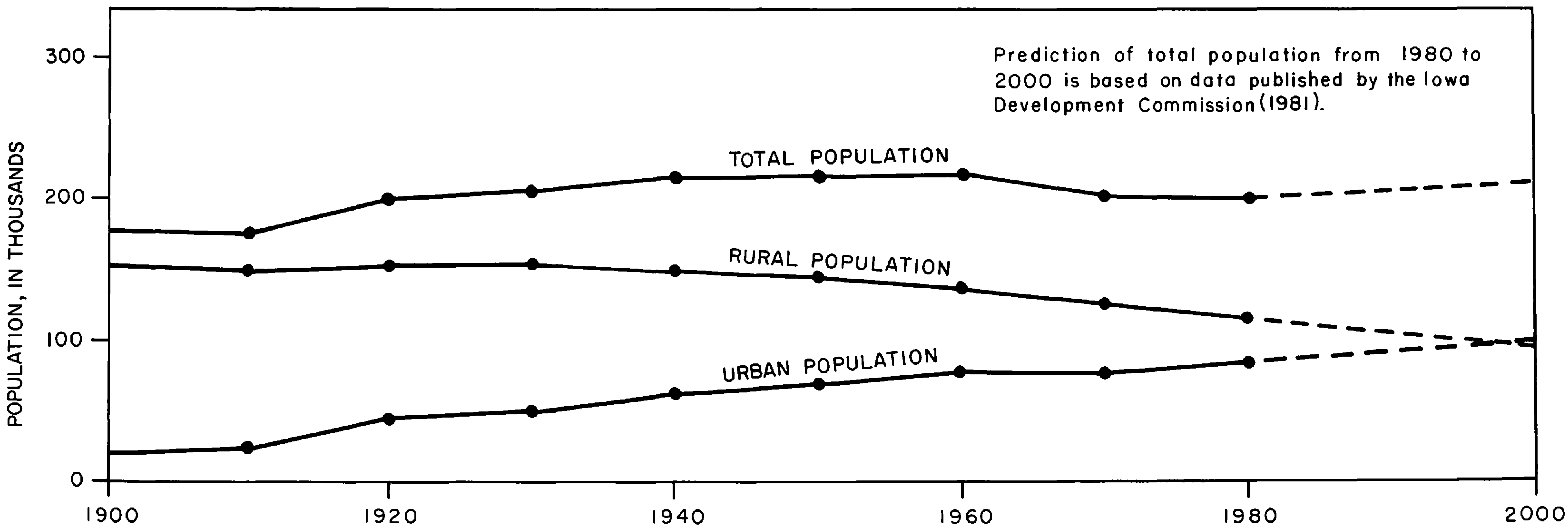


Figure 4. Population trends in north-central Iowa, 1900-2000

THE LAND SURFACE

The land-surface features of north-central Iowa are the result of modification, through weathering and erosion, of materials deposited by glacial activity. The 11-county area is part of two distinct landform regions, the Des Moines Lobe and the Iowan Surface (figure 5). The Des Moines Lobe was formed during Wisconsin-age glaciation, the last glaciation, and only has been slightly altered since the ice retreated. This is an area characterized by flat land, broken by abrupt bands of knob and kettle terrain, with many ponds and marshes having no surface drainage outlets. These landform features generally are classified as knob and kettle topography. The Iowan Surface, an abrupt change from the Des Moines Lobe topography, is composed of older Pre-Illinoian-age material and is typically gently rolling with long sloping hills with little relief. The topography is uneven or stepped from stream courses to drainage divides. In addition, solution of soluble limestone and dolomite under a thin or nonexistent cover of glacial drift has caused local collapse of the land surface, forming what is known as karst topography. This land surface feature is most prevalent in Mitchell and Floyd Counties.

The Des Moines Lobe region has little drainage development. Many small, slight-gradient streams meander toward a few larger rivers. The larger streams flow through valleys wider than would be created from present-day flows, sometimes eroding to the bedrock and having large terraces of sand and gravel. These valleys probably were formed when large volumes of water, created from melting of the ice sheet, drained from the area. In contrast, drainage is well developed on the Iowan Surface, but the streams also have slight gradients.

North-central Iowa is a relatively flat, little-relief area ranging from a low in the southeast corner of about 900 feet above sea level to a high of about 1,400 feet above sea level in the extreme northeast corner (figure 6). The greatest local relief is in the southeastern section of the area along the stream courses. Stream valleys and their associated uplands are the major contributing factor to the topographic relief of the study area.

Aquifers and water levels are conveniently referenced to sea level. To estimate drilling depths and water-level depths for well design, the altitude of the land surface needs to be known. The topographic map (figure 6), which shows altitudes in 100-foot intervals, is useful for preparing preliminary estimates of aquifer and water depths. For more detailed vertical control, however, topographic maps published by the U.S. Geological Survey are available (figure 22) and can be purchased through the agencies listed in the section of the report entitled Floods.

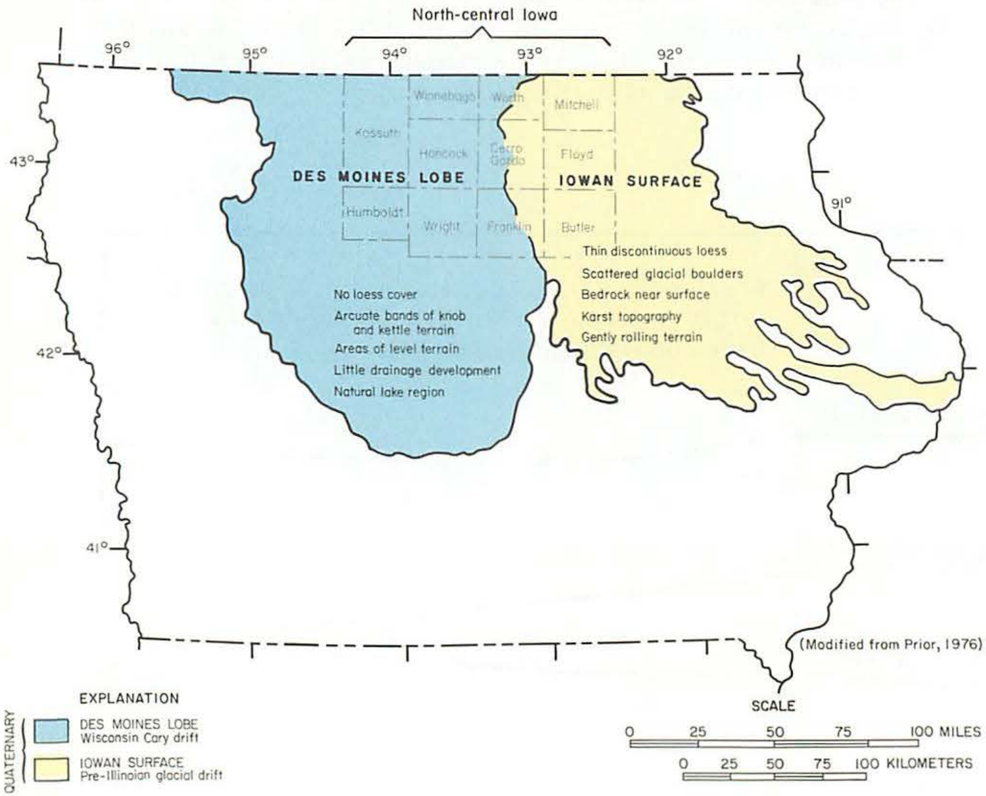


Figure 5. Landform regions in north-central Iowa

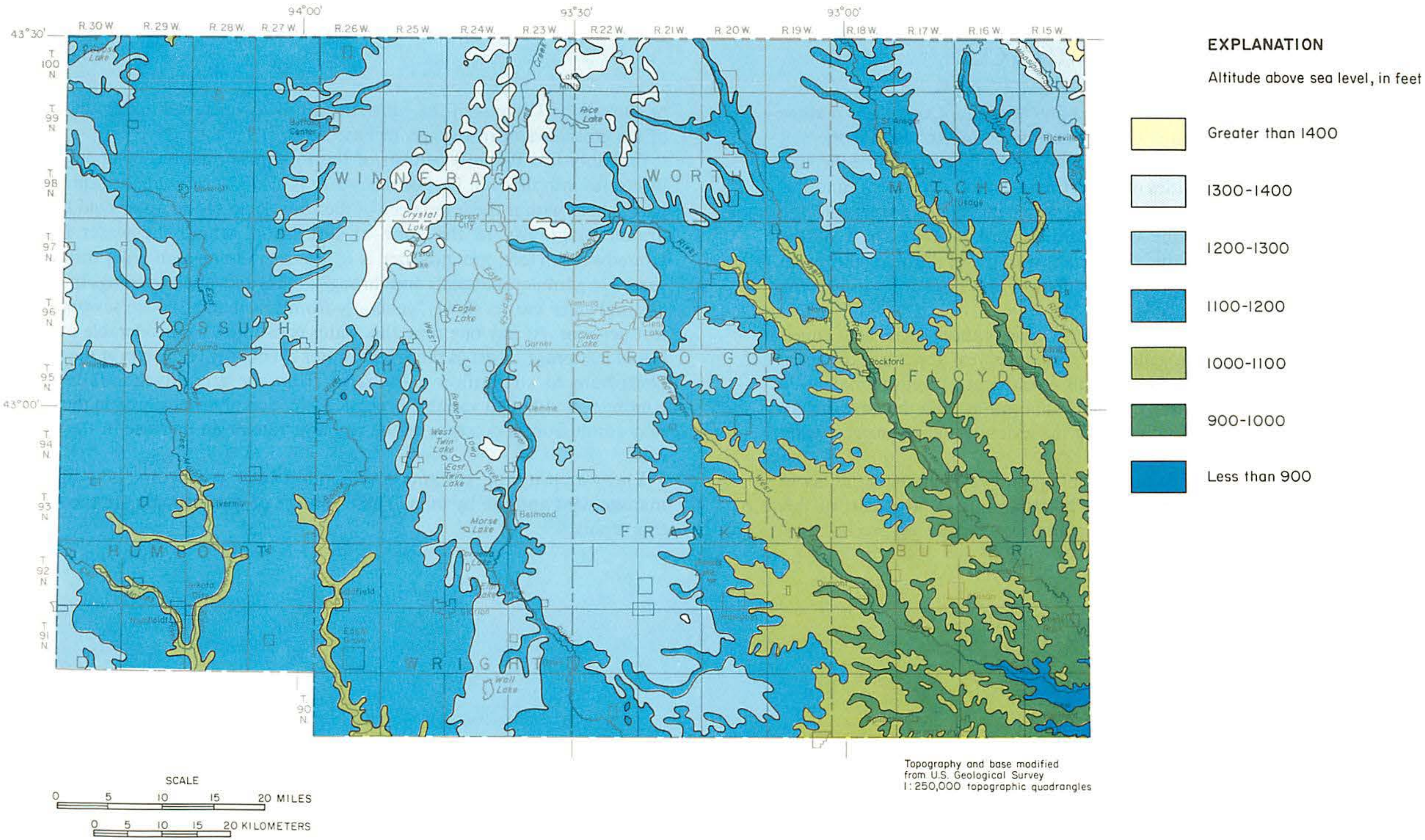


Figure 6. Generalized topography of north-central Iowa

SOURCES OF WATER

THE HYDROLOGIC CYCLE

The principal source of our useable water is precipitation. Once water reaches the land surface it evaporates, runs off to streams, or infiltrates into the soil (figure 7). Most of the precipitated water is returned to the atmosphere through evapotranspiration. Lesser quantities of water travel overland as storm runoff or infiltrate into the soil. Some of this infiltrated water percolates deeper into the ground where it reaches the zone of saturation and becomes part of the groundwater in storage. Eventually this water will travel through the earth materials and layers of rock toward the streams where it discharges to become part of the streamflow.

Normal annual precipitation for north-central Iowa is about 32 inches. This is an average of about 3,380 billion gallons of water per year for the entire area. About 78 percent of this precipitation, or an equivalent of approximately 25 inches, is returned to the atmosphere through evaporation from the land surface and transpiration by plants, without entering the groundwater or surface-water systems.

Streamflow, composed of surface runoff and groundwater discharge, is about 7 inches or about 21 percent of the annual precipitation. A large part of this runoff occurs during times of flood or high streamflow shortly after precipitation or snowmelt. The rest of the time streamflow is sustained mainly by discharge of the groundwater in storage, or base flow.

Probably less than 10 percent of the total precipitation, or about 3 inches, infiltrates into the soil. Part of this water is also lost by evapotranspiration and part is held within the interstices of the soil. Some of the water held by the soil drains by gravity to the zone of saturation, where the water is termed groundwater. Here, groundwater is in transient storage, moving through open spaces in granular materials and through cracks and small openings in the rocks. Groundwater moves slowly, generally from less than a foot to several hundred feet per year. At any one time this water constitutes a considerable quantity of liquid in storage. Most of the groundwater eventually reappears at the surface to contribute to streamflow. Discharge from the groundwater reservoir is a continuous, although variable process. Depletion of water stored in the reservoir may result from a decrease in the recharge rate or an increase in the discharge rate.

The water in the streams and groundwater reservoirs is available for management and use by man. These sources of water supply are the subject of this report.

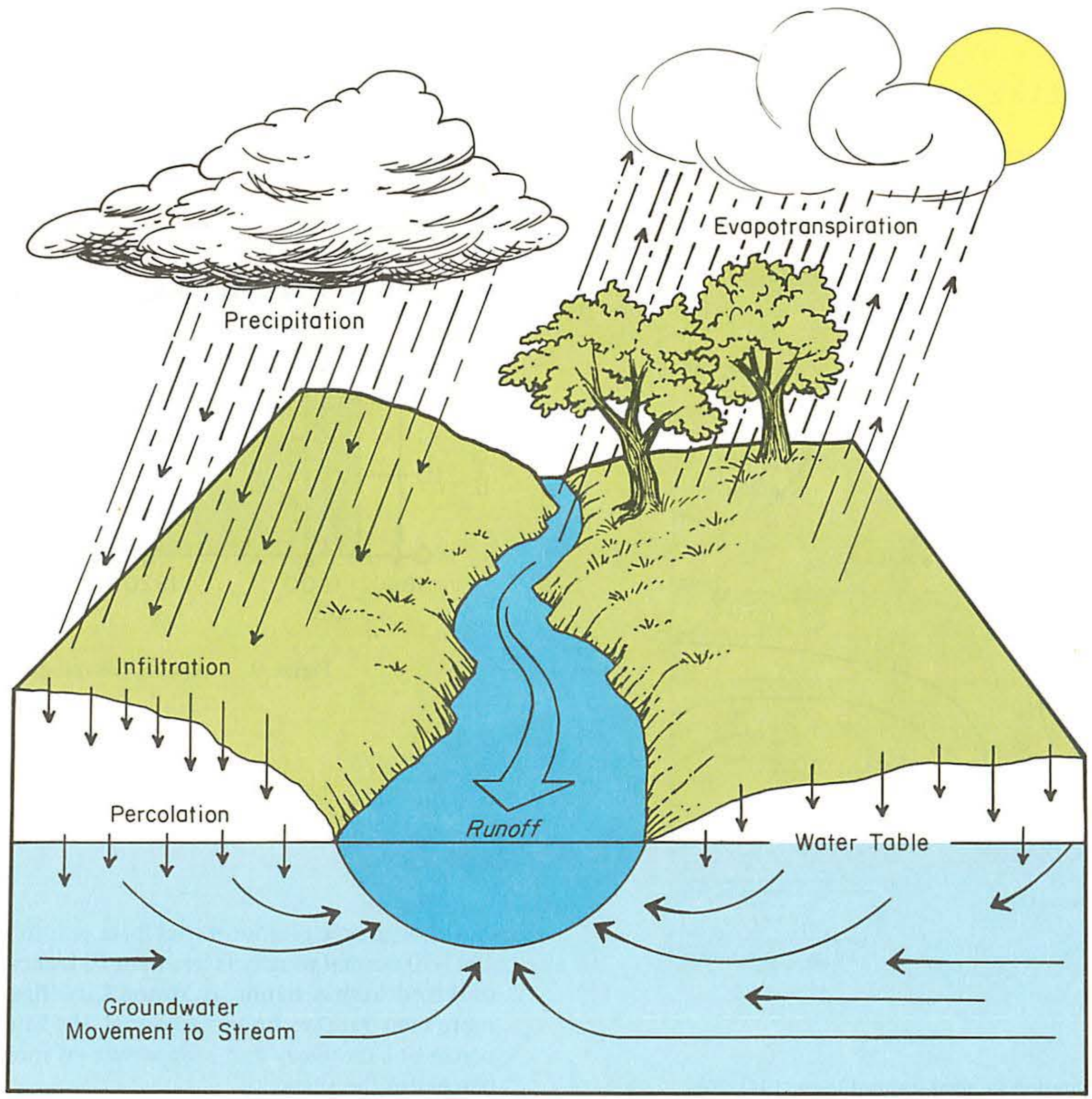


Figure 7. The hydrologic cycle

CLIMATE

The normal annual precipitation for the report area is quite varied; at different stations within the area it ranges from 27.82 to 34.08 inches (figure 8) (National Oceanic and Atmospheric Administration, 1981).

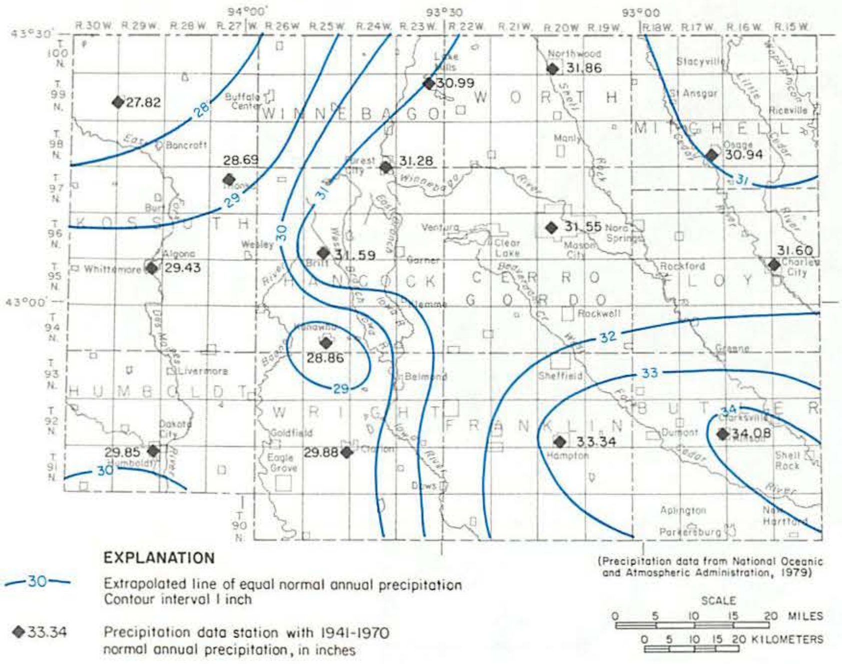


Figure 8. Normal annual precipitation in north-central Iowa, 1941-70

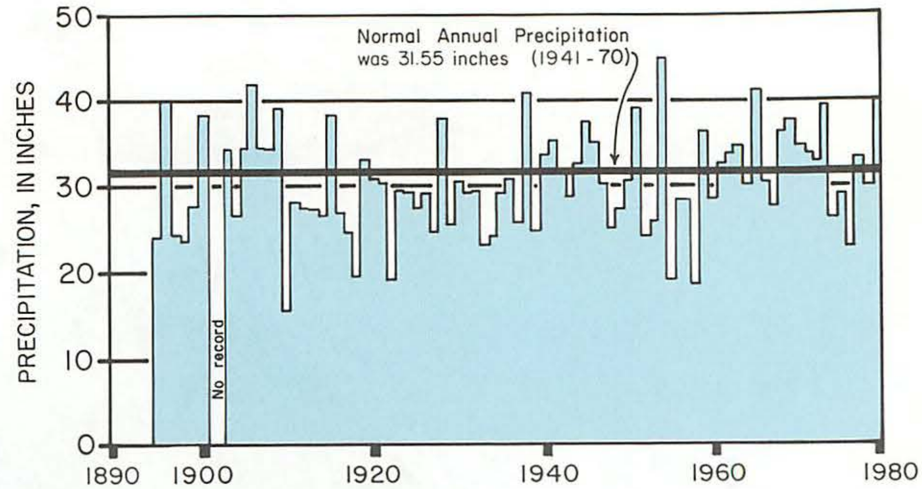
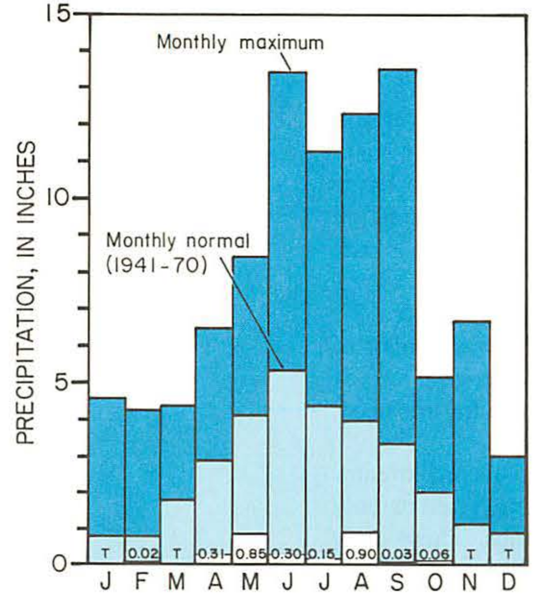


Figure 9. Annual precipitation at Mason City, Iowa

Although precipitation varies from year to year, the annual departure from the 1941-70 normal usually is less than 10 inches. For example, analysis of 82 years of record from a station at Mason City (figure 9) indicates that a departure of more than 5 inches from the normal 31.55 inches occurred in approximately 41 percent of the years and a departure of more than 10 inches in only about 8 percent of the years.



EXPLANATION

0.85 Monthly minimum (inches)

T Trace

Figure 10. Monthly extremes and normal precipitation at Mason City, Iowa

Normal monthly precipitation is greatest during the spring and summer months and least in the fall and winter months. During a normal year, most rainfall occurs from May through August, but monthly precipitation can vary considerably from year to year (figure 10).

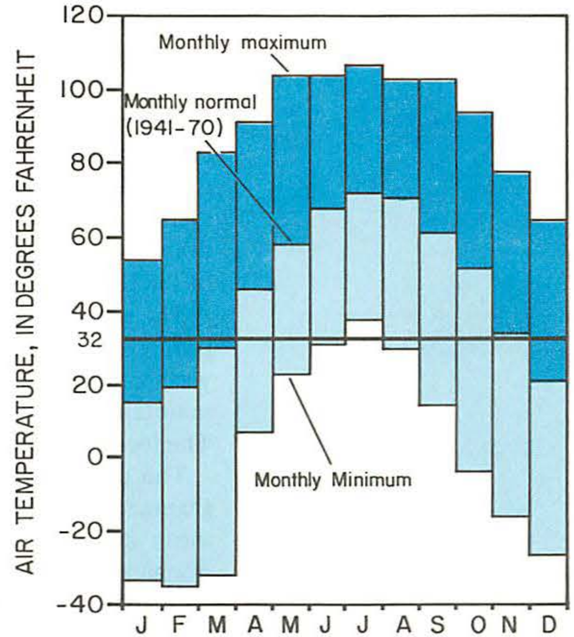


Figure 11. Monthly extremes and normal air temperature at Mason City, Iowa

The normal annual air temperature in the report area is 46.1° Fahrenheit, F (7.8° Celsius, C). Monthly normal temperatures throughout the area range from about 15° to about 72° F (−9.4° to 22° C) (figure 11). Temperatures of more than 100° F (37.8° C) have occurred at Mason City in each month from May through September, and temperatures have been less than freezing (32° F or 0° C) at least once in every month except July.

SURFACE-WATER RESOURCES

The surface-water resources of north-central Iowa include parts of five major river systems, one large natural lake, and a number of smaller natural and man-made lakes (figure 12), ponds, marshes and other wetlands.

Most of the eastern one-half of the region is drained by the Cedar River and its many tributaries toward the south and east; the Wapsipinicon River basin drains a small area in the extreme northeast. The Des Moines and Iowa River systems drain most of the western one-half to the south; and the Blue Earth River drains the remaining northwestern part to the north. All of the drainage is part of the Mississippi River system.

The surface waters in Iowa, especially the rivers, are a dynamic resource. To properly evaluate them, it is necessary to collect information for a number of years and then examine it in a historical perspective. The U.S. Geological Survey maintains a network of stream and lake stations that provide data for this need. The location of the data collection stations is shown in figure 12.

The principal component of this network is the continuous-record stream-gaging stations where daily gage-heights are collected and then converted to daily mean discharge through the use of stage-discharge relationships. These daily discharge records are published by the U.S. Geological Survey in separate reports (U.S. Geological Survey annually to 1961, 1961-75, 1976-79). A list of the continuous-record stations and a summary of their streamflow statistics appear in table 1.

The two other types of stations operated by the U.S. Geological Survey are low-flow, partial-record stations, where low-flow measurements are made during times of base flow; and high-flow, partial-record stations where high-flow measurements are made and peak gage height recorded. Information on these stations is shown in tables 2 and 3 respectively.

All stations in the network are assigned a number which places them in downstream order with all other U.S. Geological Survey stations throughout the country. The leading numerals "05" refer to the Upper Mississippi River basin and are common to all of these stations.

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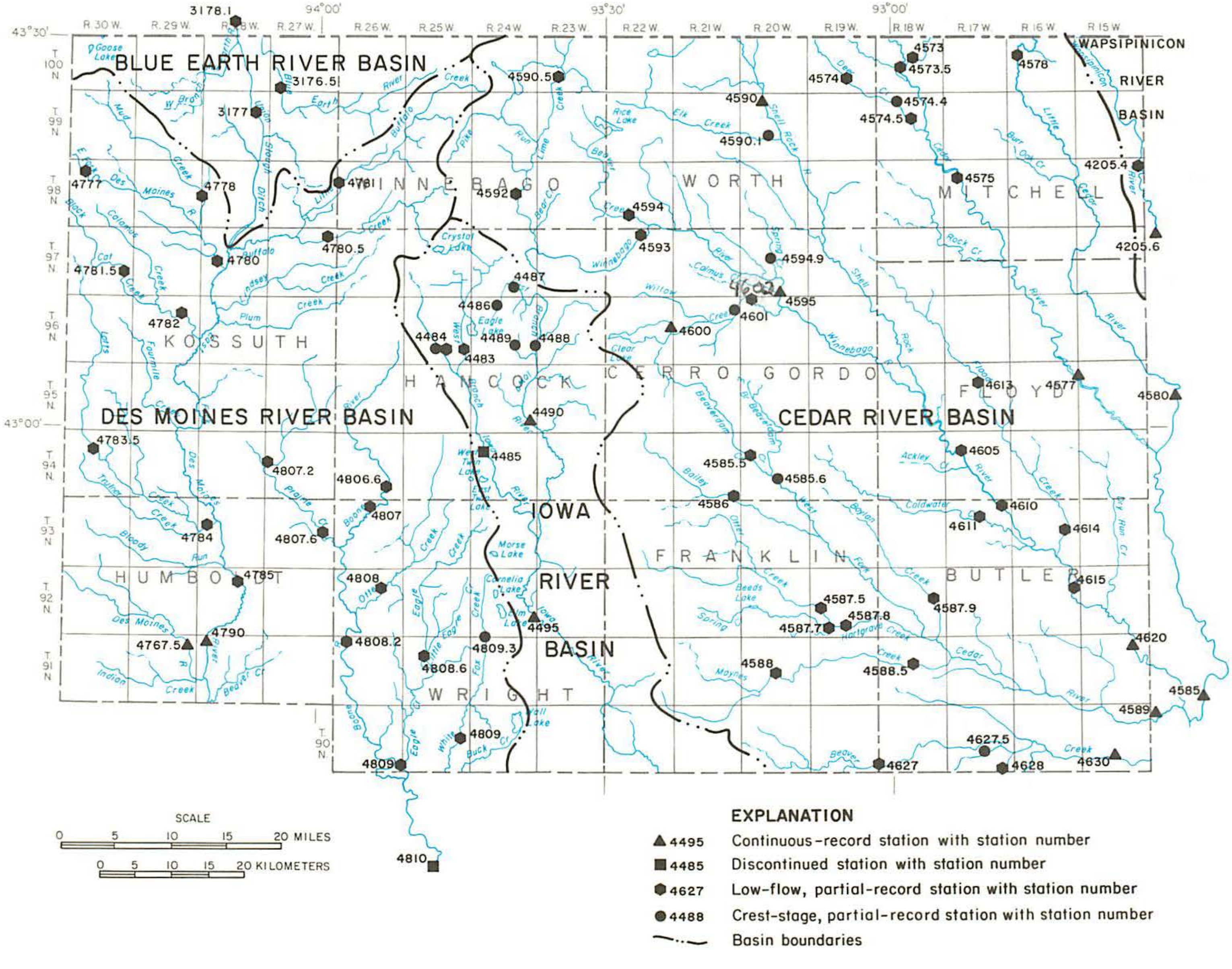


Figure 12. Surface-water data sites in north-central Iowa

STREAMFLOW VARIABILITY

Streamflow varies because of a variety of factors. Some of these are the physiographic characteristics of the drainage area, such as its size, slope, and drainage density, geology, climate, land use, and season. Generally, in north-central Iowa, streamflow per unit area increases from west to east based on precipitation and physical characteristics of the land.

Precipitation is the most important factor affecting streamflow. An illustration of this is presented in figure 13. In the 1973 water year about 45.0 inches of precipitation fell on the basin of the West Fork Cedar River upstream of Finchford, resulting in 18.64 inches of runoff—the greatest recorded. In 1956, however, the 24.6 inches of precipitation produced only 1.05 inches of runoff—the least recorded. Another example, presented in figure 14, shows comparative plots of the average monthly runoff at the Boone River gaging station and the normal monthly precipitation at Clarion, which is located on the basin upstream of the gaging station. When precipitation is least (January) runoff also is least; when precipitation is greatest (June) so is runoff.

Although this general relationship exists between precipitation and runoff, total precipitation is not the only factor affecting runoff. Note that both the March and April average runoff is greater than May despite less precipitation, and that there is a large percentage decrease in runoff compared to rainfall from June to August (figure 14). In March and April the following usually affect streamflow: lack of plant growth (negligible evapotranspiration); frozen or saturated ground (decreased infiltration); moderating temperatures (release of precipitation stored in snow). During the peak growing season from June to August, the combination of high temperatures and abundant plant growth contributes to a higher evapotranspiration rate that comprises a large share of the precipitation that would otherwise be available for runoff.

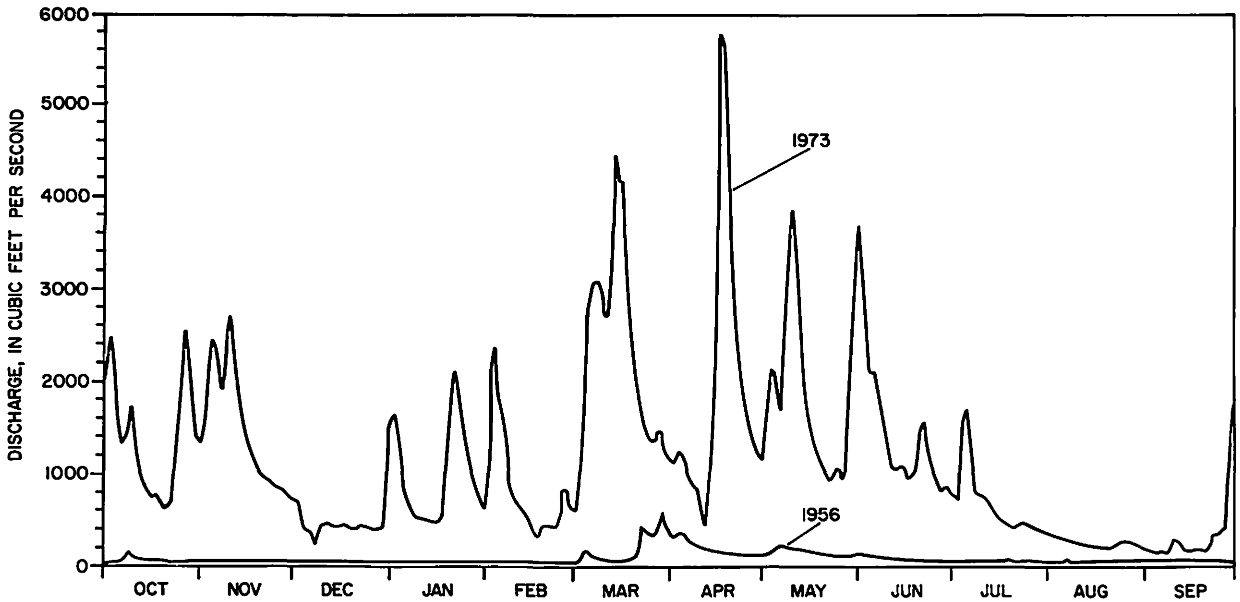


Figure 13. Average daily streamflow in West Fork Cedar River at Finchford, Iowa, in 1956 and 1973

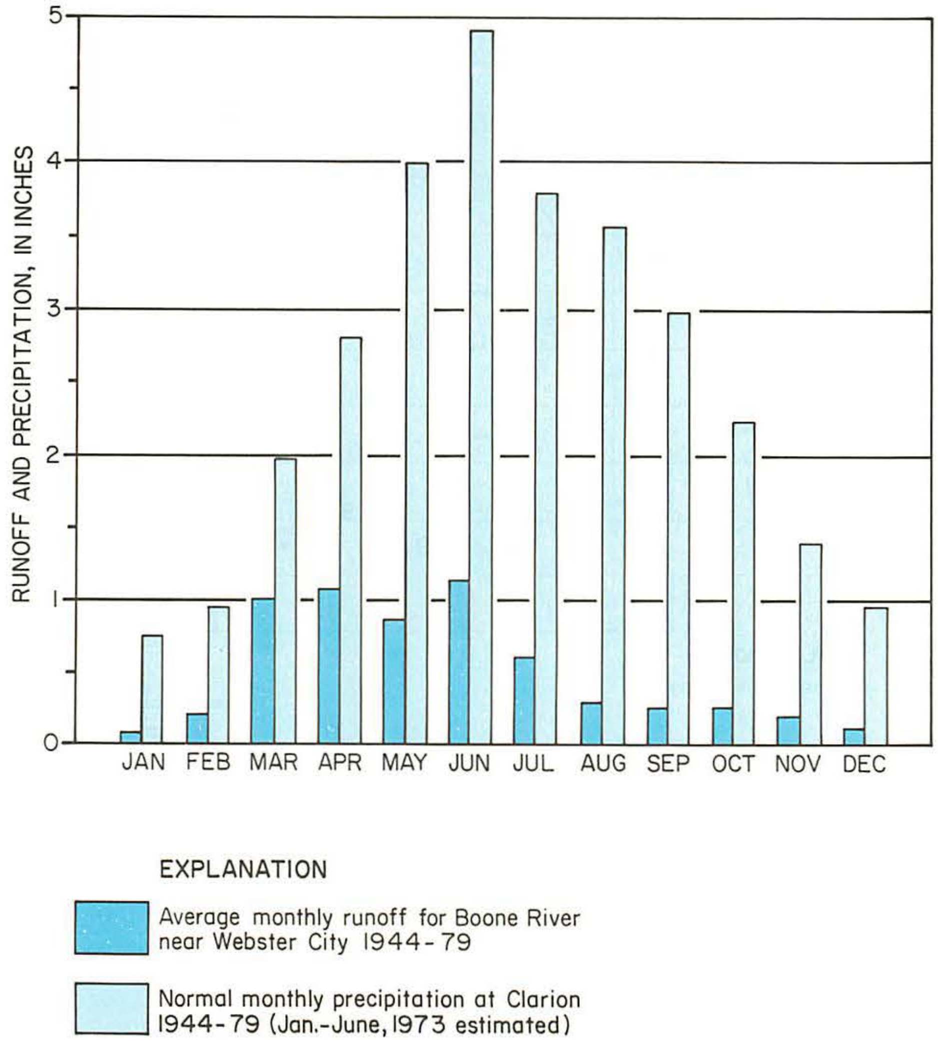


Figure 14. Average monthly runoff of Boone River near Webster City, Iowa, and normal monthly precipitation at Clarion, Iowa

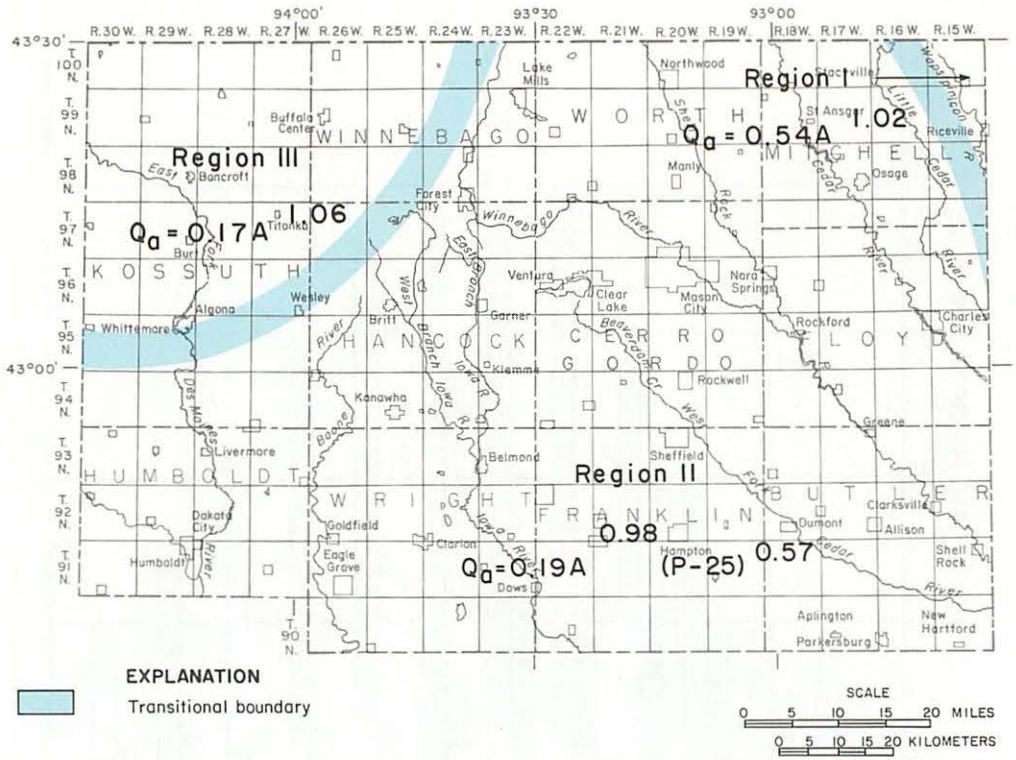


Figure 15. Regional average-discharge areas and equations in north-central Iowa

AVERAGE DISCHARGE

Average discharge is one of the easier statistics to derive from the records of streamflow (table 1) and yet is one of the most informative. For a given site, it is representative of the maximum quantity of water available for use. Much also can be learned about the variability of streamflow throughout an area when discharges from area gaging stations along with their respective drainage areas are examined collectively.

Lara (1979) has evaluated records for the entire State and with the use of drainage area (A) and average annual precipitation (P) has developed equations for the computation of average discharge for any location in Iowa. The regional areas and their equations are shown in figure 15. Of the three regional equations Lara developed, all are represented in the north-central area. Graphical representations of the equations are shown in figure 16 along with the individual station values from table 1. There is some scatter of the actual station values in relation to the regional equations, due in part to varying lengths of record and climatic conditions during those periods, but overall the correlation is good.

In regions I and III the average discharge is dependent only on drainage area but in Region II the average annual precipitation (figure 8) also is a factor used to compute discharge. The increasing average streamflow from west to east is seen by examining the values of discharge for a hypothetical 100-square-mile drainage area: region I, 60 ft^3/s, region II, 38 to 53 ft^3/s, and region III, 22 ft^3/s. Whereas some of the regional variation in average runoff is because of increasing precipitation from west to east, much of the variance also is because of the difference in physical basin characteristics across the study area. These same variations also will be seen in the sections on flow duration and floods.

The average-discharge figures for the low-flow, partial-record stations in table 2 were determined from the regional equations. The values in table 1 are from individual station records and are indicative only of the period for which records are available. If a period of record coincides with a time of predominantly high or low precipitation, its average discharge (as well as other flow characteristics) will reflect this bias. Stations with short periods of record need to be compared to stations with long periods of record and possibly adjusted. See the example for the Cedar River at Charles City/Cedar River at Janesville in Lara (1979) for an explanation of this adjustment procedure.

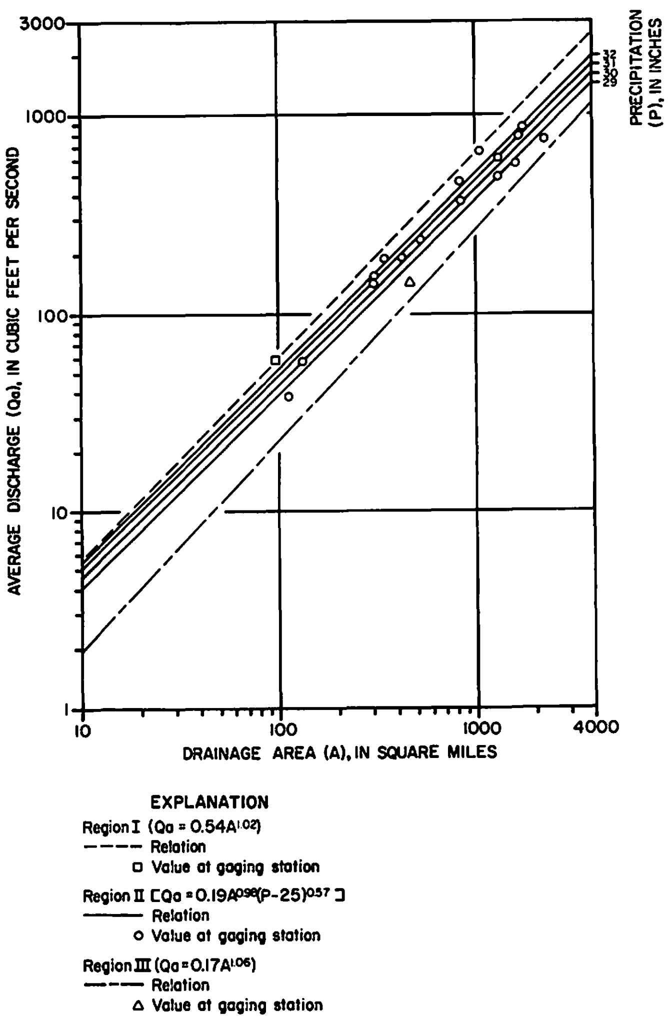


Figure 16. Average discharge in relation to drainage area in north-central Iowa

Station number	Station name	Period of record	Drainage area (square miles)	Average discharge	Minimum daily mean discharge	7-day low-flow for given period		Discharge equaled or exceeded for percent of time indicated					Maximum discharge recorded	Year occurred	2-year flood	10-year flood	50-year flood	100-year flood
						2-year	10-year	5	50	80	90	99						
WAPSIPINICON RIVER BASIN																		
05420560	Wapsipinicon River near Elma	1958-79	95.2	58.7	1.9	7.4	4.6	211	16	8.8	6.8	2.9	10,100	1974	2,220	7,310	13,500	16,500
IOWA RIVER BASIN																		
05448500	West Branch Iowa River near Klemme	1948-58	112	38.2	0.2	1.2	.30	146	8.4	2.3	1.4	.36	1,920	1954	525	1,330	2,100	2,430
05449000	East Branch Iowa River near Klemme	1948-79[a]	133	58.3	0.2	3.1	.75	239	14	5.4	3.5	.68	5,960	1954	1,040	2,960	5,000	5,920
05449500	Iowa River near Rowan	1940-79[a]	429	193	2.9	14	5.5	799	60	23	15	5.8	8,460	1954	2,080	4,900	7,500	8,580
05450000	Iowa River near Iowa Falls	1911-14	665	—	2	—	—	—	—	—	—	—	4,700	1914	—	—	—	—
05457500	Cedar River near Mitchell	1933-42	826	288	5	—	—	—	—	—	—	—	13,000	1934	—	—	—	—
05457700	Cedar River at Charles City	1964-79[b]	1,054	650	60	169	113	2,290	345	200	169	107	21,000[c]	1965	11,400	20,400	27,700	30,600
05458000	Little Cedar River near Ionia	1954-79	306	153	3.0	18	6.3	579	54	26	18	5.5	10,800	1961	2,820	8,180	14,200	17,000
05458500	Cedar River at Janesville	1904-06 1914-27 1932-42 1945-79	1,661	787	28	136	68	2,700	389	198	146	73	37,000	1961	10,300	25,300	39,400	45,300
05458900	West Fork Cedar River at Finchford	1945-79	846	456	5.9	44	14	1,745	166	63	41	11	31,900	1951	5,190	17,200	30,900	37,200
05459000	Shell Rock River near Northwood	1945-79	300	141	0	18	4.0	608	55	23	16	4.1	3,400	1965	1,140	2,310	3,260	3,640
05459500	Winnebago River at Mason City	1932-79	526	238	2.5	20	7.1	955	88	30	19	7.0	10,800	1933	3,240	7,260	10,900	12,400
05460000	Clear Lake at Clear Lake	1933-79	22.6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
05460500	Shell Rock River at Marble Rock	1933-53[d]	1,318	611	6	63	30	2,422	252	92	65	27	22,700	1951	10,400	21,400	31,000	34,900
05461500	Shell Rock River near Clarksville	1915-27 1932-34	1,626	562	10	—	—	—	—	—	—	—	23,800	1933	8,650	18,900	29,100	33,700
054620000	Shell Rock River at Shell Rock	1953-79	1,746	863	38	151	69	2,897	414	196	138	57	33,500[e]	1961	8,230	23,800	41,700	50,200
05463000	Beaver Creek at New Hartford	1945-79	347	188	2.3	15	4.9	650	67	24	15	4.7	18,000	1947	4,120	11,800	20,400	24,300
DES MOINES RIVER BASIN																		
05476750	Des Moines River at Humboldt	1964-79	2,2561	757	13	65	28	2,987	306	94	63	29	18,000	1969	4,070	10,800	17,300	20,100
05478000	East Fork Des Moines River near Burt	1951-74	462	144	0	2.3	.28	684	37	4.9	2.3	.31	5,000	1965	1,210	3,080	4,890	5,650
05479000	East Fork Des Moines River at Dakota City	1940-79[f]	1,308	486	4.8	23	10	2,039	156	33	21	9.8	18,800[g]	1954	3,960	11,700	20,300	24,300
05481000	Boone River near Webster City	1940-79	844	375	0	12	4.3	1,658	102	23	14	4.8	20,300[h]	1954	4,990	11,300	17,400	20,000

[All discharges are in cubic feet per second]

a Station discontinued October, 1976 to June, 1977
b Records collected September, 1945 to June, 1954 but not published due to extreme regulation by dam upstream. This period was used in computation of flood-frequency values.
c Discharge exceeded outside period of record—29,200 cubic feet per second in 1961
d Published as "at Greene" prior to October, 1942—drainage area of 1,357 square miles
e Discharge exceeded outside period of record—45,000 cubic feet per second in 1856
f Published as "near Hordy" prior to October, 1954—drainage area of 1,268 square miles
g Discharge exceeded outside period of record—22,000 cubic feet per second in 1938
h Discharge exceeded outside of period of record—21,500 cubic feet per second in 1918

Table 1. Streamflow statistics for continuous-record gaging stations in north-central Iowa

Station number	Stream and location	Drainage area (square miles)	Computed average discharge	Computed low-flow 7-day 2-year	7-day 10-year	84-percent duration
CEDAR RIVER BASIN						
05459400	Beaver Creek near Fertile	54.9	26	0.8	0.1	2.7
05460200	Willow Creek at Mason City	86.0	41	3.3	1.4[a]	5.9
05461100	Cold Water Creek near Greene	56.8	29	0	0	.3
05461300	Flood Creek near Rockford	59.3	30	0	0	0
05461400	Flood Creek near Packard	145	73	0	0	0
05462700	Beaver Creek near Ackley	55.5	28	1.6	.4[a]	3.4
05462800	South Beaver Creek near Parkersburg	114	58	4.5	1.5[a]	9.5
DES MOINES RIVER BASIN						
05477700	East Fork Des Moines River near Swea City	314	75	0	0	5.0
05477800	Mud Creek at Bancroft	68.1	15	.4	*	1.6
05478050	Buffalo Creek near Titonka	47.9	10	0	0	.3
05478100	North Buffalo Creek near Buffalo Center	62.5	14	.2	0	1.6
05478150	Black Cat Creek near Lone Rock	58.2	13	*	0	.5
05478200	Black Cat Creek near Algona	112	25	*	0	.8
05478350	Lotts Creek near West Bend	66.2	27	1.2	.5	3.0
05478400	Lotts Creek at Livermore	165	68	1.6	.5[b]	5.6
05480660	Boone River near Kanawha	71.4	32	.1	0	1.6
05480700	Boone River near Renwick	132	60	.2	*	3.2
05480720	Prairie Creek near Luverne	68.6	31	.4	*	2.1
05480760	Prairie Creek near Renwick	118	53	.2	*	2.4
05480800	Otter Creek near Goldfield	75.5	35	.2	*	.9
05480820	Boone River near Goldfield	419	186	1.3	.2	6.4
05480860	Eagle Creek near Eagle Grove	62.8	29	.6	.3	1.4
05480900	Eagle Creek near Woolstock	105	48	1.4	.6[a]	2.9
05480940	White Fox Creek near Woolstock	62.0	29	1.6	.7[a]	3.5

[All discharges are in cubic feet per second]

* Less than 0.1 cubic feet per second
a Estimated from extrapolated correlation curve
b Estimated from generalized map

Table 2. Streamflow statistics for low-flow, partial-record stations in north-central Iowa

FLOW DURATION

A flow-duration curve or table constructed for a particular location on a stream represents the percentage of time a certain discharge is equaled or exceeded. If the curve is given in its entirety the complete range in discharge that has occurred during the period of record will be shown. Flow-duration data are applicable to such uses as: setting regulatory limits on water withdrawal, determination of potential water supplies, development of power plants, and comparison of drainage-basin characteristics.

A summary of flow-duration discharges is given in table 1 for all stations with 10 or more years of record. These values are from Lara (1979) as are the 84-percent seasonal-duration values (April 1 to September 30) for all of the low-flow, partial-record stations listed in table 2. The Iowa Department of Water, Air, and Waste Management uses the 84-percent value for regulatory purposes. The values from table 2 were determined by correlating discharge measurements at low-flow sites with concurrent flows at continuous-record stations of similar basin characteristics and then estimating the desired low-flow statistic from the correlation.

The shape of a flow-duration curve is determined by the hydrologic and geologic characteristics of the drainage area. The curve may be used to study the characteristics of a drainage basin or to compare the characteristics of one basin with those of another.

The flow-duration curves for five gaging stations in north-central Iowa are plotted in Figure 17. A curve with a steep slope throughout, such as the one for the East Fork Des Moines River near Burt, denotes a highly variable stream whose flow is largely from direct runoff, whereas a curve with a flatter slope, such as the one for Little Cedar River near Ionia indicates the presence of surface storage or groundwater discharge. The slope of the lower end of the duration curve shows the characteristics of the storage in the drainage basin; a flat slope at the lower end indicates a large amount of storage, steep slopes indicate negligible storage. Streams that have high flows resulting mainly from snowmelt tend to have flat slopes at the upper end of the curve. The same is true for streams with large flood-plain storage or those draining wetlands.

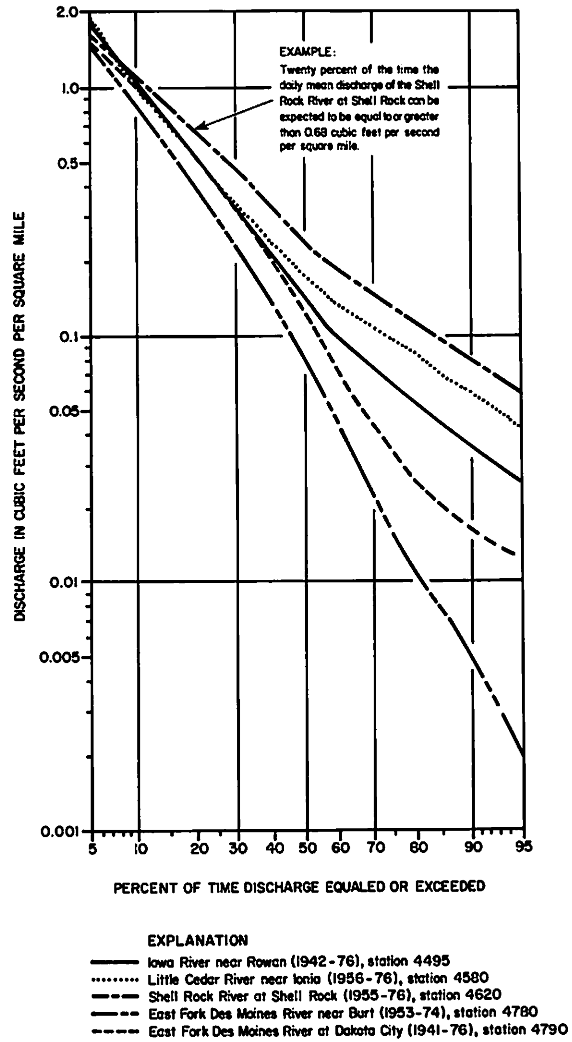


Figure 17. Flow-duration curves for five north-central Iowa streams

LOW-FLOW FREQUENCY

Although the average discharge for a particular site is the maximum amount of water available, it is not a value that can be depended upon for continuous use, because much of the total flow occurs during relatively short periods of high-water and floods. It is, therefore, necessary to examine other flow characteristics that are better indicators of water availability during dry periods.

Two characteristics commonly used are the 7-day average low flows for the 2-year and 10-year recurrence intervals; many other combinations of days and recurrence intervals also are possible. The 7-day, 2-year low flow is the minimum average flow for 7 consecutive days which is expected to occur on the average of once in 2 years. Put another way, in any 1 year there is a 50-percent chance of having a minimum 7-day average flow equal to or less than the 7-day, 2-year low-flow value. Similarly, the 7-day, 10-year low flow will occur on the long-term average of once in 10 years, or have a 10-percent chance in any 1 year of averaging at least this value for 7 consecutive days.

To derive these statistics the minimum average discharge for 7 consecutive days (or any other period) for each climatic year of record is identified and listed. The data set is ranked according to discharge and then fitted either mathematically to a special function or graphically to obtain the various recurrence intervals and corresponding discharges. Lara (1979) has done this for several periods and recurrence intervals for each of the continuous-record stations with 10 or more years of record. By correlation with a continuous-record station of similar characteristics the 7-day, 2-year and 10-year low flows for many of the low-flow partial-record sites also were derived. For a partial listing of these values for north-central Iowa see tables 1 and 2.

To illustrate some of the relationships discussed, the yearly 7-day low flows for the Winnebago River at Mason City have been plotted in figure 18. Note that the climatic year actually begins on April 1 of the calendar year. For 43 years of record it would be expected that 4 or 5 years would be equal to or less than the 10 year low flow—there are 3 less than and 2 approximately equal to it. Similarly there are 20 years less than and 2 years equal to the 2-year value which is the number expected for a 2-year recurrence interval. Notice also that the high and low years generally are grouped together.

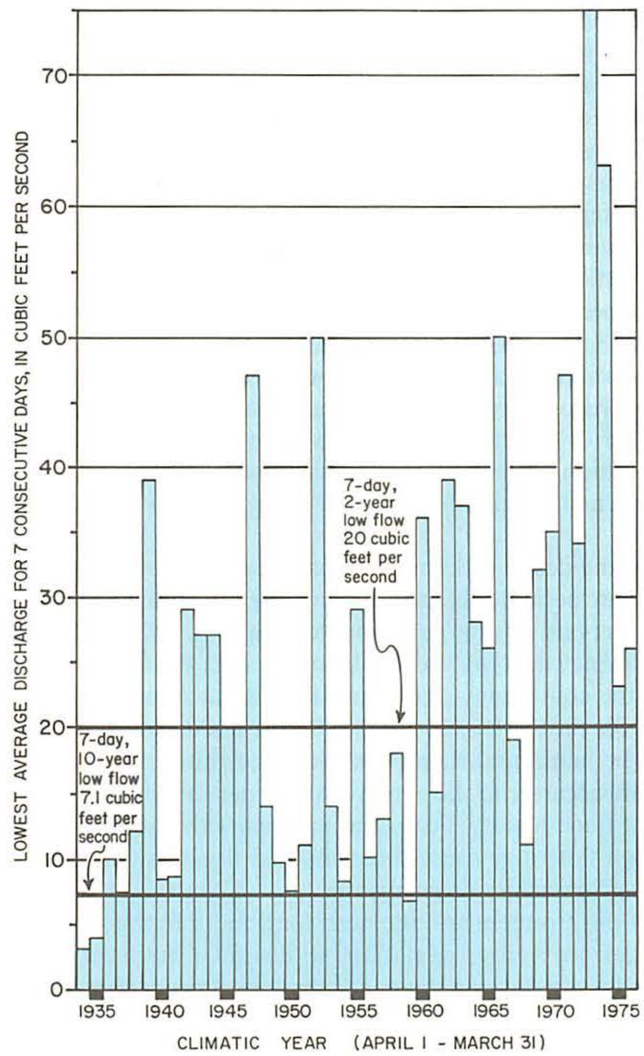


Figure 18. Annual, 7-day minimum flows for Winnebago River at Mason City, Iowa

FLOODS

Floods are one of the more spectacular of nature's events, commonly causing much damage and at times even loss of life. The U.S. Geological Survey maintains records of flood flows that can be helpful in formulating measures for alleviating or decreasing some of the problems caused by such high flows. Some of the uses of this information are: the design and construction of roads, bridges, dams and levees; the regulation of floodplains; flood inundation mapping; and flood forecasting.

Flooding occurs when the transport capacity of a stream is exceeded and its banks are overflowed. Thus, the initial indicator of a flood is the river's water stage and not necessarily its flow. The determination of a flood's relative "size" is related to the peak discharge of the stream, because ice, debris, and late summer vegetation can all cause higher water stages than would otherwise occur for that flow. Historically in north-central Iowa the largest floods on record have occurred either in March or April when rapid snowmelt is possible or in June when precipitation is greatest. The known maximum floods for the continuous-record stations and the high-flow, partial-record stations are listed in tables 1 and 3 respectively.

Because of the desire to know how often certain flows can be expected, the flood records are periodically analyzed to determine discharge values for various recurrence intervals. Using guidelines of the U.S. Water Resources Council (1977), a frequency analysis was made for the data through the 1979 water year for most of the continuous-record and the partial-record stations in the study area. Values for the 2-, 10-, 50-, and 100-year floods are shown in tables 1 and 3. It should be noted that these values are the result of statistical procedures, which only are accurate to the extent that the data available is representative of the long-term flood history. For gaging stations with a short period of record an extremely high flow may cause the computed flood values to be much greater than what the true values probably are.

Because of this problem and the need for flood information at ungaged sites, the flood data from a group of stations with similar basin characteristics can be analyzed together to develop regional equations more representative of the true values and applicable to any site in the area. Regional equations were developed by Lara (1973) and may be consulted for more detailed information. The regional areas shown in figure 19, and the plots of the equations in figure 20, were derived from this publication.

The flood-frequency curve for both types of analyses are shown in figure 21 for the Iowa River near Rowan. It is seen from this plot, that the discharge for the 50-year flood computed by the regional method is 20 percent greater than that computed by analysis of the individual station data, indicating that discretion needs to be used when applying this information.

It is important to note the differences that exist in the two regional flood areas, differences that also were evident in the low-flow and average-discharge characteristics as well. Region I has a much greater runoff per unit area than does Region II. This difference is due more to physical characteristics of the basin, as described in the section on the land surface, than to climatic variability.

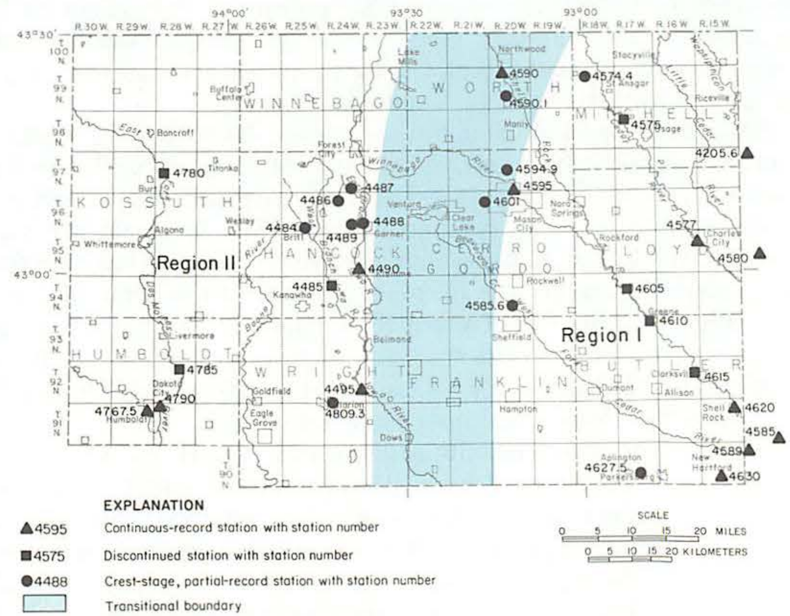


Figure 19. Regional flood-frequency areas in north-central Iowa

Station number	Station name	Period of record	Drainage area (square miles)	Discharge for indicated recurrence interval, in years				Maximum discharge	Year occurred
				2	10	50	100		
IOWA RIVER BASIN									
05448400	Westmain Drainage Ditch 1&2 near Britt	1966-79	21.2	326	798	1,280	1,510	372	1,975
05448600	E. Branch Iowa River above Hayfield	1953-79	2.23	71	180	297	354	250	1965
				49[a]	213[a]	439[a]	552[a]		
05448700	E. Branch Iowa River near Hayfield	1952-79	7.94	168	416	676	801	457	1954
				159[a]	368[a]	557[a]	635[a]		
05448800	E. Branch Iowa River near Garner	1952-79	45.1	541	1,310	2,080	2,450	1,120	1961
				477[a]	940[a]	1,320[a]	1,460[a]		
				139	345	562	668	206	1954
05448900	E. Branch Iowa River trib. near Garner	1952-79	5.98	96[a]	191[a]	268[a]	299[a]		
CEDAR RIVER BASIN									
05457440	Dear Creek near Carpenter	1966-79	91.6	—	—	—	—	2,100	1973
									1975
05458560	Beaverdam Creek near Sheffield	1966-79	123	—	—	—	—	3,500	1979
05459010	Elk Creek near Kensett	1966-79	58.1	642	1,550	2,450	2,880	1,000	1971
05459490	Spring Creek near Mason City	1966-79	29.3	—	—	—	—	2,820	1975
05460100	Willow Creek near Mason City	1966-79	78.6	—	—	—	—	1,080	1979
05462750	Beaver Creek trib. near Applington	1966-79	11.6	731	2,160	4,060	5,050	900	1979
				804[a]	1,840[a]	2,820[a]	3,240[a]		
DES MOINES RIVER BASIN									
05480930	White Fox Creek at Clarion	1966-79	13.3	238	586	944	1,120	400	1979

[All discharges are in cubic feet per second]

a Values computed from individual station data using guidelines from U.S. Water Resources Council (1977). All other values from regional equations in Lara (1973).

— Gaging-station drainage basin located in area where flood characteristics are in transition between Regions I and II. Insufficient data to determine proper weighting of regional equations.

Table 3. Streamflow statistics for high-flow, partial-record stations in north-central Iowa

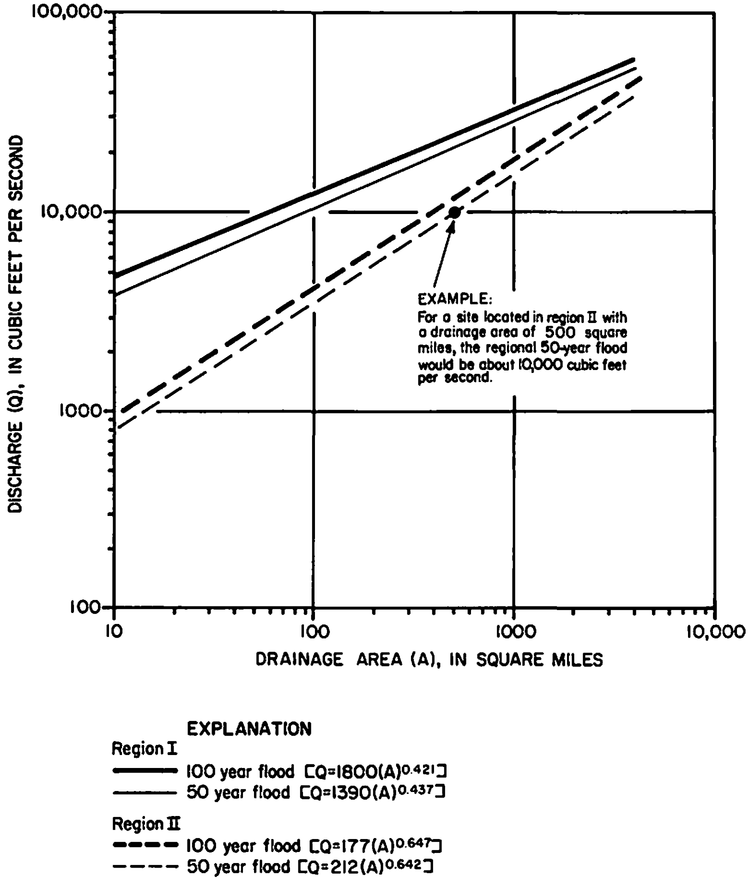


Figure 20. Relation between flood discharge and drainage area for given recurrence intervals in north-central Iowa

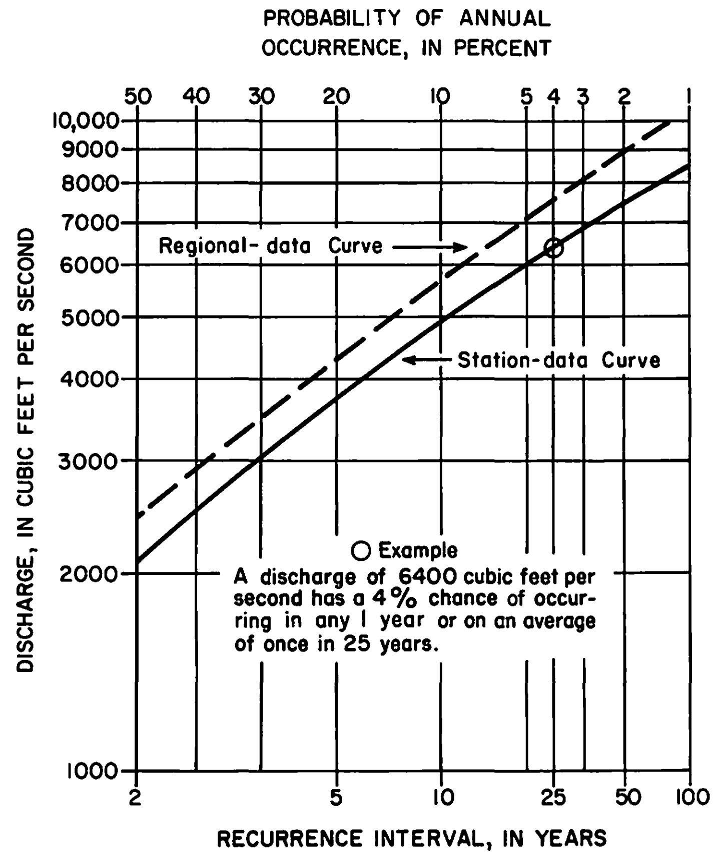


Figure 21. Flood-frequency curve for the Iowa River near Rowan, Iowa

The U.S. Geological Survey has produced 7½-minute topographic maps covering north-central Iowa, as shown in figure 22. For some of these maps the 100-year, flood-inundation limits for area streams have been outlined and the maps have been published as flood-prone-area maps. These flood-prone-area maps can be obtained from the U.S. Geological Survey, P. O. Box 1230, Iowa City, Iowa 52244. Topographic maps can be purchased from the Iowa Geological Survey, 123 North Capitol Street, Iowa City, Iowa 52242 or ordered from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colorado 80225.

Two other sources of more detailed flood information are the U.S. Geological Survey flood-profile reports and the U.S. Department of Housing and Urban Development flood-insurance-rate studies of cities. U.S. Geological Survey flood-profile reports are available for the Cedar River basin (Schwob, 1963), the Upper Des Moines River basin (Schwob, 1970, and Heinitz, 1979), and the Iowa River basin (Heinitz, 1973).

Cities for which flood-insurance-rate studies have been completed are listed below; the individual communities should be contacted for more detailed information:

City	County
Algona	Kossuth
Charles City	Floyd
Forest City	Winnebago
Greene	Butler
Humboldt	Humboldt
Leland	Winnebago
Mason City	Cerro Gordo

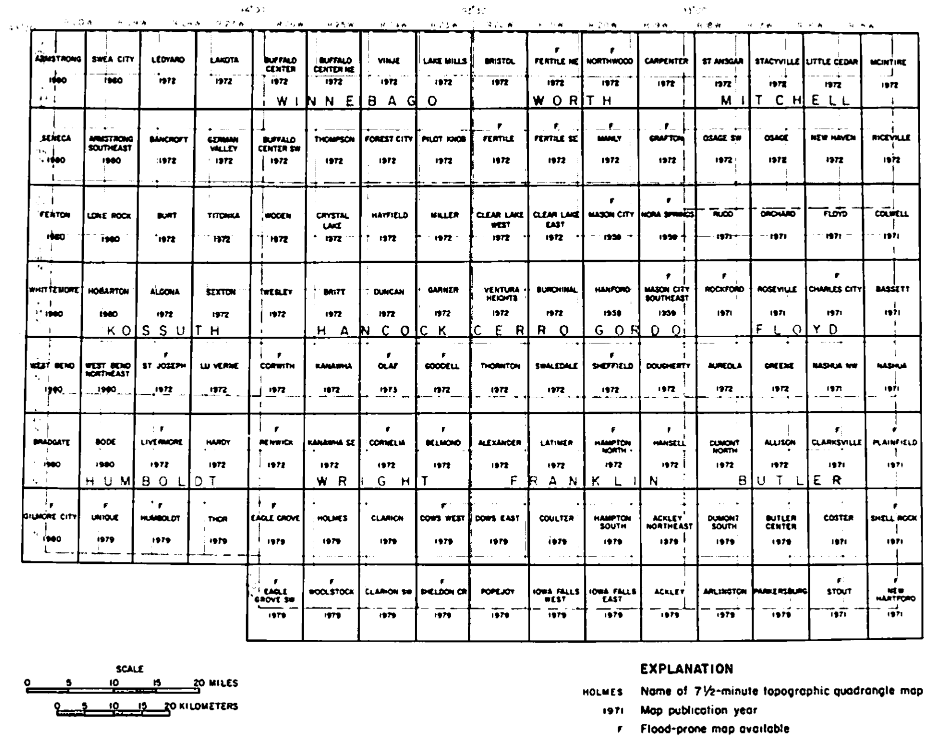


Figure 22. Topographic and flood-prone area maps available for north-central Iowa

WETLAND AREAS

The western two-thirds of north-central Iowa (Des Moines Lobe landform region) was once an area densely covered by many shallow lakes, marshes, sloughs and potholes. Many of these areas have since been drained and are used for agriculture. Numerous natural lakes and wetlands do remain, however, and some artificial impoundments have been created. These areas are primarily used for recreation, wildlife habitat conservation, or both, although Clear Lake is used also as a source of drinking water. Almost all of the larger wetland areas are under the jurisdiction of the Iowa Conservation Commission. A list of selected lakes, compiled from unpublished information provided by the Commission, is shown below:

Name	Type*	County	Area (acres)
Lakes - 100 Acres and Larger			
Silver Lake	N	Worth	316
Clear Lake	N	Cerro Gordo	3684
Beeds Lake	A	Franklin	100
Rice Lake	N	Winnebago	530
Crystal Lake	N	Hancock	244
West Twin Lake	N	Hancock	109
Lake Cornelia	N	Wright	243
Goose Lake	N	Kossuth	110
Marshes - 200 Acres and Larger			
Big Marsh	A	Butler	1100
Elk Creek Marsh	A	Worth	823
Zirbel Slough	N/A	Cerro Gordo	230
Ventura Marsh	N	Cerro Gordo/Hancock	360
Myre Slough	N	Winnebago	300
Rice Lake Marsh	N	Winnebago/Worth	372
Eage Lake	N	Hancock	895
Big Wall Lake	N	Wright	905
Elm Lake	N	Wright	420
Union Slough	A	Kossuth	1000
Buffalo Creek	A	Kossuth	230

*N - Natural, A - Artificial

The largest lake, and most significant in terms of surface-water resources, is Clear Lake. The U.S. Geological Survey has published lake levels (stage) since 1933. The yearly range in stage is shown in figure 23.

Another type of wetland area occurs when dams are built across streams, thus backing up water into the channel upstream. The Iowa Department of Water, Air, and Waste Management (DWAWM) is responsible for the regulatory aspects of construction, operation and maintenance of these dams as specified elsewhere in this atlas (see Water Resources Laws and Regulations). A list of existing dams 6 feet and higher on rivers in north-central Iowa is shown below; it is from unpublished information provided by DWAWM.

Stream	Nearest town	County	Current use	Storage (acre-feet)	
				Maximum	Normal
Little Cedar	Staceyville	Mitchell	Recreation	400	180
Cedar	St. Ansgar	Mitchell	Recreation	600	250
Cedar	Mitchell	Mitchell	Recreation	1,454	1,454
Cedar	Charles City	Floyd	Recreation	606	606
Shell Rock	Rockford	Floyd	Recreation	153	153
Shell Rock	Marble Rock	Floyd	Recreation	836	836
Shell Rock	Greene	Butler	Recreation	856	856
Shell Rock	Shell Rock	Butler	Recreation	229	152
Winnebago	Fertile	Worth	Recreation	116	116
Winnebago	Mason City	Cerro Gordo	Recreation	102	102
West Fork Des Moines	Rutland	Humboldt	Recreation	1,026	1,026
West Fork Des Moines	Humboldt	Humboldt	Recreation	3,071	3,071

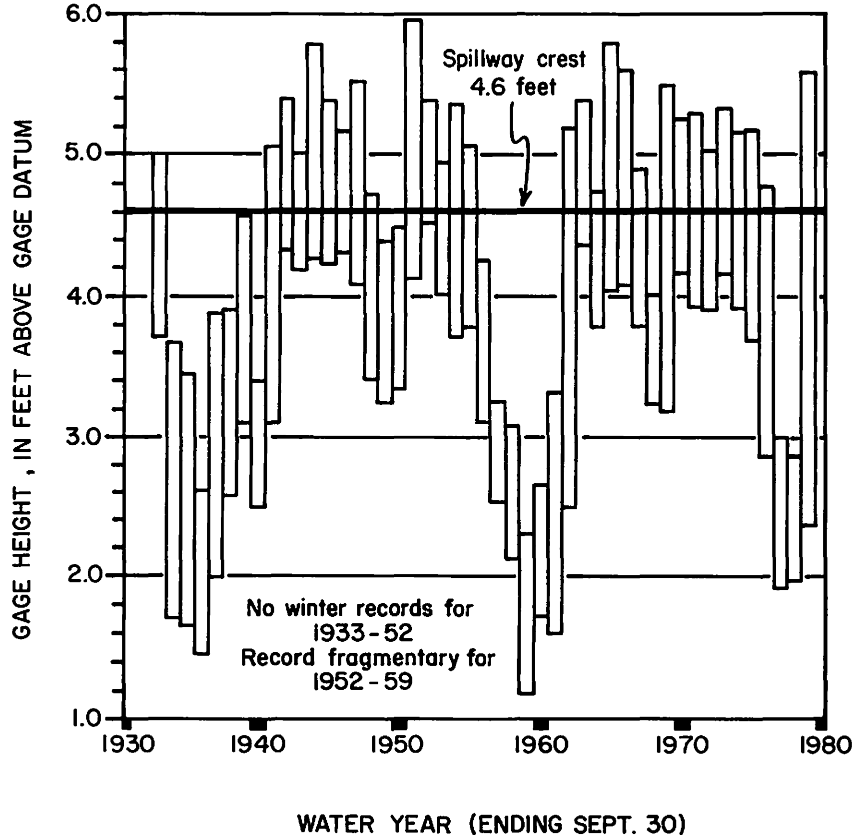


Figure 23. Maximum and minimum stages of Clear Lake at Clear Lake, Iowa

GROUNDWATER RESOURCES

THE AQUIFERS

Wells supply water for many communities, farms, and industries in north-central Iowa. The water from these wells comes from deposits of unconsolidated materials and layered rocks with characteristics consistent enough to allow fairly reliable predictions of their water-yielding potential. These predictions are based on the analysis of records from about 1,300 wells in the report area and adjacent counties (figure 24).

Rocks and sediments that store and transmit water are called aquifers. There also are rocks and sediments present that do not transmit water very well, although they may store large quantities of water. These rocks and sediments are called confining beds. Confining beds are a significant aspect of the groundwater system. Where present, they affect water levels, water quality, and well yields by restricting interaquifer flow and mixing. In this report, only those aquifers that yield appreciable quantities of water to wells are considered. The first part of this section describes the spatial relationships of the aquifers and the second part discusses the water contained within these aquifers.

In north-central Iowa, there are three different surficial aquifer types and five bedrock aquifers available for use as sources of water supplies. The unconsolidated deposits of sediment near the land surface comprise the surficial aquifers and confining beds. Beneath these deposits are layers of consolidated sedimentary rock. Some of these rock layers are aquifers and others are confining beds. The rock units that do yield significant quantities of water to wells are the Cretaceous aquifer, the Mississippian aquifer, the Devonian aquifer, the Cambrian-Ordovician aquifer and the Dresbach aquifer (figure 25). The Cambrian-Ordovician and Dresbach aquifers are the deepest of the five aquifers and are completely separated from each other by thick confining beds. This is not the case with the other rock aquifers; they are separated by confining beds only in part of the study area.

Beneath the sedimentary bedrock sequence lies metamorphic and igneous crystalline rocks of Precambrian age which are referred to as the "basement complex". Presumably these rocks have little or no water-yielding potential but reliable well data are lacking.

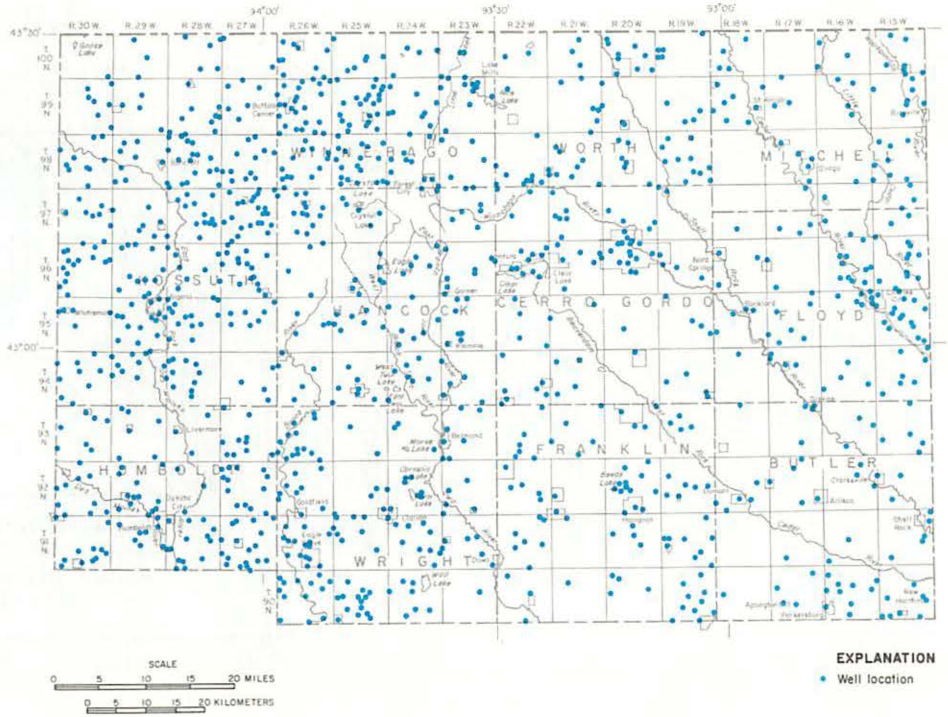


Figure 24. Availability of well data for north-central Iowa

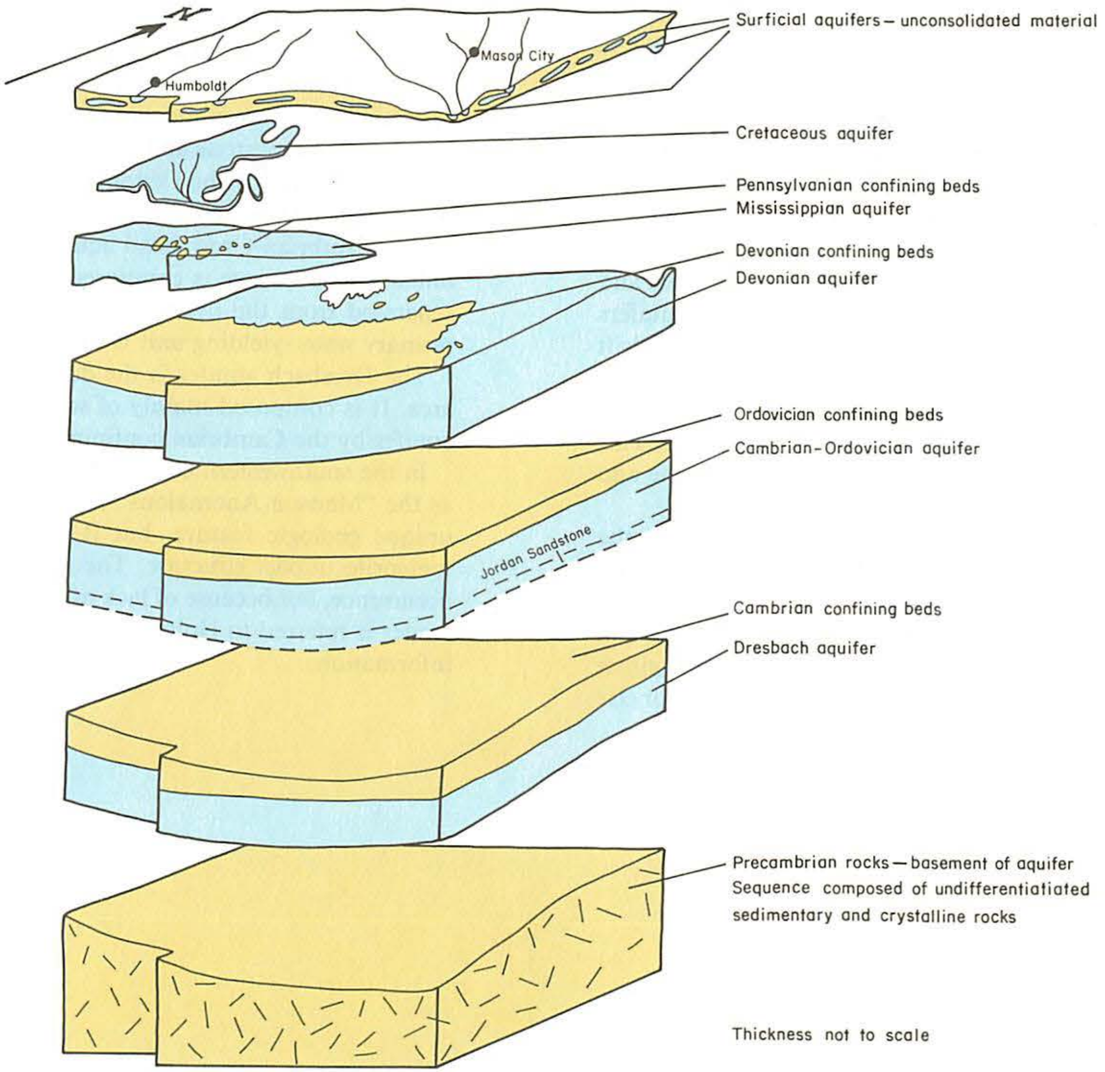


Figure 25. The aquifers in north-central Iowa

The rock units of north-central Iowa are listed in table 4. This stratigraphic sequence contains many rock units that are distinguishable from one another because of numerous physical, mineralogical, and paleontological characteristics. However, for the purpose of describing the general availability of water, these units are grouped into aquifers and confining beds on the basis of their water-yielding characteristics. The information contained in the following pages is concerned with the areal distribution, depth, and thickness of the aquifers.

The surficial aquifers consist of unconsolidated sands and gravels deposited by glaciers and streams. Silt and clay are confining beds. On the basis of areal and vertical distribution as well as water-bearing characteristics, the surficial aquifers are subdivided into three types: alluvial, buried-channel, and glacial-drift aquifers.

The Cretaceous aquifer is geologically the youngest of the bedrock aquifers, and is the shallowest bedrock aquifer in the western part of the study area. This aquifer is a relatively thin and discontinuous unit composed of sandstone and shale.

The Mississippian aquifer forms the uppermost bedrock in most of the southwestern corner of the report area. In some areas Mississippian rocks are overlain by Cretaceous rock and outlying Pennsylvanian rock remnants. The Mississippian aquifer is composed mainly of carbonate rocks (limestone and dolomite) with some sandstone. Generally the Mississippian aquifer is either separated from the Cretaceous aquifer by Cretaceous shale confining beds or else the two are in contact. In small isolated areas some Pennsylvanian rocks may act as a confining layer between Mississippian and Cretaceous units.

The Devonian aquifer is present beneath most of the study area, and is the uppermost bedrock in most of the northern and eastern counties. This aquifer is composed of limestone and dolomite, and where it is not the uppermost rock, is directly overlain by the Devonian confining beds, which are in turn overlain in some areas by Cretaceous rocks.

The Cambrian-Ordovician aquifer is a thick sequence of deeply-buried rock units. This sequence is composed of carbonate and sandstone units which are separated from the overlying aquifer by the Ordovician confining beds. The primary water-yielding unit is the Jordan Sandstone of Late-Cambrian age.

The Dresbach aquifer is the deepest and the least used aquifer in the study area. It is composed mainly of sandstone and is separated from the overlying aquifer by the Cambrian confining beds.

In the southwestern corner of the report area is a geologic feature referred to as the "Manson Anomalous Area" (figure 29). Very little is known about this unique geologic feature, but it has been described as a cryptovolcanic or meteorite impact structure. The feature is mentioned here to acknowledge its occurrence, but because of lack of adequate data, it is not discussed further. The reader is referred to Holtzman (1970) and Hoppin and Dryden (1958) for more information.

Hydrogeologic unit	Maximum thickness (feet)	Age of rocks	Name of rock units		Type of rock
SUPERFICIAL AQUIFER alluvial buried channel drift	325	QUATERNARY (0 to 2 million years ago)	Quaternary deposits undifferentiated		**Sand, gravel, silt, and clay; till (sandy, pebbly clay) with minor interbedded sand, gravel, silt, and clay**
CRETACEOUS aquifer	+260	CRETACEOUS (65 to 145 million years ago)	Dakota Formation		Sandstone and shale
PENNSYLVANIAN ROCKS Principally confining beds	80	PENNSYLVANIAN (280 to 310 million years ago)	Cherokee Group		Shale, clay, siltstone, sandstone and coal beds
MISSISSIPPIAN aquifer	+361	MISSISSIPPIAN (310 to 345 million years ago)	Meramecian Series	Ste. Genevieve Limestone	Shale and siltstone
				St. Louis Limestone	Dolomite, sandstone and limestone
				Spergen Formation	Limestone
			Osagean Series	Warsaw Formation	Dolomite, limestone, and chert
				Keokuk Limestone	Dolomite and limestone
			Kinderhookian Series	Gilmore City Limestone	Sandstone, limestone and shale
				Hampton Formation	Dolomite, limestone and chert
				Starrs Cave Formation	Limestone, shale and sandstone
				Prospect Hill Formation	Dolomite, limestone, sandstone siltstone and shale
				McCraney Limestone	Dolomite and sandstone
DEVONIAN confining bed	215	DEVONIAN (345 to 400 million years ago)	YELLOW SPRING GROUP	English River Formation	Dolomite and siltstone
				Maple Hill Shale	shale, dolomite and siltstone
				Applington Formation	dolomite and chert
				Sheffield Formation	shale
			Lime Creek Formation		Dolomite and shale
			Shell Rock Formation		Dolomite and limestone
DEVONIAN aquifer	450		Cedar Valley Limestone		Limestone and dolomite
			Wapsipinicon Formation		Dolomite, limestone and shale
ORDOVICIAN confining beds	581	ORDOVICIAN (425 to 500 million years ago)	GALENA GROUP	Maquoketa Formation	Dolomite and shale
				Dubuque Formation	Dolomite and shale
				Wise Lake Formation	Dolomite and chert
				Dunleith Formation	Dolomite and chert
				Decorah Formation	Limestone and shale
			ANCELL GROUP	Platteville Formation	Limestone, shale and sandstone
CAMBRIAN-ORDOVICIAN aquifer	867			St. Peter Sandstone	Sandstone
			PRARIE DU CHIEN GROUP	Shakopee Formation	Dolomite
				Oneota Formation	Dolomite and sandstone
			TREMPEALEAU GROUP	Jordan Sandstone	Sandstone
CAMBRIAN confining bed	255	CAMBRIAN (500 to 600 million years ago)		St. Lawrence Formation	Dolomite
			Lone Rock Formation		Shale, siltstone and sandstone
DRESBACH aquifer	511		ELK MOUND GROUP	Wonewoc Formation	Sandstone
				Eau Claire Sandstone	Sandstone, shale and dolomite
				Mount Simon Sandstone	Sandstone
PRECAMBRIAN rocks		PRECAMBRIAN (600 to more than 2 billion years ago)	Undifferentiated sedimentary and crystalline rocks		Sandstone, igneous and metamorphic

[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.]

Table 4. Hydrogeologic units in north-central Iowa

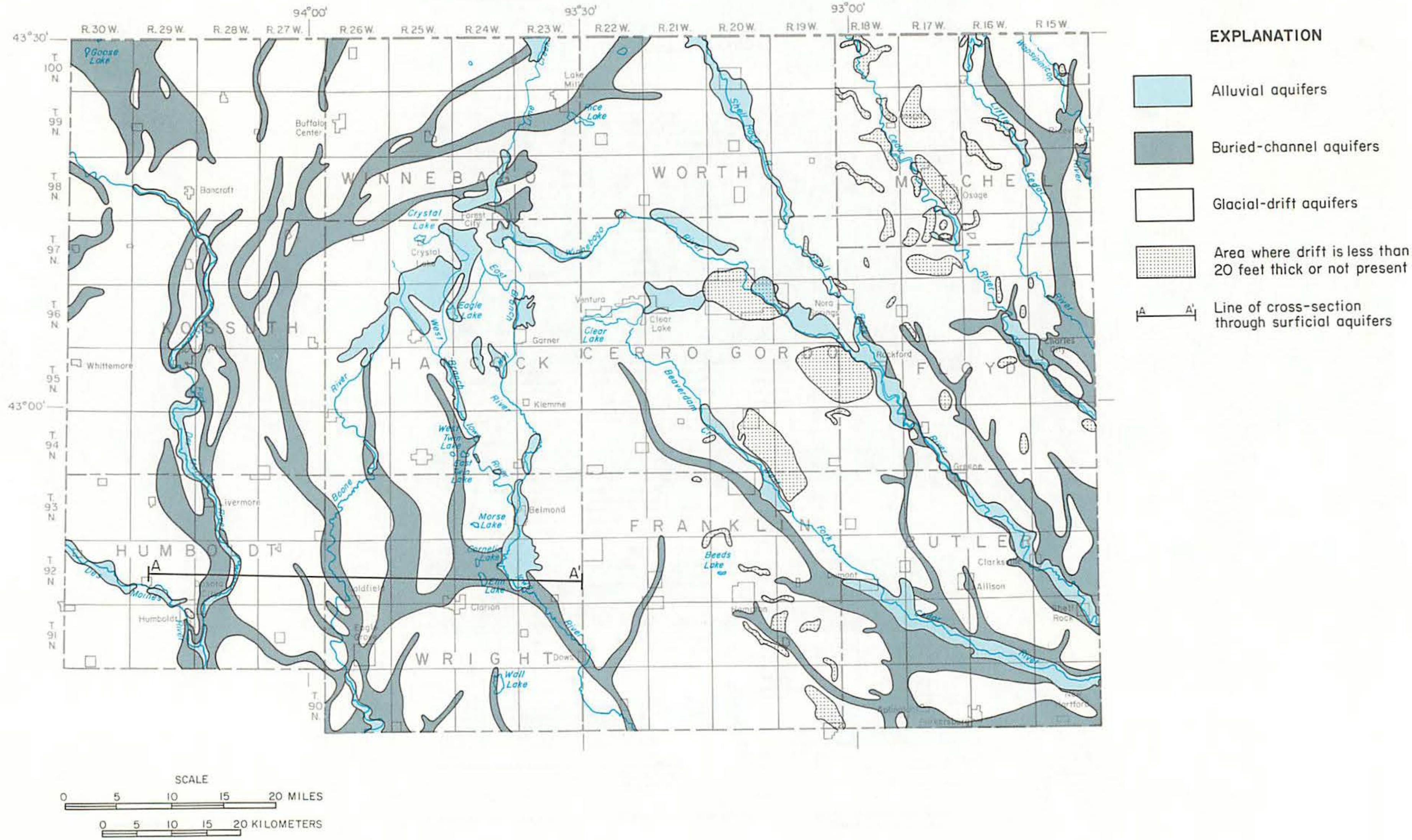


Figure 26. Areal distribution of the surficial aquifers

SURFICIAL AQUIFERS

The surficial aquifers are located within the unconsolidated materials above the bedrock surface. They are subdivided into alluvial, buried-channel and glacial-drift aquifers (figure 26).

The alluvial aquifers are deposits of stream-transported material located along present-day watercourses. They consist of sands and gravels interbedded with less permeable silts and clay which lie beneath the flood plains of the major streams. Alluvial aquifers within the report area are discontinuous along the stream drainages. The Des Moines River, the Shell Rock River, the West Fork Cedar River, and the Winnebago River have the most continuous alluvial-aquifer systems.

Buried-channel aquifers are composed of unconsolidated material deposited by ancient streams in valleys eroded prior to or between glacial advances. These ancient valleys are buried beneath the glacial drift deposited when the glaciers retreated. Many of these valleys were eroded deeply into the bedrock and are much wider than the valleys of present day streams (figure 27). Buried channels are recognized easily on the bedrock topography map (figure 28), but are indistinguishable on the modern landscape. Although the surface expression of the buried channels may be subtle, they can affect modern drainage. Flood Creek, the southern reach of the Shell Rock River, reaches of the East Fork Des Moines River, and the West Fork Cedar River, all follow ancient buried stream valleys.

The glacial-drift aquifers are irregularly occurring beds of sand, gravel, or both, which are distributed within the glacial drift. These sands and gravels were deposited by glacial meltwater and their areal extent, thickness, and stratigraphic position are not readily predictable. Thus, the potential of the glacial-drift aquifer as a water source at given locations is uncertain. Thicknesses of glacial drift are variable.

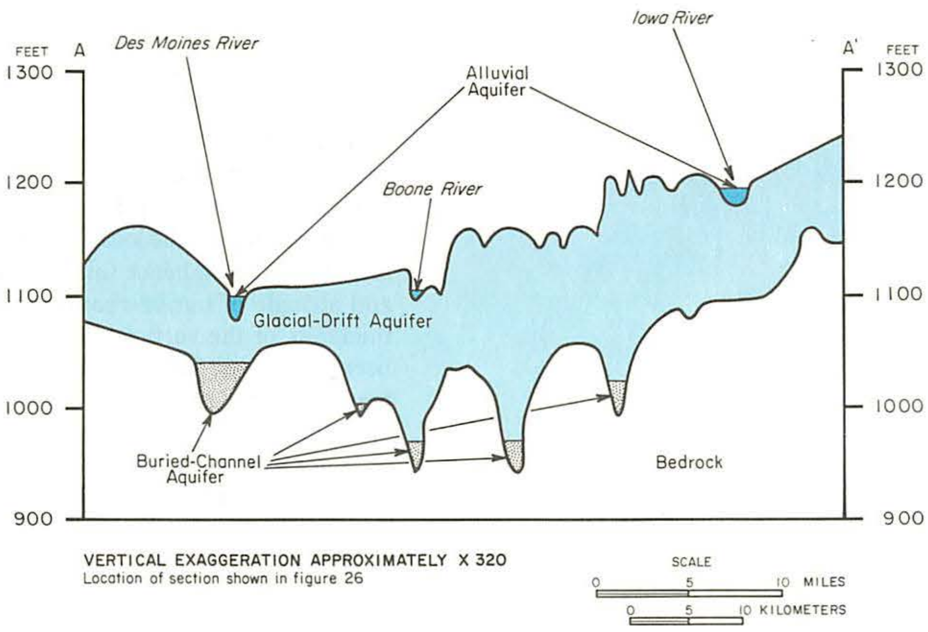


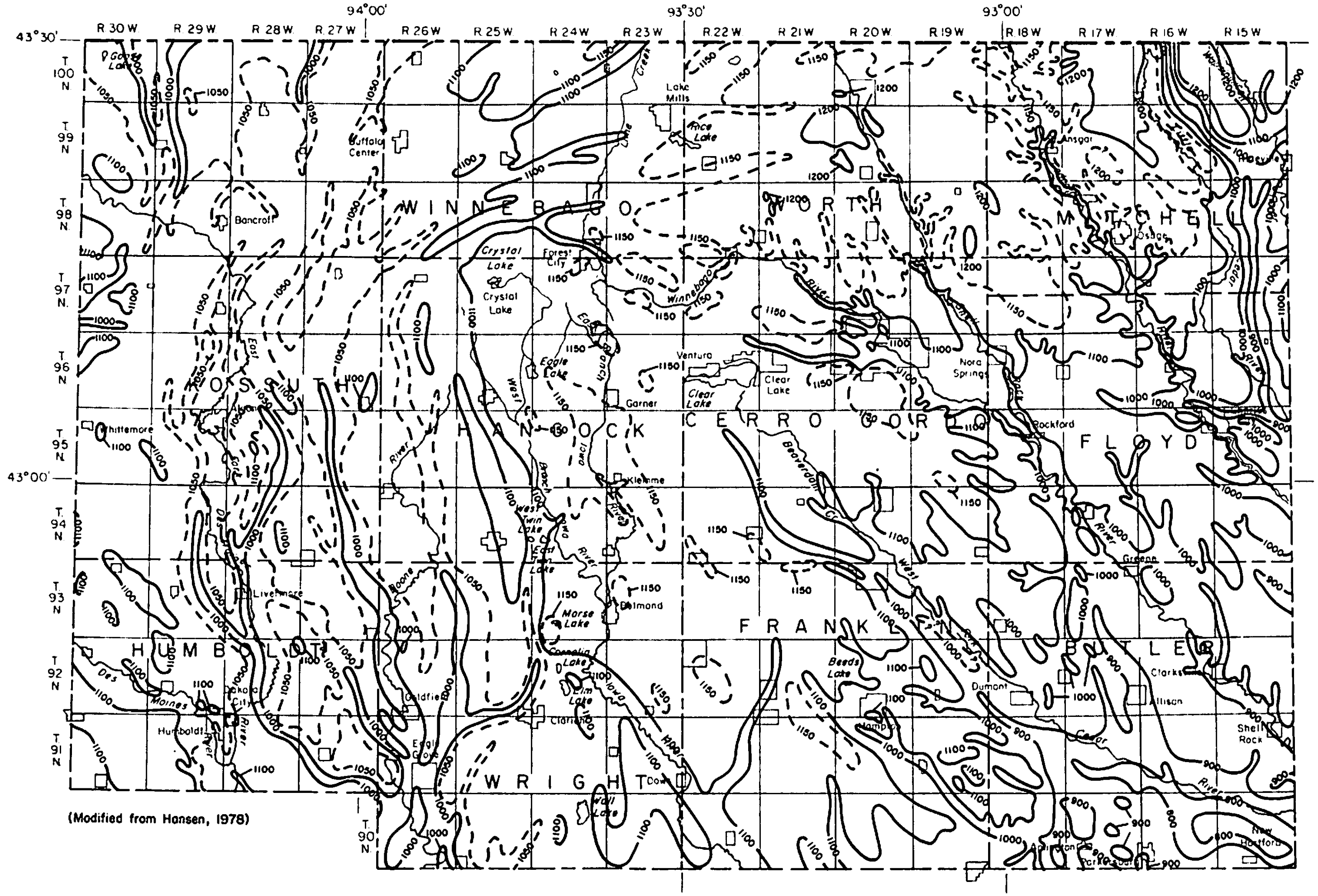
Figure 27. Generalized hydrogeologic section through the surficial aquifers in Humboldt and Wright Counties

THE BEDROCK SURFACE

The bedrock surface is the interface between the unconsolidated surficial deposits and the consolidated rock units. The altitude and configuration of this surface is shown on the accompanying map (figure 28). This is a topographic map of what would be the land surface if the surficial deposits were removed (for a more detailed map see Hansen, 1978).

The map shows the location and depth of the buried channels that were eroded into the bedrock; hence this map and figure 26 can be used to find the location and altitude of buried-channel aquifers. Depth to the bedrock surface and the thickness of the surficial deposits can be determined by taking the difference between the surface altitudes (figure 6 or U.S. Geological Survey topographic maps) and the altitude of the bedrock surface (figure 28 or Hansen, 1978).

Although the bedrock map indicates the position of the bedrock surface, it does not show what type of rock comprises this surface. The bedrock present at the bedrock surface is not always an aquifer, in some places it is a confining bed. To illustrate this for the study area a bedrock hydrogeologic map was constructed (figure 29).



SCALE

0 5 10 15 20 MILES

0 5 10 15 20 KILOMETERS

EXPLANATION

—900— Bedrock Contour
Shows altitude of bedrock surface
Contour interval 100 feet
Queried where approximately located
Supplemental 50-foot contour shown by dashed line

Figure 28. Altitude and configuration of the bedrock surface

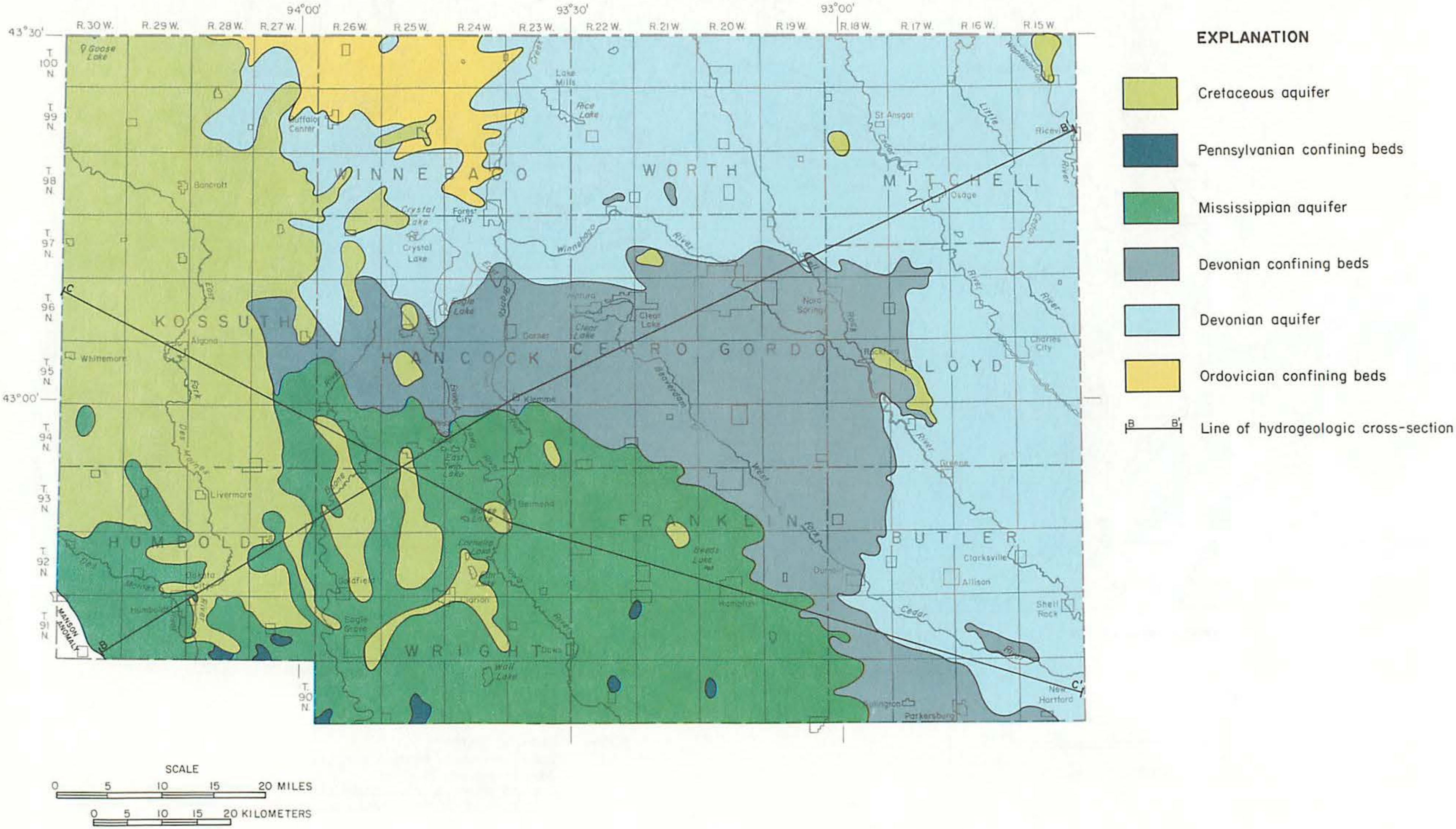


Figure 29. Hydrogeologic map of the bedrock surface

BEDROCK AQUIFERS

The bedrock hydrogeologic map (figure 29) shows the aquifers and confining beds that make up the bedrock surface in north-central Iowa. This pattern of overlapping rock types resulted from differential erosion of progressively older rock units that dip to the south and southwest. The rock units forming the bedrock surface become progressively younger in age from the northeast to the southwest, and from northern Winnebago County to the south.

The surface exposure of otherwise deeply-buried Ordovician confining beds in northern Kossuth and Winnebago counties is the result of upwarping and erosion of the younger geologic units in this area.

The Cretaceous aquifer is located in the western one-third of the study area. Along its eastern margin it is thin and dissected, but the aquifer gains greater continuity in the western direction. Outliers of the Pennsylvanian confining beds underlie parts of the Cretaceous aquifer and are exposed as part of the bedrock surface in a very small fraction of the southwestern one-third of the report area.

The Mississippian aquifer is located in the south-central to southwestern section of the region and forms the uppermost bedrock in most of Franklin and Wright Counties. Elsewhere it is intermittently covered by younger rocks.

The Devonian confining beds form the bedrock surface throughout much of the central counties and extend to the southeast into Butler County. The Devonian aquifer is the uppermost bedrock along the eastern border and most of the northern borders of the region.

Ordovician confining beds are the uppermost bedrock in portions of Winnebago and northeastern Kossuth Counties, but the older, deeper Cambrian-Ordovician aquifer does not form part of the bedrock surface in the report area. Their positions within the geologic sequence are depicted in the hydrogeologic sections (figure 30).

The relationships of the geologic units in the study area to each other are depicted in the hydrogeologic sections. These sections show that the deeper beds are approximately parallel and have a comparatively uniform thickness. The shallow beds are less uniform in thickness because their tops were eroded and they were covered by younger materials.

The Dresbach aquifer is the deepest bedrock aquifer yielding significant water within the study area, but very few wells penetrate to this depth. No thickness or altitude maps are presented for this aquifer because of a lack of data. The aquifer is shown on the hydrogeologic sections as inferred from several wells which indicate the probable thickness, and by making its surface parallel to overlying beds.

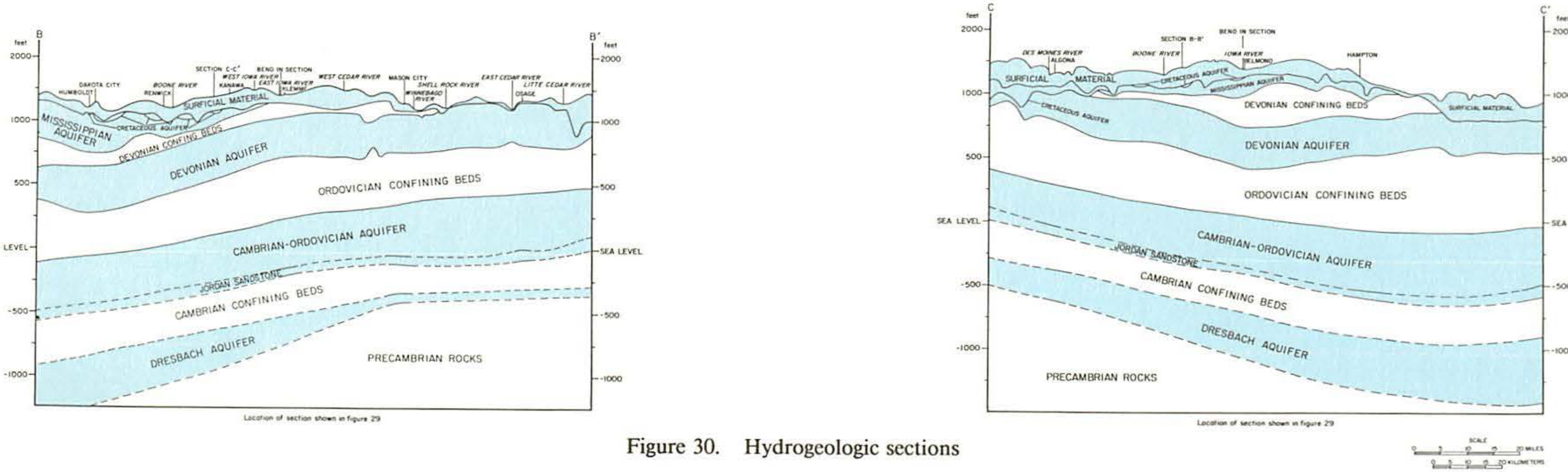


Figure 30. Hydrogeologic sections

ALTITUDE OF THE BEDROCK AQUIFERS

The depth to the bedrock aquifers varies considerably throughout the report area, due to the thickness of the surficial material, and the thickness and dip of any overlying rock units. The depth to each aquifer can be determined by taking the difference between the land-surface altitude (topographic maps and figure 6) and the altitude of the top of the various aquifers shown in figures 31-35.

The altitude and configuration of the tops of the bedrock aquifers are a result of erosion and structural deformation. Erosion, especially glacial erosion, occurred during several periods of geologic time resulting in the development of extensive drainage systems which removed large volumes of rock material.

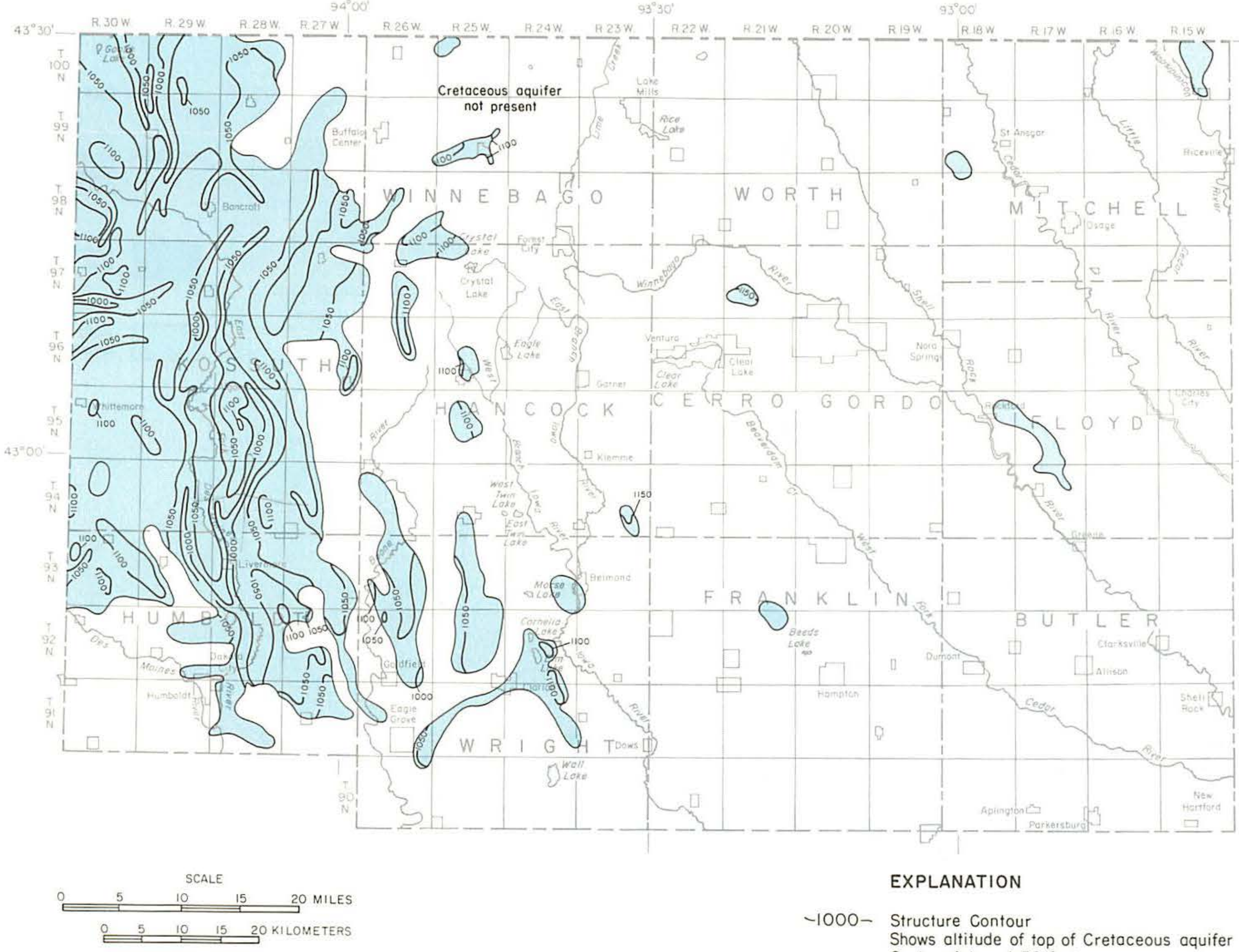
The top surface of the Cretaceous aquifer has been extensively eroded. The surface is one of low relief, about 100 feet, but is quite irregular, with many ancient stream channels having been eroded into and completely through the unit. The Cretaceous-age rocks extending into the study area are the eastern edge of a large geologic unit that is a major aquifer in northwest and west-central Iowa.

The Mississippian aquifer also has a very irregular, low relief upper surface. Erosion of exposed rock occurred during several time intervals: post-Mississippian prior to deposition of Pennsylvanian-age rocks, post-Pennsylvanian prior to Pleistocene glaciation, and during Pleistocene glaciation.

Structural deformation coupled with several periods of erosion shaped the surface of the Devonian aquifer. Most of the aquifer in the report area is overlain by Devonian-age confining units. Before deposition of the Devonian confining units, streams had deeply incised the aquifer, creating channels. A more recent period of erosion of the tilted Devonian rocks removed the confining units in the eastern and northeastern counties. The exposed aquifer surface was modified greatly prior to and during Pleistocene glaciation and subsequent burial.

Within the study area the Cambrian-Ordovician aquifer dips gently to the south. Superimposed on this dipping unit are north-south trending surface undulations. The Jordan Sandstone, which is the primary water-yielding unit of the Cambrian-Ordovician aquifer, has the same southerly dip but not the same uniform undulation.

The Dresbach aquifer is the deepest known water-bearing unit in north-central Iowa. Very few wells have been drilled deep enough to penetrate this aquifer, so very little information is available concerning its altitude and areal extent. The aquifer was deposited on Precambrian rocks and is assumed to have approximately the same southerly or southwesterly dip as the units just above it (figure 30). From the few wells that do penetrate it, the altitude of the top surface was determined to be 914 feet below sea level in Butler County, 302, 364, and 375 feet below sea level in Cerro Gordo County, 881 feet below sea level in Humboldt County and 371 feet below sea level in Kossuth County.



EXPLANATION

—1000— Structure Contour
Shows altitude of top of Cretaceous aquifer
Contour interval 50 feet

Area where Cretaceous aquifer is present

Figure 31. Altitude of the top of the Cretaceous aquifer

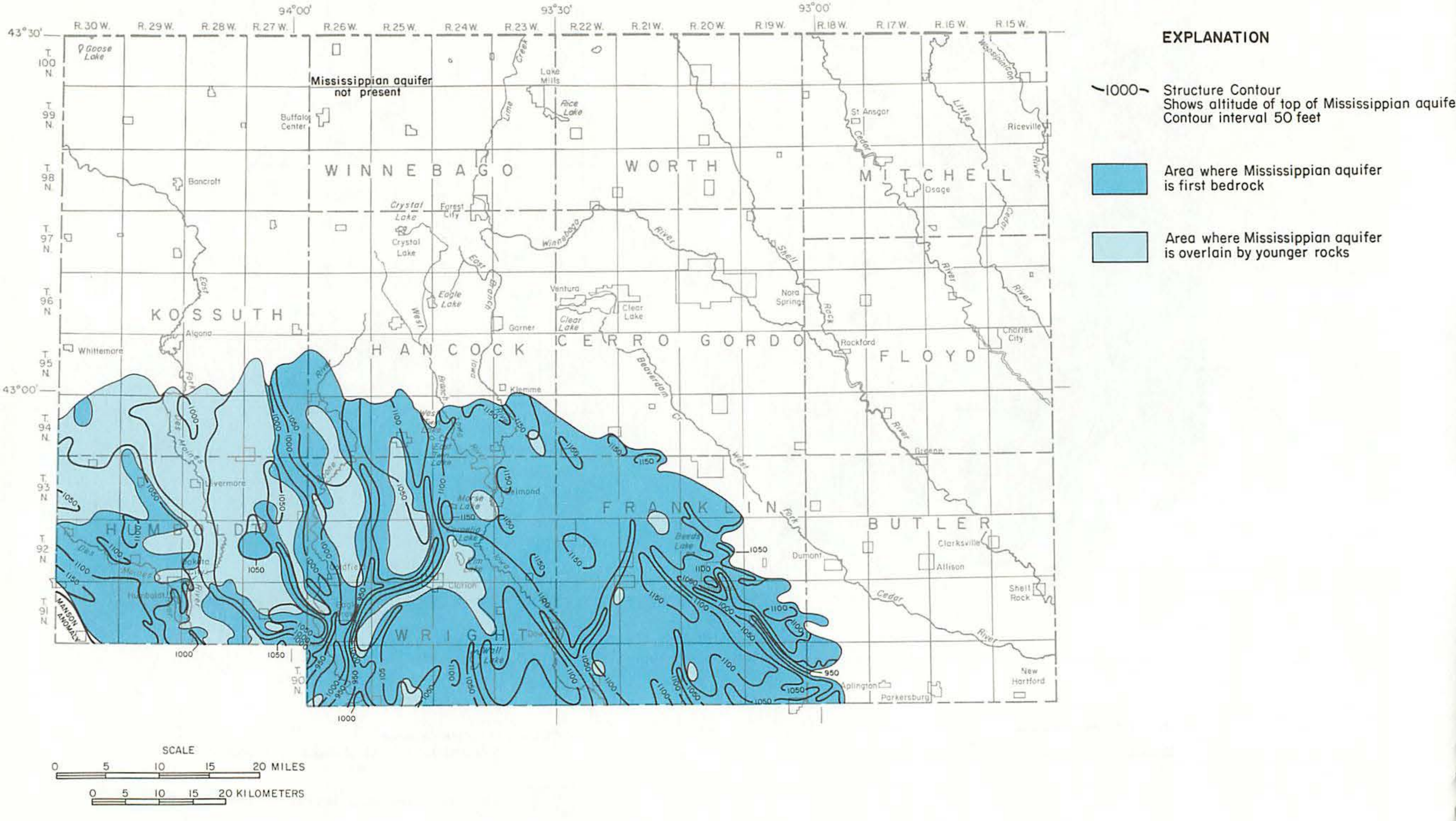


Figure 32. Altitude of the top of the Mississippian aquifer

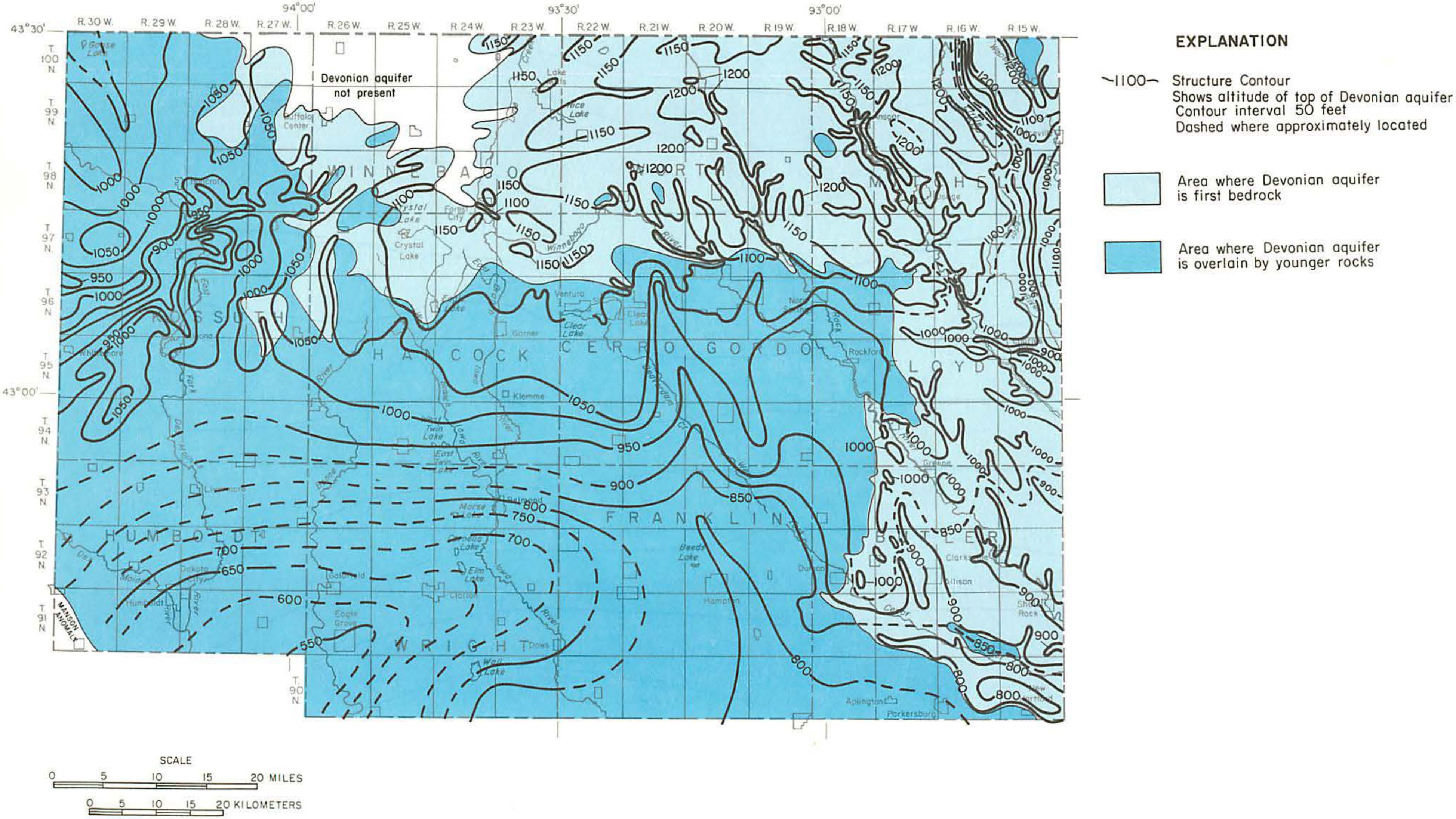
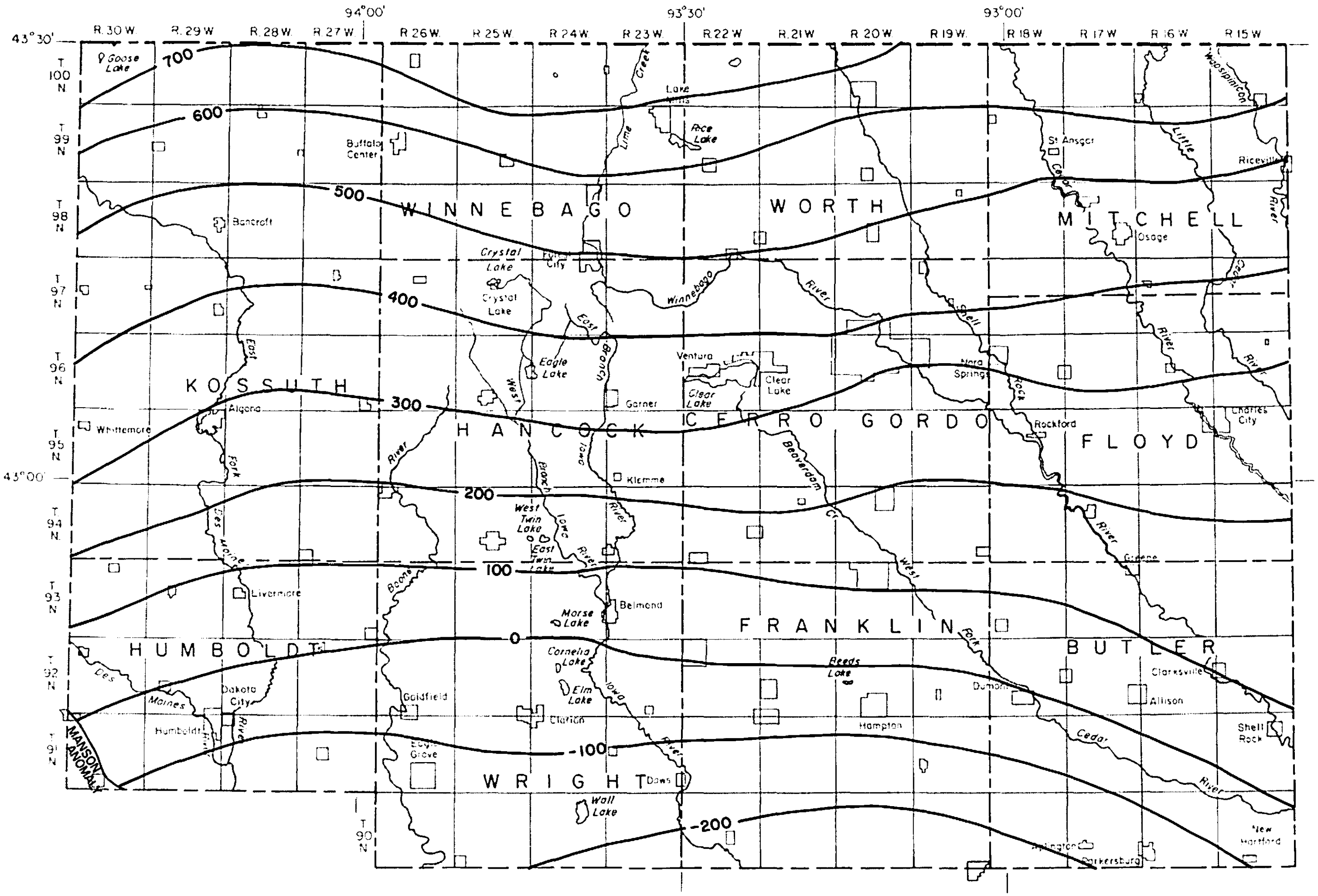


Figure 33. Altitude of the top of the Devonian aquifer



SCALE

0 5 10 15 20 MILES

0 5 10 15 20 KILOMETERS

EXPLANATION

—100— **Structure Contour**
Shows altitude of top of Cambrian-Ordocian aquifer
Contour interval 100 feet

Figure 34. Altitude of the top of the Cambrian-Ordovician aquifer

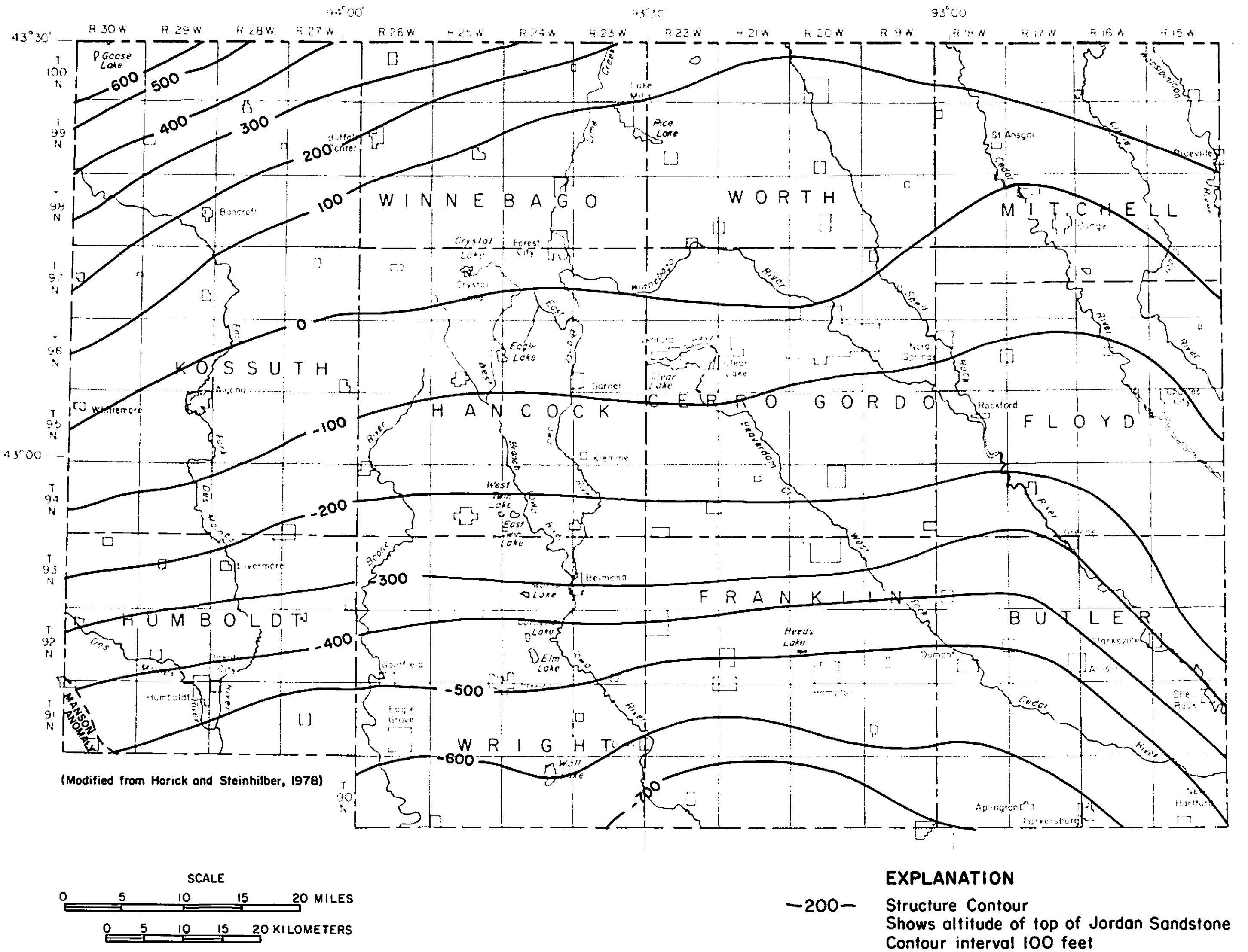


Figure 35. Altitude of the top of the Jordan Sandstone

THICKNESS OF THE BEDROCK AQUIFERS

An aquifer will normally yield the largest quantity of water to a well where the aquifer is thickest, assuming that the well fully penetrates the rock unit and the aquifer is homogeneous. Maps depicting the thickness of the aquifers (figures 36-40) can be used in conjunction with altitude maps to determine the depth to which wells need to be drilled to fully penetrate the water-bearing rocks.

The thickness of each bedrock aquifer varies locally throughout north-central Iowa because: (1) The surface upon which these rocks were deposited was irregular and more sediment accumulated in lower areas than higher areas; (2) more material was deposited over some areas than others; and (3) erosion has subsequently removed large volumes of material from some places.

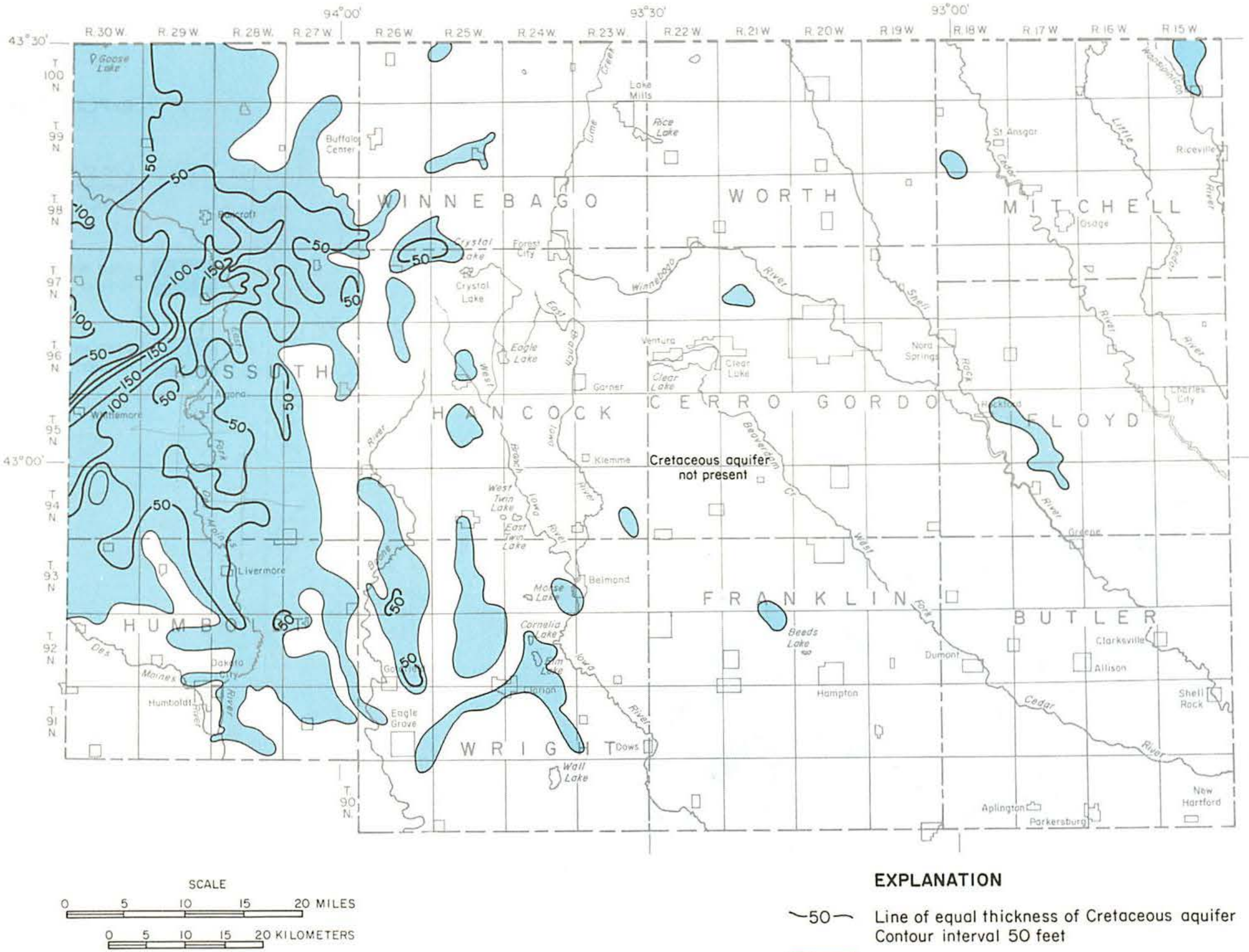
The thickness of the Cretaceous aquifer is quite variable, ranging from 0 to about 200 feet. This variability is due to erosion prior to and during glaciation. Many ancient stream channels eroded into and across the surface. The aquifer is thinnest in the southern and eastern parts of the study area and becomes thicker toward the north and west. Some thicker areas of Cretaceous rocks are the result of greater deposition in pre-Cretaceous age channels.

The Mississippian aquifer ranges in thickness from approximately 50 to 350 feet. This is the northernmost edge of the Mississippian aquifer in Iowa. Post-Mississippian and pre-Pleistocene erosion removed the aquifer to the north. The aquifer thickens progressively from east to west and from north to south, and is thickest along the southern border of Humboldt and Wright Counties.

Extensive erosion of the Devonian surface created considerable variation in the thickness of the aquifer. This aquifer ranges in thickness from 0 to about 400 feet. The thinnest areas are in the erosional channels and in Winnebago and Kossuth Counties adjacent to where it has been removed completely.

The total thickness of the Cambrian-Ordovician aquifer is not known in the study area because very few wells completely penetrate it. The thickness of the Cambrian-Ordovician aquifer ranges from approximately 400 to 700 feet. The Jordan Sandstone, one of the most dependable water-yielding units in the Cambrian-Ordovician aquifer, ranges in thickness from about 40 to 100 feet.

Four wells fully penetrate the Dresbach aquifer. Well logs show a considerable variation in the regional thickness of the aquifer. Logs from two wells in Cerro Gordo County indicate that its thickness is 58 and 237 feet; in wells in Kossuth and Butler Counties the thickness of the aquifer is 255 and 1,770 feet, respectively.



EXPLANATION

—50— Line of equal thickness of Cretaceous aquifer. Contour interval 50 feet

Area where Cretaceous aquifer is present

Figure 36. Thickness of the Cretaceous aquifer

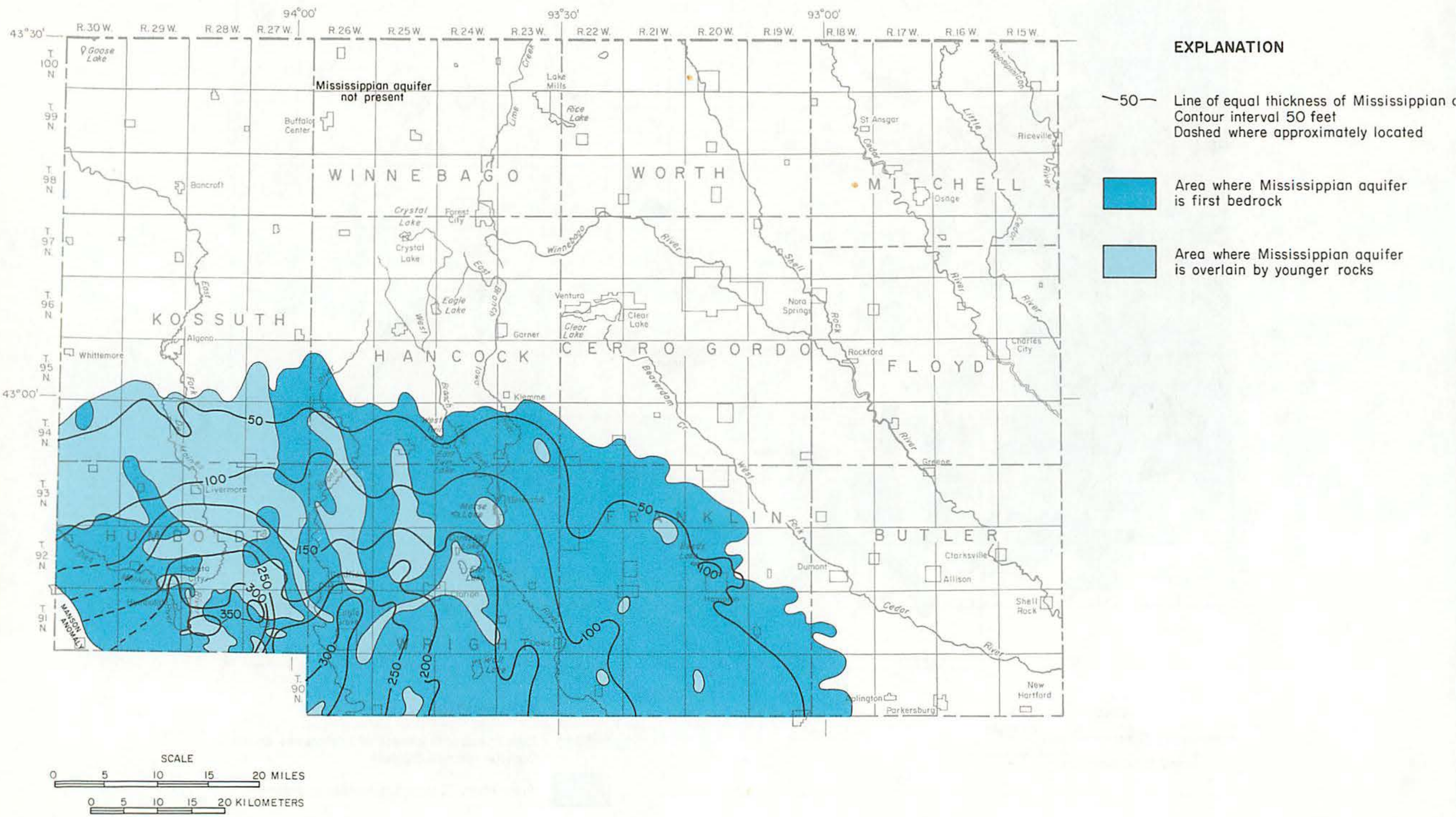


Figure 37. Thickness of the Mississippian aquifer

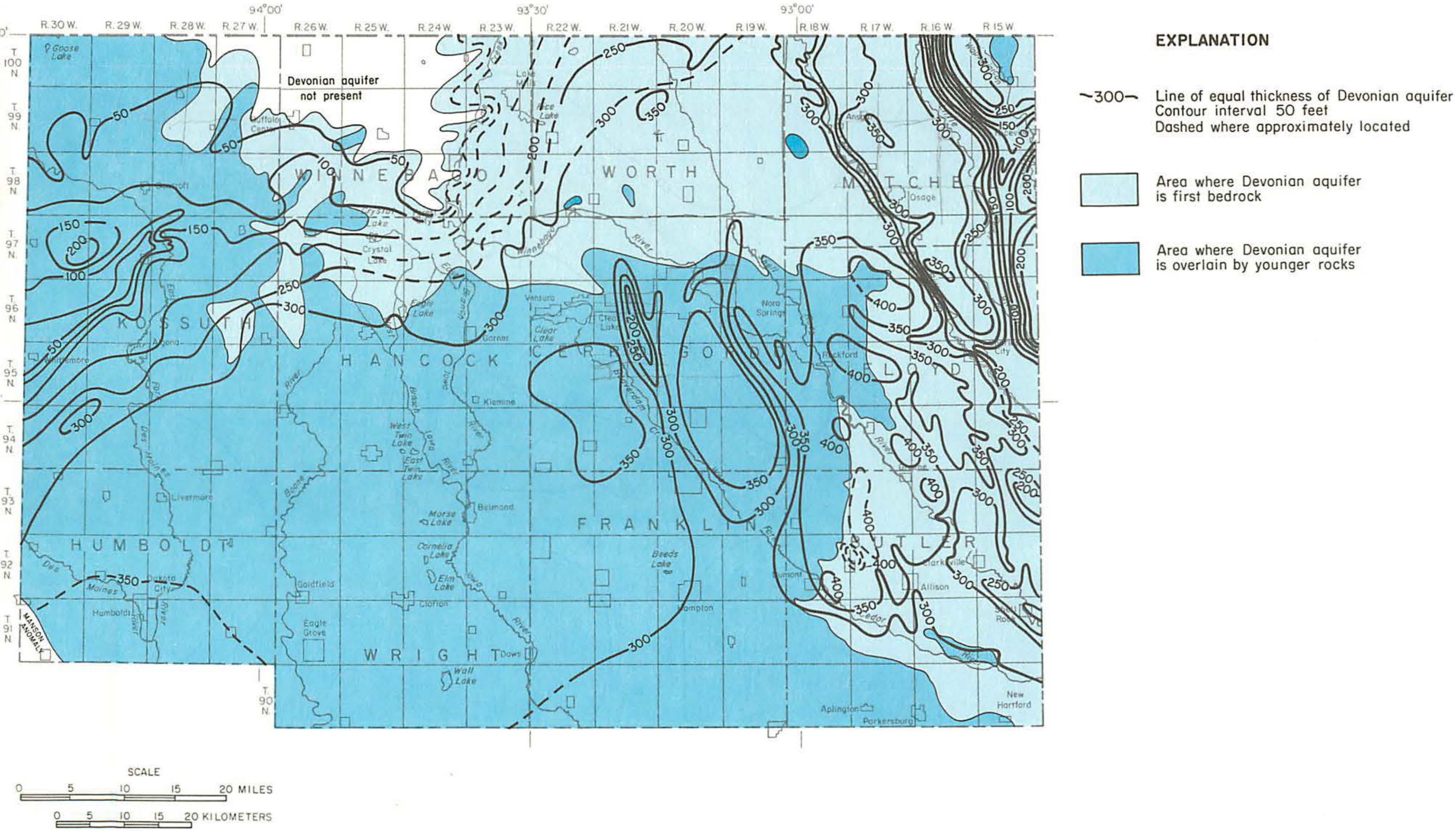
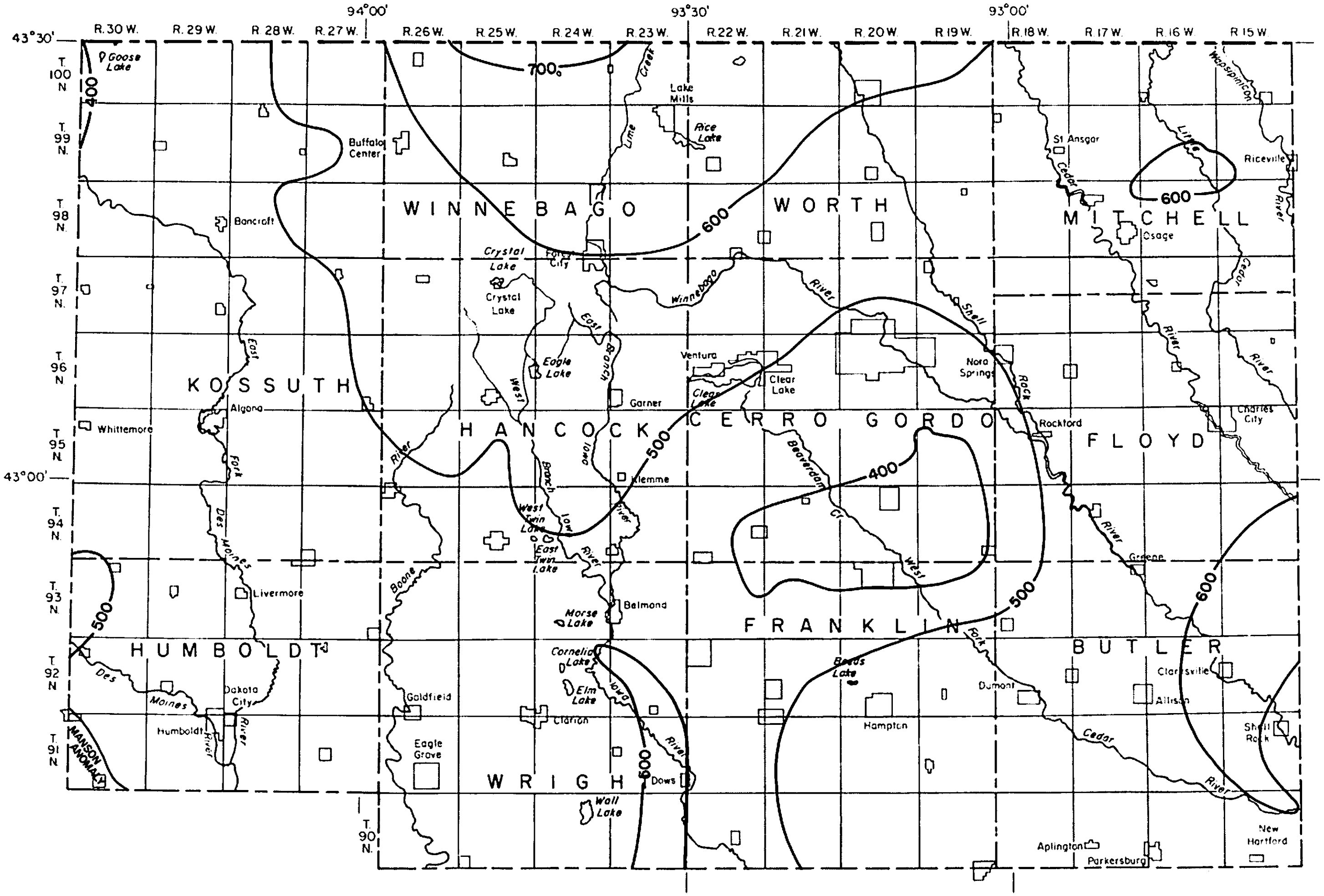


Figure 38. Thickness of the Devonian aquifer



SCALE

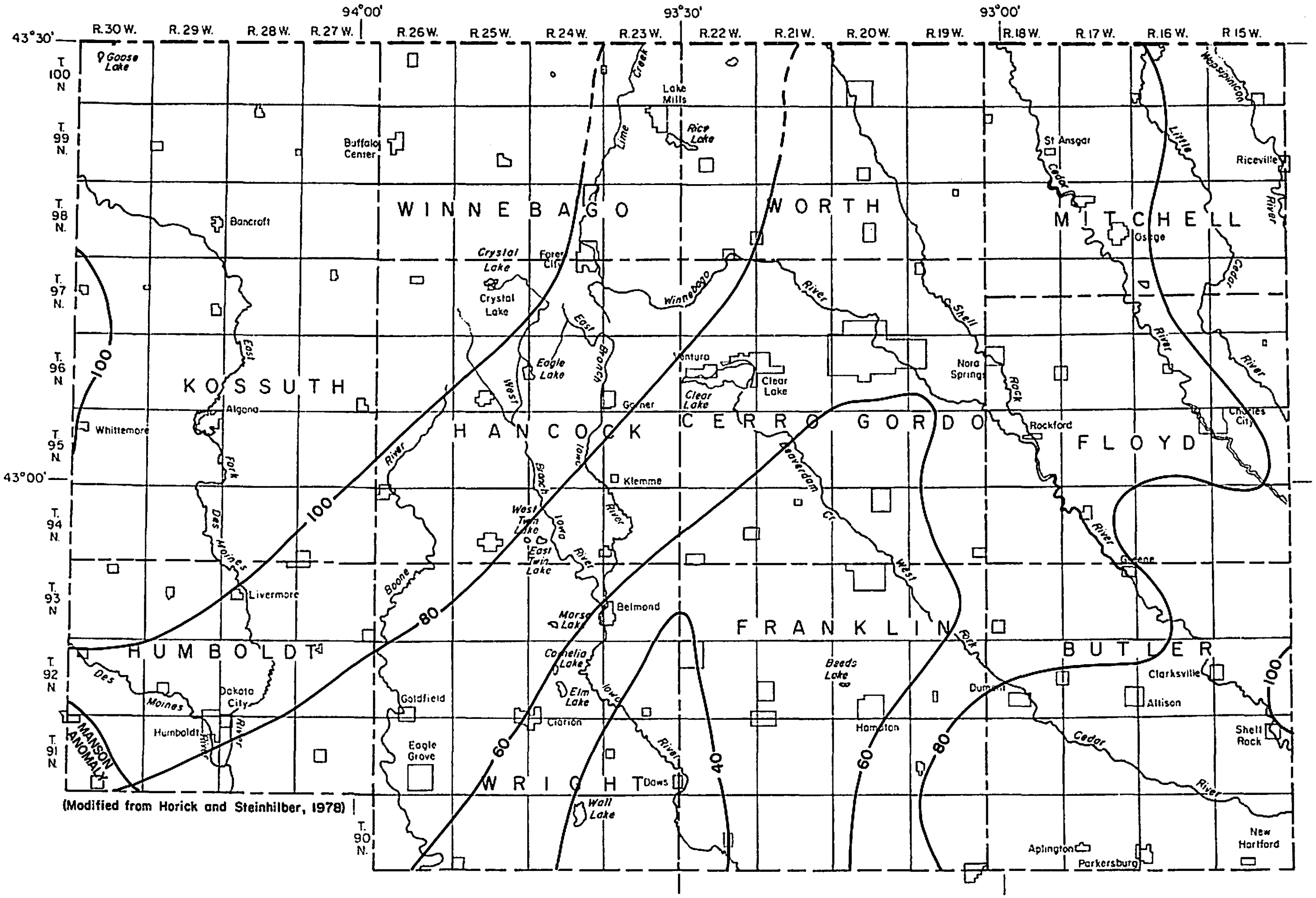
0 5 10 15 20 MILES

0 5 10 15 20 KILOMETERS

EXPLANATION

—600— Line of equal thickness of Cambrian-Ordovician aquifer
Includes St. Peter Sandstone, Prairie du Chien Group, and Jordan Sandstone
Contour interval 100 feet

Figure 39. Thickness of the Cambrian-Ordovician aquifer



SCALE

0 5 10 15 20 MILES

0 5 10 15 20 KILOMETERS

EXPLANATION

—100— Line of equal thickness of Jordan Sandstone
Dashed where approximately located
Contour interval 20 feet

Figure 40. Thickness of the Jordan Sandstone

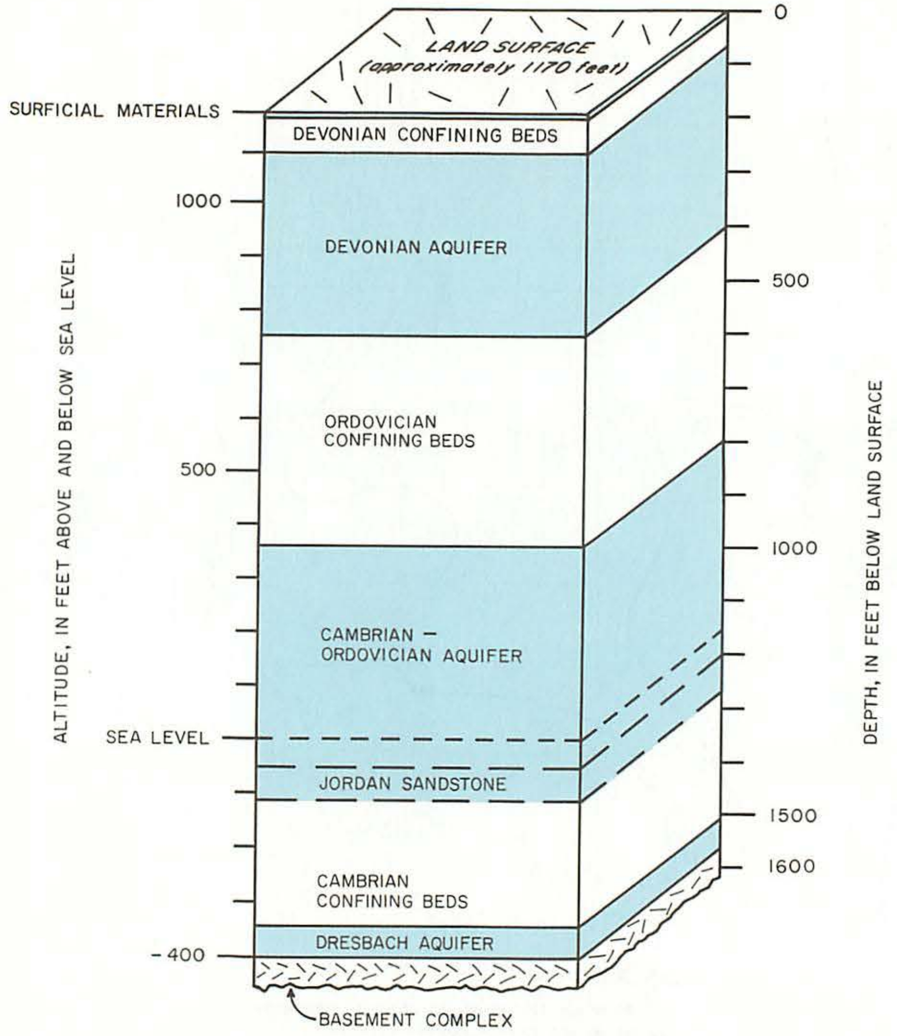


Figure 41. Aquifer depths and thicknesses from Mason City well number 2

USE OF MAPS TO ESTIMATE DEPTHS OF DRILLING

The preceding maps can be used to predict aquifer depths and thicknesses, a to aid in estimating the accessibility of groundwater. Well depths and requir length of casing can be estimated from the maps as a guide in designing a estimating costs of new wells. The land surface, the bedrock surface, and the to of the major aquifers are all referenced to sea level to facilitate such plannin

The depth to a given aquifer is the difference between the land-surface altitu (figure 6) and the altitude of the aquifer top (figures 31-35). The total depth o well fully penetrating an aquifer is the sum of the depth to the top of the aqui and the thickness of the particular aquifer (figures 36-40). Figure 41 compa depth and elevations for deposits encountered in Mason City well 2.

WATER IN THE AQUIFERS

Vater occurs in saturated sand and gravel deposits and in most sedimentary ·ks, filling void spaces in sandstone and filling the joints, fractures and solution annels in limestone and dolomite (figure 42). Aquifers consist of rocks and liments with numerous or relatively large interconnected openings that can ld appreciable quantities of water to wells.

Although aquifers are of primary concern in the discussion of water resources, nfining beds have considerable hydrological significance. They prevent or ard the movement and mixing of water between the land surface and the uifer, and between separate aquifers. Aquifers overlain by confining beds do t readily receive recharge from local precipitation.

Confining beds, either rock or sediment, can store large quantities of water but ld very little to wells. These materials are very fine-grained and quite porous, t tend to retain the water. Attraction between the water and the rock particles e to the small pore size, along with limited connection between voids, restricts id movement. Other confining beds consist of limestones and dolomites ich contain few openings through which water can flow. These rocks may be arly dry.

n the bedrock aquifers, and in some of the surficial aquifers that are overlain confining beds, the water is contained under pressure. Water in a well that is npleted in these confined aquifers rises above the top of the aquifer. Under se conditions, the aquifer is called artesian.

The level to which water will rise in a well completed in an aquifer represents point on an imaginary plane referred to as a potentiometric surface. The entiometric surface in artesian aquifers is a pressure surface rather than an ual water surface (figure 43). It is the height to which the water would rise if h a well were constructed at that particular location. Each aquifer in the report a has a separate potentiometric surface.

Vhere the aquifers are not overlain by confining beds, such as some of the ficial aquifers and parts of the Devonian aquifer, the top of the zone of uration is not restricted in vertical movement, and the aquifer can receive harge from local precipitation. Under this condition the aquifer is called an confined or water-table aquifer, with the upper surface of the zone of uration called the water table (figure 43).

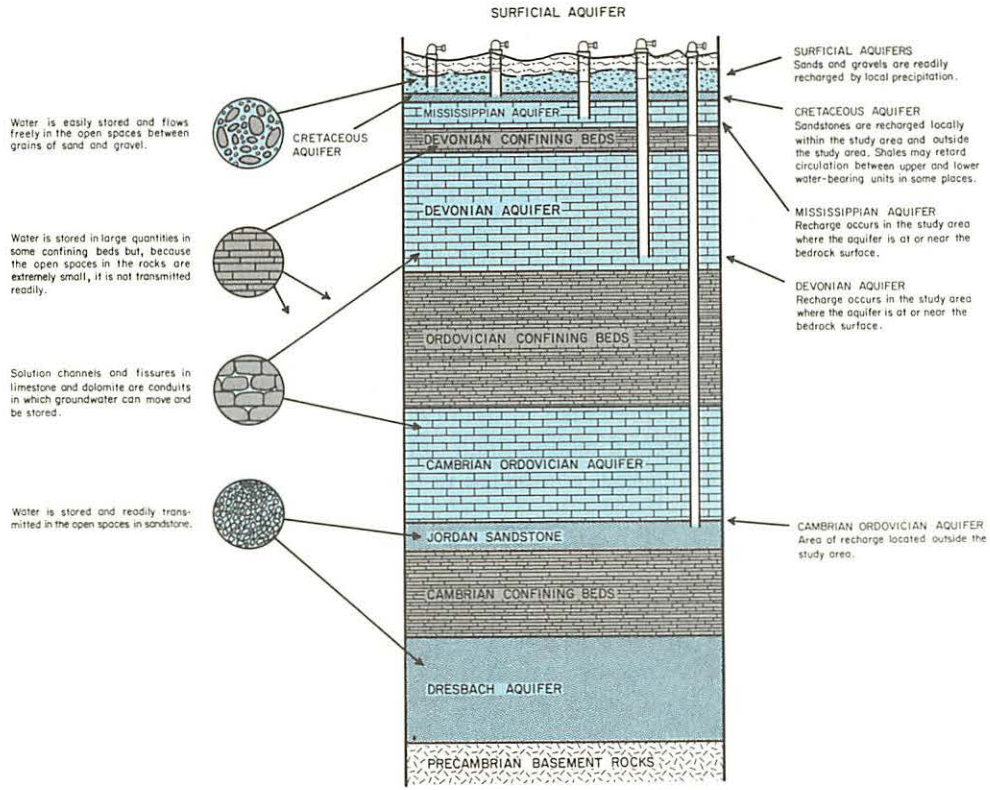
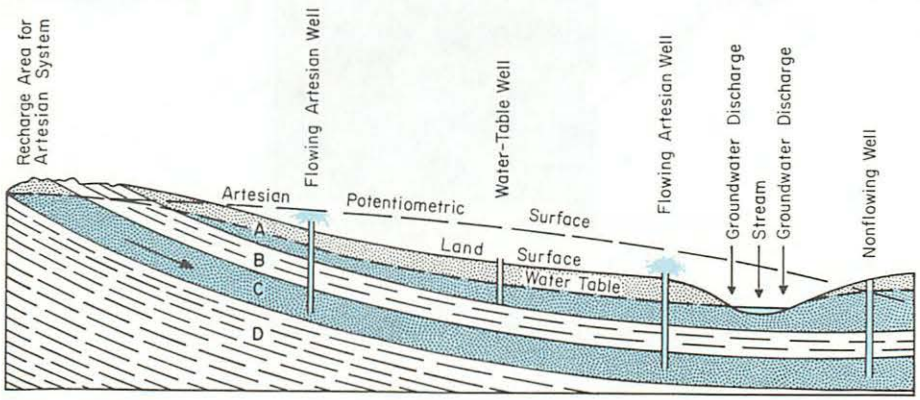


Figure 42. Occurrence of water in the aquifers

WATER LEVELS

The water level in a properly constructed well represents the position of the potentiometric surface at the well site. A number of water-level measurements at a given time from many wells completed in a particular aquifer defines the potentiometric surface of that aquifer. This surface is represented on maps by altitude contours in much the same way that the land surface or the tops of the aquifers are mapped. Such maps can be used to predict nonpumping water levels for proposed wells properly completed in that aquifer.

The configuration of the potentiometric surface defines groundwater movement in two dimensions. Water in each aquifer moves from areas of high hydraulic head (high potentiometric-contour values) to areas of low hydraulic head (low potentiometric-contour values) with the general direction of flow perpendicular to the contours. A hypothetical section through an unconfined and confined aquifer system is represented in figure 43. This section shows water movement in the downgradient direction (high to low hydraulic head), and the altitude of the water levels in wells completed in both types of aquifers.



EXPLANATION

A Permeable surficial material
B Upper confining bed
C Artesian aquifer
D Lower confining bed

Figure 43. Artesian and water-table conditions

The generalized depth to a water level in a given bedrock aquifer can determined by taking the altitude of the potentiometric surface from t appropriate map (figures 45-49) and subtracting it from the generaliz topography map (figure 6) in a given location.

Deep confined aquifers, such as the Cambrian-Ordovician and Dresba aquifers, contain water that is usually moving laterally across a region. Becau of the depth and areal extent of these aquifers the water generally moves gre distances from recharge areas to discharge areas. Local topography and strear have little or no effect on the direction of water movement in these deep confin aquifers.

In contrast, shallower aquifers, such as the surficial, Cretaceous, Mississi pian, and Devonian, contain water that usually is affected by local topograph These aquifers may have higher hydraulic head values in the upland areas a lower values near streams, which indicates that recharge and discharge occu within the area. Recharge to these aquifers is from local precipitation, dischar is to nearby streams.

Most recharge (from snowmelt and rain) reaches the water table a near-surface artesian aquifers during two periods each year. Between the spri thaw and the beginning of the growing season, water is available for rechar because plant transpiration is negligible. The water infiltrates into the unfroz soil and percolates down to the water table. Recharge also occurs in the interv between the first killing frost in the fall and the freezing of the ground in late f or winter because plant transpiration again is negligible. During most of t winter when the soil is frozen, very little water infiltrates the ground. During t growing season, vegetation intercepts and transpires most infiltrating moistu Only large rainstorms or periods of prolonged precipitation will provide enou water to meet the demands of plants and still leave an excess which mig percolate to the saturated zone. Hence, water levels in water table a near-surface artesian aquifers generally are highest during late spring and fa and are lowest during late summer and winter.

During droughts, recharge is minimal or nonexistent in unconfined aquife and because discharge is a continuous process, the water table declines. Shallo wells completed in unconfined aquifers may "go dry" in summer and wint months. These wells go dry because the water table declines below the bottom the well. Water will again be available to these wells when recharge is sufficie raise the water table above the well bottom. Because water levels in ater-table wells fluctuate considerably, maps of water-table aquifers usually are ised on water-level measurements made within a short time interval.

Water levels in artesian aquifers, especially those that are deeply buried, are ily slightly affected by short-term changes in recharge. The major areas of charge for these aquifers usually are tens to hundreds of miles away. The effects i the potentiometric surface due to variations in weather is minimized because the distance from the recharge area. The large volume of these aquifers and the rge volume of water they store also decreases the effect of changes in charge.

In addition to fluctuations produced by weather, water levels also decline hen artificial discharge, through pumping wells, is imposed on the hydrologic stem. When water is removed from a well completed within an unconfined luifer, the water table at and near the well declines. This creates a conical epression, a drawdown cone, in the water table surrounding the pumped well gure 44). In artesian aquifers, the withdrawal of water has a similar effect in at it produces a depression in the potentiometric surface, represented by a crease in the hydrostatic pressure in the aquifer surrounding the well.

The size and shape of a drawdown cone surrounding a pumping well depends i the characteristics of the aquifer along with the rate and duration of pumping. ith the same pumping rate, the diameter of the upper boundary of the cone of i artesian aquifer generally is measured in thousands of feet, while the diameter the upper boundary of the cone in an unconfined aquifer is measured in indreds of feet.

When two or more pumping wells are located close to each other, their awdown cones may overlap (figure 44). This interference accentuates the size the respective cones resulting in possible decreased yields from each well. The ater levels within the wells may even decline to the point where pumping costs come prohibitive. For this reason, wells pumping large volumes of water from e same aquifer need to be spaced an appropriate distance apart. If data on luifer characteristics are available, they can be used to determine the distances eded between wells to avoid interference or to keep it within acceptable nits.

Continuous pumping of an artesian or water-table well at a constant rate ceeding the well's recharge rate, will cause a lowering of the potentiometric surface in the vicinity of the well, and an enlarging of the drawdown cone. The cone will spread until it covers an area large enough to intercept a sufficient volume of water to supply the demands of pumping and recharge. At this time, the water level in the well will stabilize, but any increase in the pumping rate will again lower water levels. At a decreased pumping rate, the drawdown cone will adjust by becoming shallower and smaller in diameter. If pumping is stopped entirely, water levels will return to approximate prepumping levels.

Because of the inherent characteristics of water-table and artesian aquifers, each has advantages and disadvantages. A thick water-table aquifer can usually sustain a moderate to large supply of water (if long droughts do not occur), because recharge is local and rapid. The water levels in water-table wells are not excessively deep; therefore the cost of pumping water is less. These aquifers are responsive to local, short-term changes in weather. Artesian aquifers, especially the deeper ones, can supply large quantities of water throughout droughts. Because water levels in artesian wells tend to be deeper and may continue to decline with sustained pumping, pumping costs may be expected to be greater.

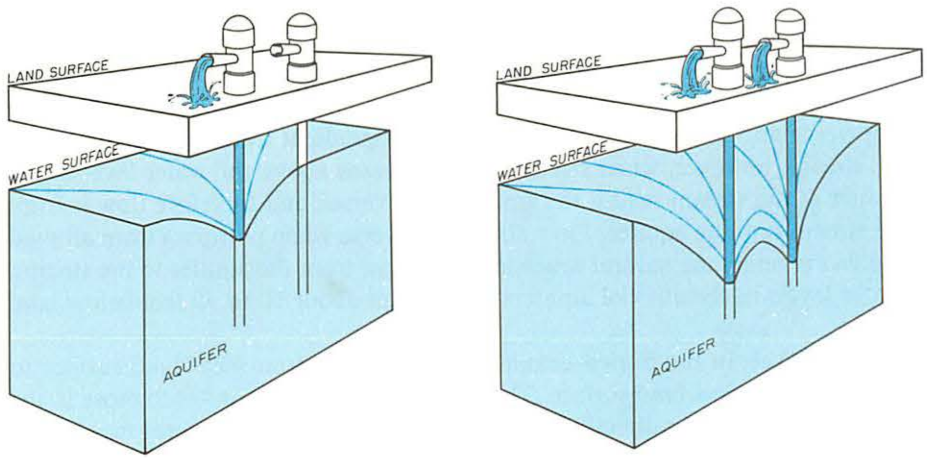


Figure 44. Drawdown cones around pumping wells

WATER LEVELS IN SURFICIAL AQUIFERS

Water levels in the surficial aquifers of north-central Iowa are quite variable. The depth to water in a well depends on the part of the surficial aquifer system penetrated and the aquifer position in relation to the local topography and streams. The areas where the three types of surficial aquifers occur in north-central Iowa are shown in figure 26. Seasonal fluctuations of water levels are common because of variations in recharge and discharge, but water levels have not changed significantly after many years (Hershey and others, 1970).

Water levels in the glacial-drift aquifers range from slightly above land surface (flowing) to more than 100 feet below the land surface. Water levels may be different in wells completed at different depths at the same location either because glacial-drift aquifers may contain several layers of water-bearing material between relatively impermeable materials or because of complex hydraulic flow relationships. One major factor controlling the general depth to water in glacial-drift aquifers is the topographic position of the well site. Wells located in upland areas along stream divides generally have water levels that are at a greater depth below land surface than wells located in lowland areas. This usually is the case even though the sea-level elevations of the upland water levels are higher than the elevations of the lowland wells' water levels. The water levels in the glacial-drift aquifers fluctuate in response to seasonal recharge from precipitation.

Water levels in alluvial aquifers differ from water levels in other types of water-table aquifers in that there is usually a direct hydraulic connection between the stream and the aquifer. Water moves downgradient from the valley sides to the stream; however, when stream stage increases above the water level in the aquifer of the stream banks, the gradient is reversed and therefore flow is from the stream into the aquifer. Flow also may reverse when pumping from alluvial aquifers reverses the natural water-level gradient from the aquifer to the stream. Water levels in the alluvial aquifers range from about 10 to 50 feet below land surface.

Water levels in the buried-channel aquifers range from near land surface to about 50 feet below land surface. The water levels may be similar to those in the bedrock if the aquifer directly overlies a bedrock aquifer. In general the deepest water levels may occur in topographically high areas and the shallowest in topographically low areas. Where unconfined, the water level fluctuates seasonally in response to precipitation.

WATER LEVELS IN BEDROCK AQUIFERS

Water levels in the Cretaceous aquifer range in altitude from about 1,080 f in south-central Kossuth and eastern Humboldt Counties to about 1,170 feet western Kossuth county (figure 45). In relation to the land surface, the wa levels range from about 100 to about 190 feet below the surface across the stu area.

Where present, the Cretaceous aquifer is the uppermost bedrock aquifer ar therefore, may be in hydrologic connection with an overlying surficial aqui and have similar water levels. The potentiometric contours for the Cretacec aquifer on figure 45 show that the water levels are lowest along the Des Moir River valley in southern Kossuth and eastern Humboldt Counties. The conto pattern also indicates that groundwater movement in the Cretaceous aquifer from the north, west, and east into the Des Moines River valley. In the cent and eastern parts of the study area where the Cretaceous aquifer occurs outliers, water levels are not available because the wells generally are open overlying or underlying aquifers.

Water levels in the Mississippian aquifer range in altitude from about 1,0 feet in south-central Humboldt County along the Des Moines River and in t southeast corner of Franklin County to about 1,200 feet on the adjacent corn of Franklin, Wright, Hancock and Cerro Gordo Counties (figure 46). In relati to the land surface, the water levels range from slightly above the surfa (flowing) to about 90 feet below the surface. The potentiometric contours figure 46 show that the flow in the aquifer is toward the Des Moines River vall in Kossuth and Humboldt Counties, toward the Iowa River valley in southea Wright County, and toward the tributaries of the Cedar River in eastern Frankl County.

Water levels in the Devonian aquifer range in altitude from about 900 feet southeast Butler County to about 1,250 feet in northwest Worth and northea Mitchell Counties (figure 47). In relation to the land surface the water lev range from above land surface (flowing) to about 150 feet below land surface most of the study area. The exception is Mason City and vicinity where wa levels may be as much as 250 feet below land surface. This area of relatively de water levels is evident on the potentiometric map (figure 47) and is the result pumping in that area. The potentiometric contours (figure 47) show that wa movement in the Devonian aquifer in the eastern part of the study area is towa Mason City, and toward the Cedar River and its tributaries. In the western pa

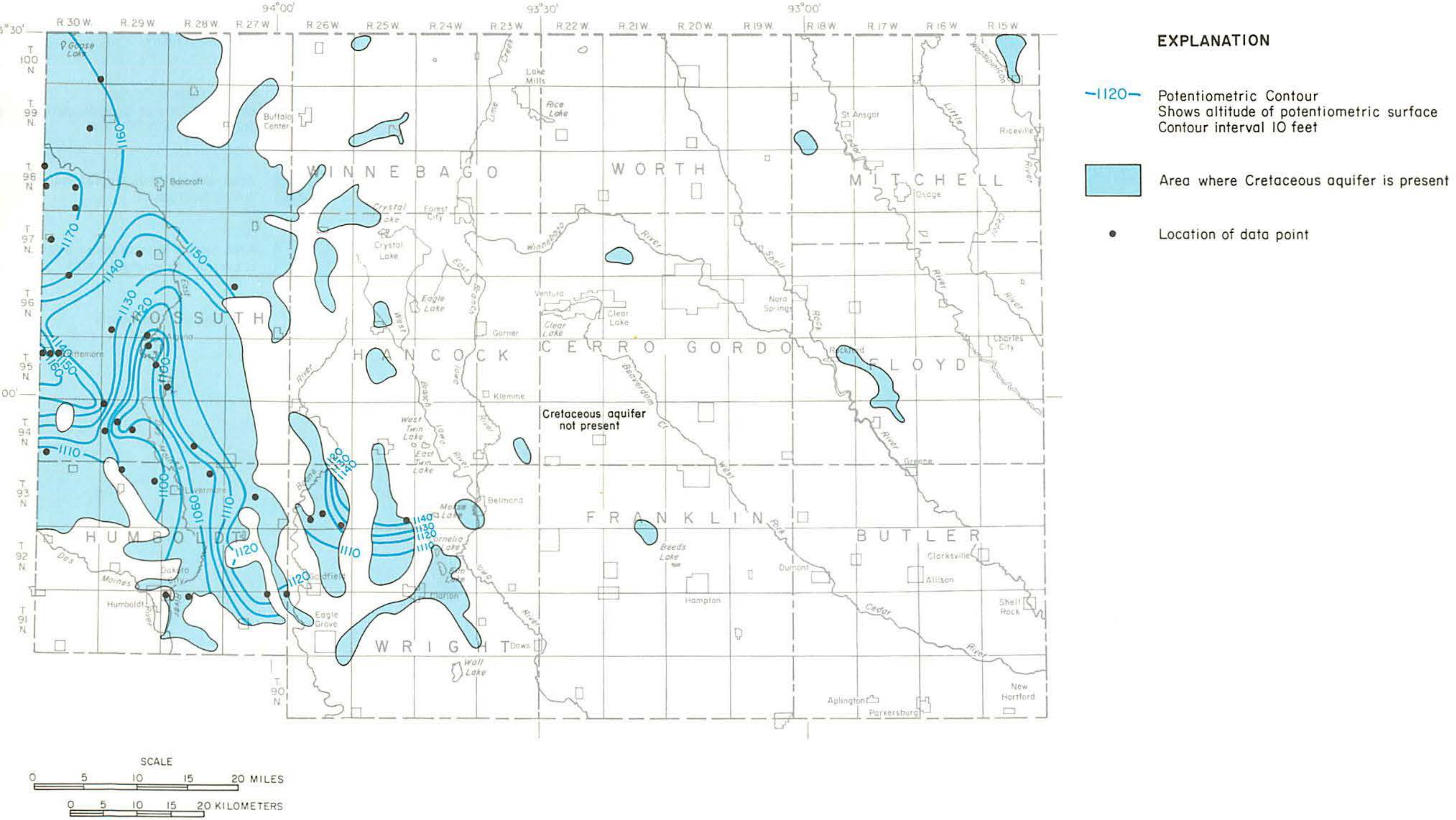


Figure 45. Generalized potentiometric surface of the Cretaceous aquifer

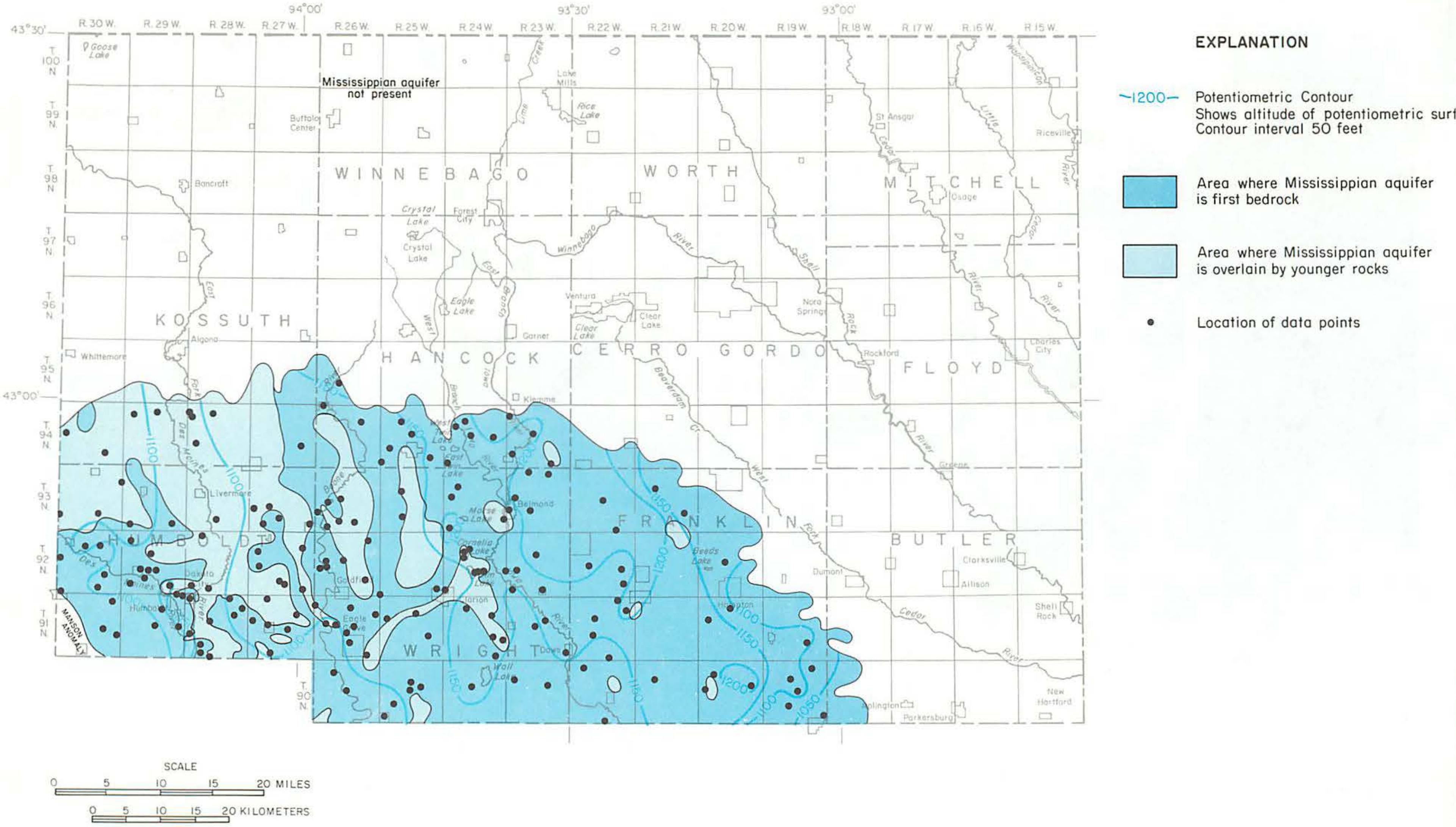


Figure 46. Generalized potentiometric surface of the Mississippian aquifer

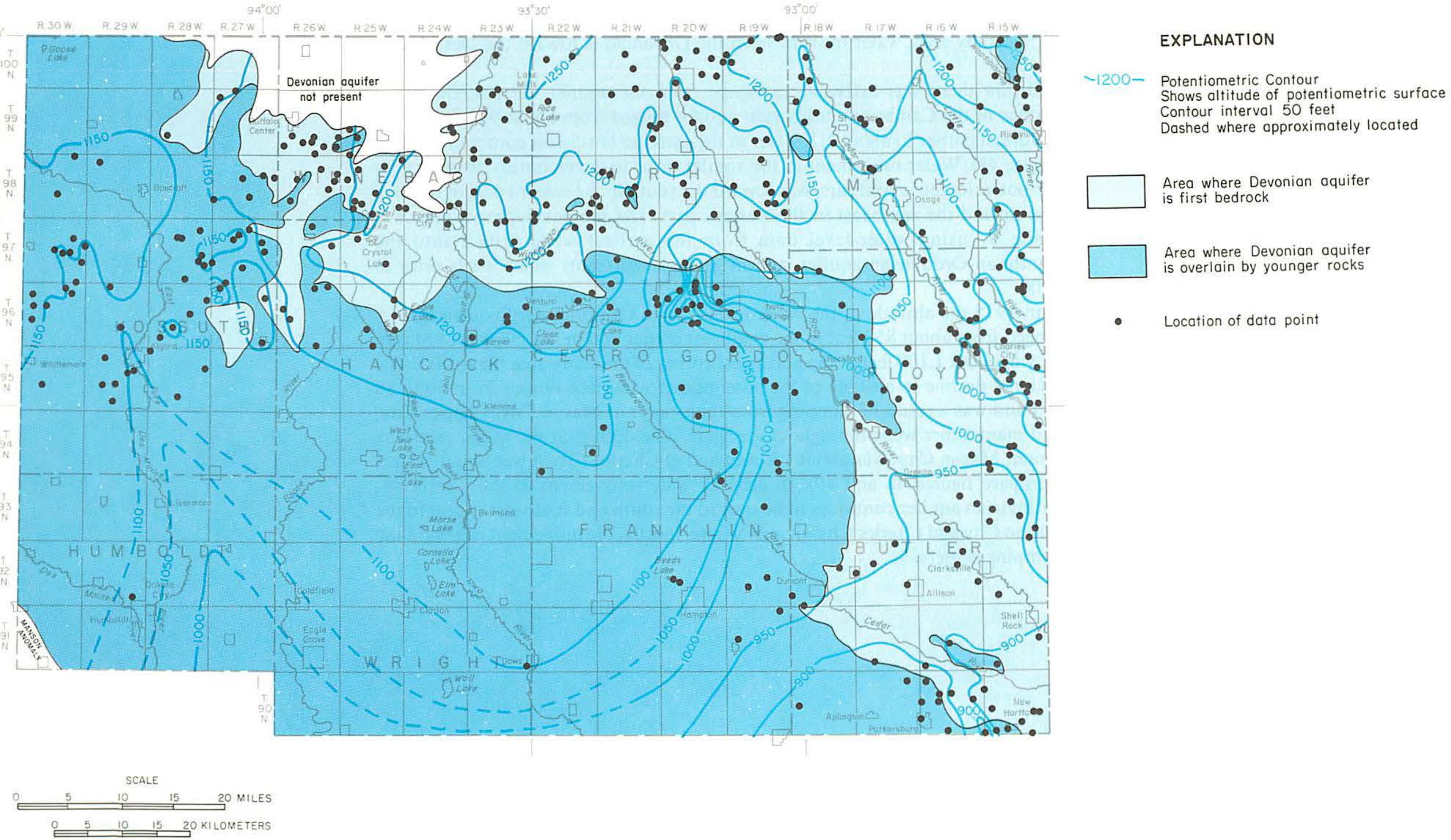
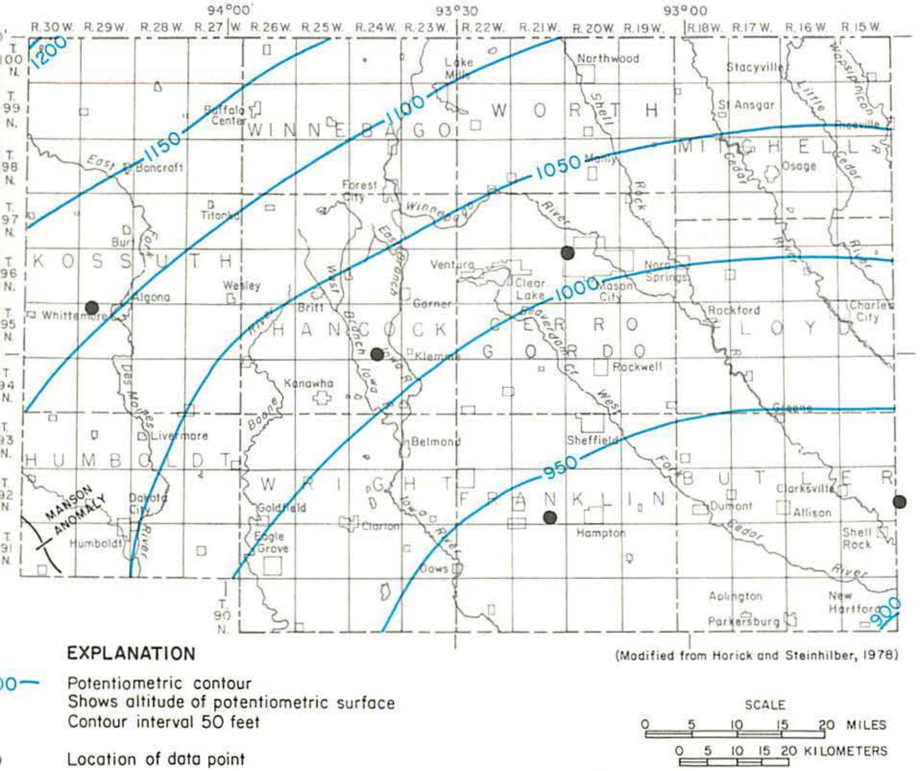


Figure 47. Generalized potentiometric surface of the Devonian aquifer

of the study area, water movement in the Devonian is toward the Des Moines River.

Before there was extensive pumpage from the aquifer the potentiometric surface of the Cambrian-Ordovician aquifer ranged from about 900 feet in the southeast corner to about 1,200 feet in the extreme northwest corner of the area (figure 48). Water movement in the aquifer prior to development, as shown by the potentiometric contours, was toward the south in the eastern part of the area and toward the southeast in the western part. The pre-development map was made by using water-level data from the earliest wells drilled into the Cambrian-Ordovician aquifer, and in general, represents water levels prior to 1900.

In 1975 the altitude of the water levels in the Cambrian-Ordovician aquifer ranged from about 850 feet in the southeast corner and in the vicinity of Mason City to about 1,100 feet in the northwest corner of the study area (figure 49). The regional decline in altitude of the potentiometric surface ranged from 50 to 88 feet and was a result of pumping from the aquifer at Mason City, Charles City, and many other wells throughout the State. The decline at the major pumping center, Mason City, was about 150 feet and at Charles City it was about 90 feet (compare figures 48 and 49). In general, water movement in the Cambrian-Ordovician aquifer continues to be toward the south and southeast except in the Mason City and Charles City vicinity where, locally, the movement is toward the pumping centers.



ure 48. Generalized predevelopment potentiometric surface of the Cambrian-Ordovician aquifer

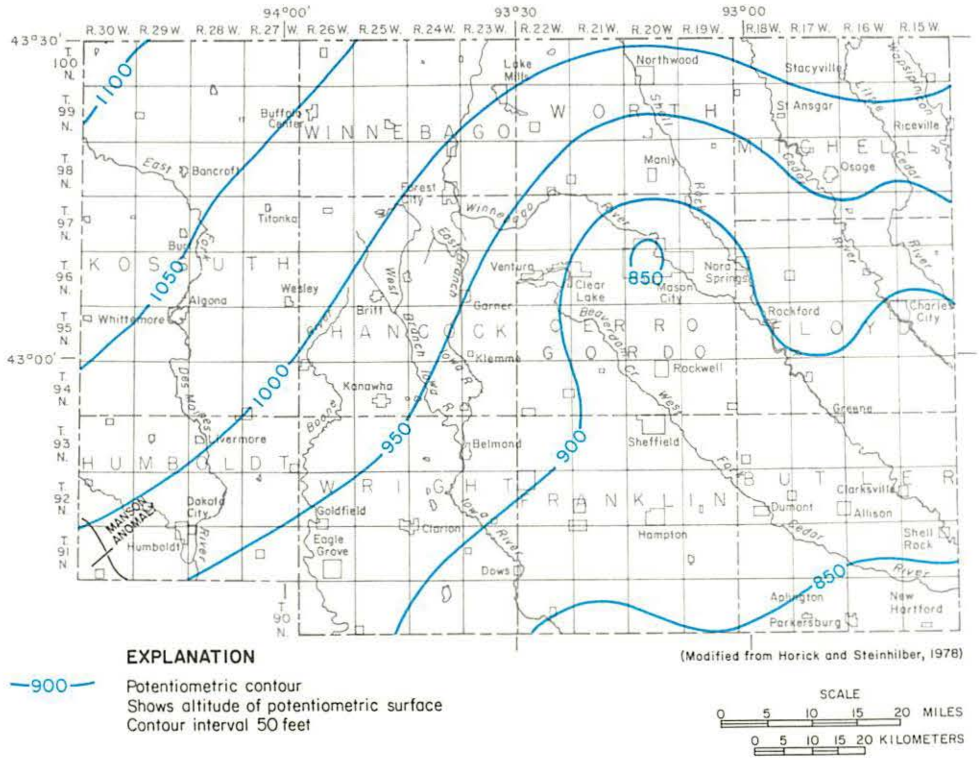


Figure 49. Generalized potentiometric surface of the Cambrian-Ordovician aquifer, 1975

WELL YIELDS

The yield maps (figures 50-53) are based on information available during 1981 and represent known and predicted yields from the several aquifers in the report area. The rate at which water can be withdrawn from wells in the area is not only different for each of the various aquifers, but varies areally within each aquifer. On the next few pages, maps for each aquifer delineate probable yields that can be obtained from properly constructed wells. The data used in constructing these maps include production records of existing wells and regional geologic information.

Production records include the pumping rate and the drawdown (the decline in the water level in the well in response to sustained pumping rates). From these data, estimates were made of the probable maximum sustainable yield for a well. This value is independent of the capacity of the pump that may be installed in the well.

Geologic data indicate the type of rock or sediment that comprise each aquifer, the thickness of the rock units, the spatial relationships of the aquifers, and the characteristics of the rock openings. In areas where limestone and dolomite are near the land surface and are not covered by confining beds, one can expect any joints, cracks, and fissures to have been enlarged by solution, the karstification process. This facilitates more rapid movement of water and the material contained in it, into and through the aquifer than in areas where the rock has only small openings. Other factors being equal, the thicker the aquifer the more water it will yield to a well. Sand and gravel deposits will yield more water to wells in localities where the deposits are exposed at the surface and can be recharged readily by infiltrating precipitation or induced infiltration from streams. In some areas where alluvial aquifers directly overlie buried-channel aquifers, greater yields may be expected from the combined aquifers. If the spaces between the grains of a granular aquifer are partly filled with other materials, such as clay or carbonate cement, water cannot move through the aquifer as readily, and a decrease in yield to individual wells will result.

An important part of the planning phase for large-capacity wells includes test-drilling and test-pumping programs in order to determine the water-producing capabilities of the aquifer. This is particularly important when planning development of the surficial aquifers because the water-yielding sands and gravels are seldom uniform in thickness, areal extent, or hydrologic character.

YIELDS FROM SURFICIAL AQUIFERS

The three surficial-aquifer types shown in figure 26 have reported yiel varying from less than 10 to more than 600 gallons per minute. Because of th variability it is difficult to predict yields to individual wells. The alluvial aquife in particular, not only has variable yield but its occurrence generally is limit to relatively narrow valley areas. In addition the yield of wells in the alluvi aquifer are dependent on the aquifer position in relation to the adjacent strear The yields may vary throughout the range given above within relatively sho distances.

The quantities of water available from the glacial-drift aquifers also a variable. However, the variability in yield is less than alluvial aquifers, wi reported yields being from less than 10 to more than 90 gallons per minute (figu 50). The quantity of water the glacial-drift aquifer will yield to a well is depende on the thickness and lateral extent of the water-bearing material and the gra size and degree of sorting within the water-bearing material. Relatively thic medium-to coarse-grained, well-sorted saturated sand beds would have a larg yield than thin, fine-grained, poorly-sorted beds. The glacial-drift general contains water-bearing sand or gravel at or near the bottom of the glacial-dri sequence and in contact with the underlying bedrock. These basal sands general are the most productive zone within the glacial-drift sequence because th generally are more extensive laterally than water-bearing beds in the overlyi material and may be in hydraulic connection with underlying bedro aquifers.

Estimated yields of individual wells from the buried-channel aquifer ran from about 100 to 600 gallons per minute (figure 50). These estimates are bas on reported yields from several wells and the thickness of the sand and grav occurring in the buried bedrock channels indicated in figure 28. Because t sands and gravels in these buried channels occur in lenticular beds, which m change in water-bearing character within a short distance, the yield patter shown in figure 50 encompass relatively wide ranges. It must be emphasized th the yields indicated in figure 50 are intended to be a general guide for locati of potential development sites. Each site needs to be evaluated by test drilli and pumping before development plans are made.

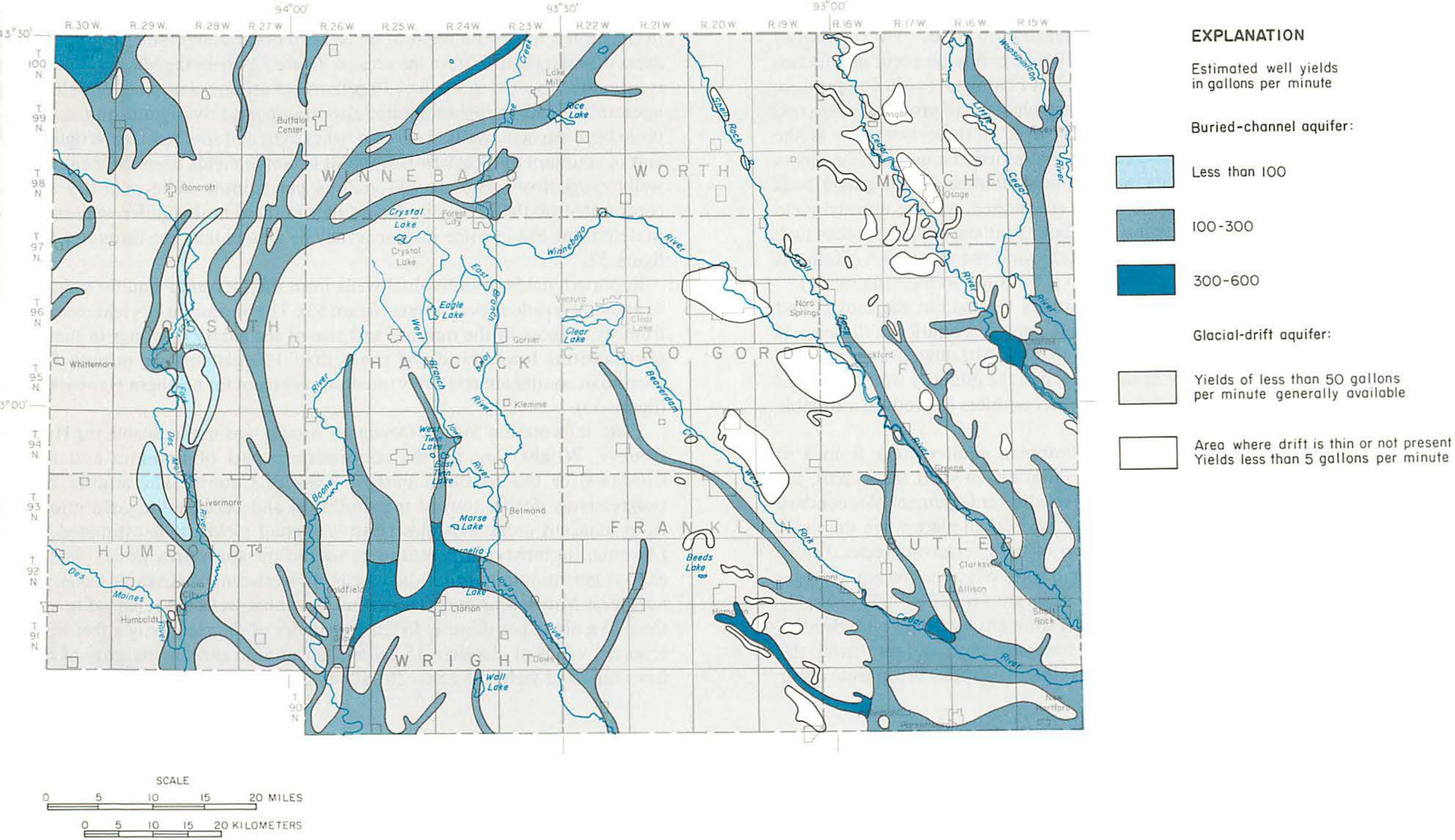


Figure 50. Estimated yields to individual wells from buried-channel and glacial-drift aquifers

YIELDS FROM BEDROCK AQUIFERS

Known yields from the Cretaceous aquifer range from about 10 to 700 gallons per minute. Reported yields greater than 30 gallons per minute occur in only two locations, both in Kossuth County, where a well at Fenton is reported to produce 700 gallons per minute and 2 wells at Algona are reported to produce 500 to 600 gallons per minute. Although the producing unit at these two sites is the Cretaceous aquifer, both sites are in areas where a buried-channel aquifer occurs (figure 26). Records for the Algona wells indicate that sand and gravel beds directly overlie the Cretaceous aquifer and it is assumed that the unusual yield at these two sites result from production from both aquifers. Although other such sites may occur, their locations are unpredictable and the maximum estimated yield solely from the Cretaceous aquifer is 30 gallons per minute (figure 51).

The Cretaceous aquifer occurs as small outliers throughout the central and eastern parts of the study area (figure 25). The Cretaceous aquifer in these areas generally is relatively thin and of limited extent. Although water may be available from the Cretaceous aquifer in these areas, the quantity would be small and most wells also would have to penetrate other aquifers to produce a suitable supply.

Yields to individual wells from the Mississippian aquifer range from 5 to about 65 gallons per minute (figure 52). The variations in yield are, in part, the result of the aquifer thickness and the result of solution enlargement of secondary openings in the rock. This solution action may have taken place when the rocks were exposed to weathering before deposition of the Cretaceous rocks, before and during the Pleistocene glacial period, or during relatively recent geologic time. The random nature of the greater yield areas shown in figure 52 probably is the result of periods of solution action under different hydrologic conditions. Yields of 10 gallons per minute or more generally are available from the Mississippian aquifer in this area. Yields of less than 10 gallons per minute occur in only a few areas and seem to be isolated occurrences rather than predictal areas of small yield. Within the areas in figure 52 where the Mississippian aqui is estimated to yield more than 20 gallons per minute, a number of wells that a open to the Mississippian aquifer also are open to overlying aquifers. Most these large-capacity wells occur in northeastern and southeastern Wright Cour and in southern and eastern Humboldt County. Yields from these multiaqui wells range from 100 to 900 gallons per minute. The quantity of wa contributed by the Mississippian aquifer to these multiaquifer wells is diffic to determine but in some instances may be greater than the estimates shown figure 52.

Reported yields to individual wells from the Devonian aquifer range from to about 300 gallons per minute (figure 53). The variations in yield result mai from differences in the number and size of secondary openings in the rock. north-central Iowa, yields of more than 150 gallons per minute from t Devonian aquifer are relatively uncommon except for northern Hancock Cou (figure 53).

Yield information for the Devonian aquifer was not available for Humbol County, Wright County, the southwestern part of Franklin and Hanco Counties, or the southern part of Kossuth County. The aquifer becom progressively deeper toward the southwest and because the yield informati from adjacent areas indicates relatively small yields, it is estimated that t Devonian in most of this southwest part of the study area would yield 5 to gallons per minute to individual wells. In west-central Kossuth County and northeast Mitchell County, numerous Devonian wells are reported to yield le than 15 gallons per minute. In the remainder of the area, only a few wells ha reported yields of less than 15 gallons per minute and the majority of the we have reported yields of 15 to 25 gallons per minute.

Figure 51. Estimated yields to individual wells from the Cretaceous aquifer

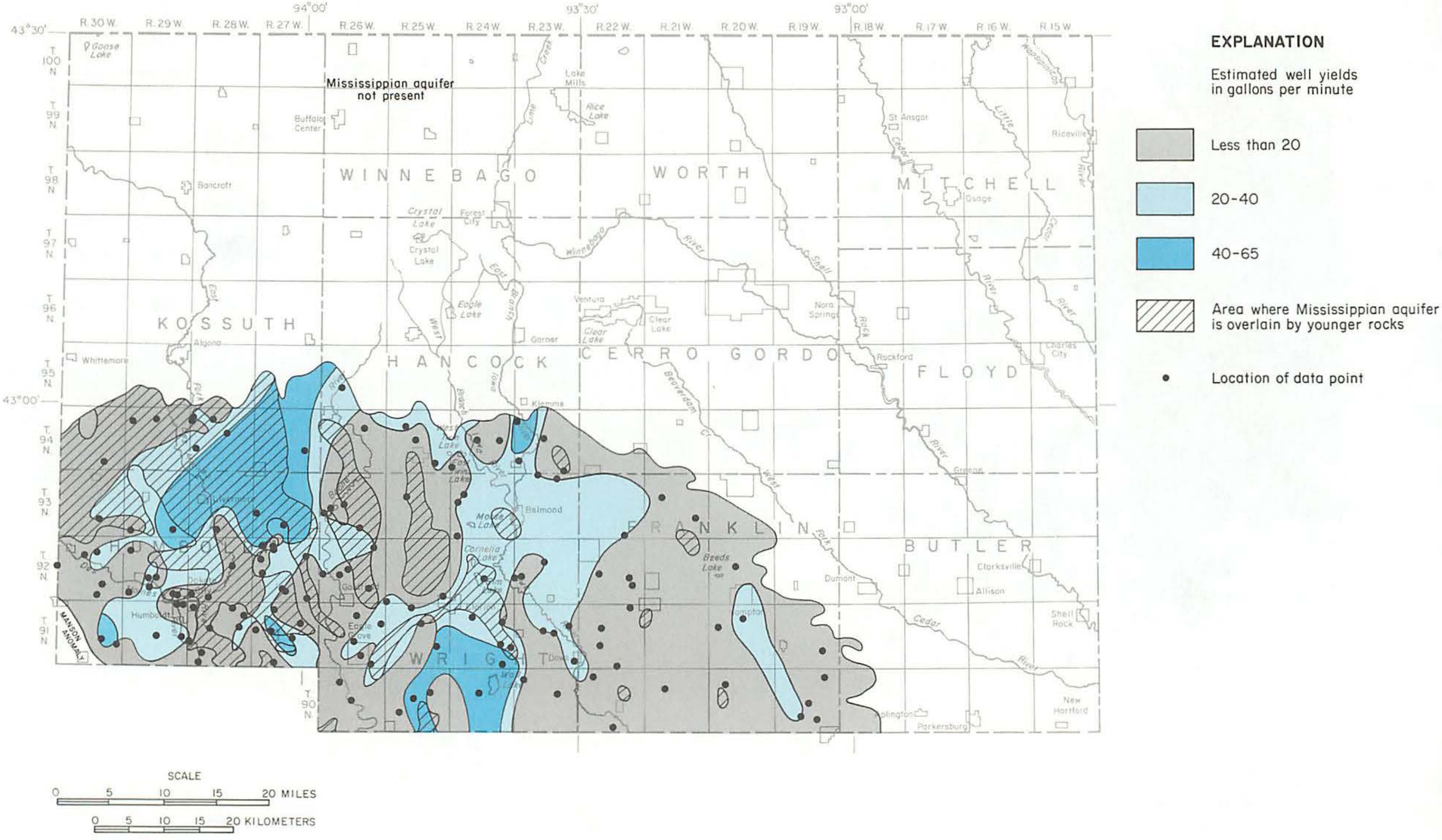


Figure 52. Estimated yields to individual wells from the Mississippian aquifer

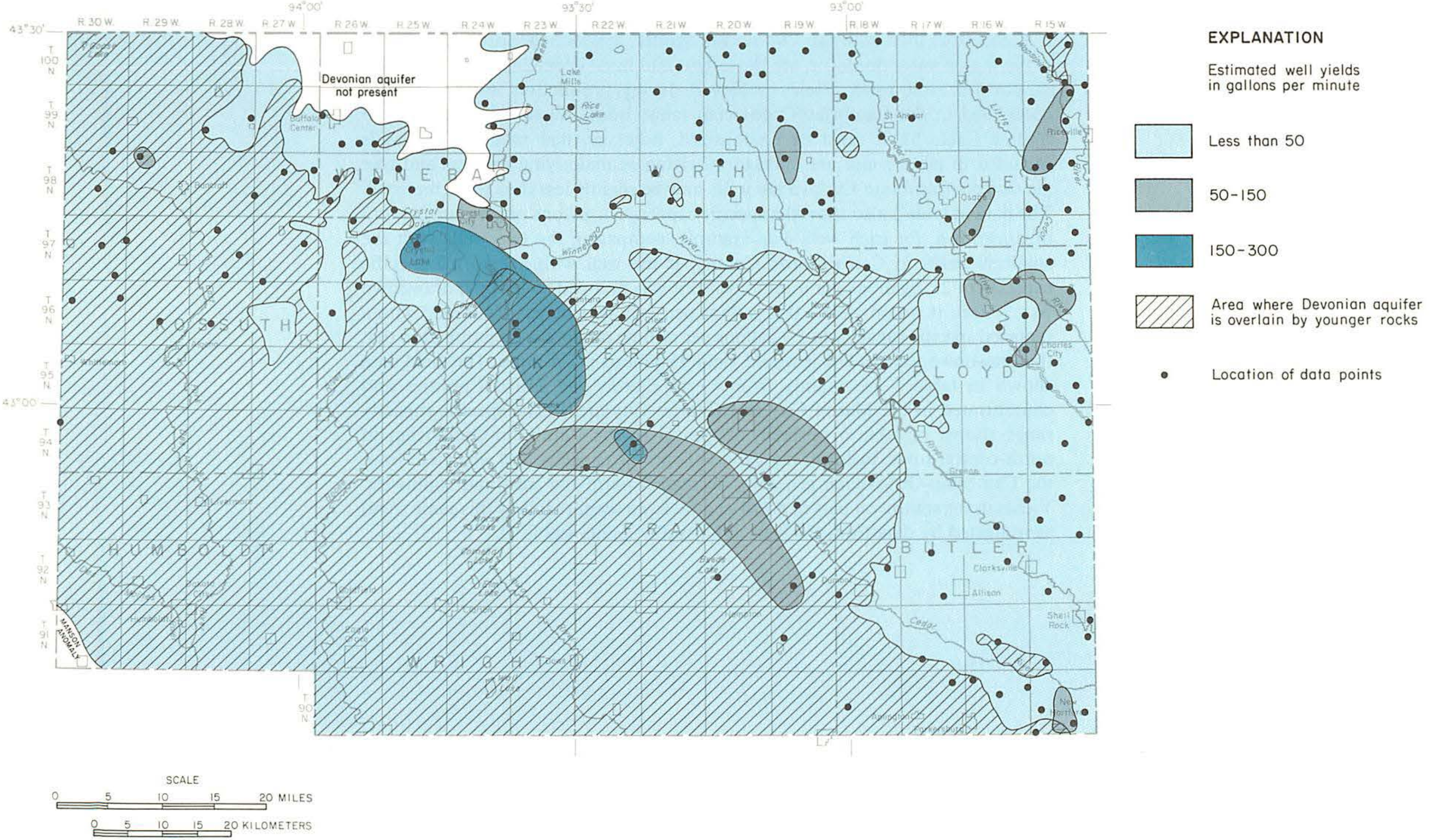


Figure 53. Estimated yields to individual wells from the Devonian aquifer

Yields from the Cambrian-Ordovician aquifer, in which the Jordan Sandstone is the major water producer, are the largest and most dependable of all aquifers in north-central Iowa. Yields achieved during production testing of wells completed in the Cambrian-Ordovician range from 180 to 1,500 gallons per minute (table 5). It must be emphasized, however, that many of the wells included in table 5 also are open to overlying or underlying aquifers and true yields from Cambrian-Ordovician wells may be slightly less than those reported. The data in table 5 also show the specific capacity, in gallons per minute per foot of drawdown, for each well. For example, comparing the two wells with the smallest yields in Cerro Gordo County, if the well with a reported specific capacity of 21.2 gallons per minute per foot was pumped so that the drawdown was 50 feet, it would yield 1,060 gallons per minute, whereas if the well with a reported specific capacity of 1.9 gallons per minute per foot were pumped so that the drawdown was 50 feet it would yield 95 gallons per minute. The yield data shown in table 5 are mainly from Cerro Gordo and Floyd Counties and concentrated in the Mason City and Charles City areas. The specific-capacity range shown in table 5 probably is typical of the Cambrian-Ordovician in north-central Iowa. In Iowa, the values of specific capacity and well yield from the Cambrian-Ordovician generally decrease toward the west and southwest. Yields in the southwest part of north-central Iowa seem to follow this same trend as indicated by data from the well in Kossuth County (table 5).

County	Location	Owner or name	Date of test	Length of test (minutes)	Discharge (gallons per minute)	Drawdown (feet)	Specific capacity (gallons per minute per foot)
Cerro Gordo	96-20-03BDC	Mason City 10	07/08/36	—	600	32	18.7
		Mason City 10	10/10/37	215	930	41.1	22.6
	96-20-03CAB	Mason City 7	10/17/37	180	780	34.9	22.3
	96-20-10BCCC	Peoples Gas & Electric 1	—/—/15	—	800	15	53.3
	96-20-10CB	Interstate Power 2	10/23/37	515	1,040	37.4	27.8
	96-20-10CBBB	Interstate Power 2	01/04/33	—	1,024	38.0	26.9
	96-20-15AAAA	Mason City 14	03/11/57	1,519	1,100	52.3	21.0
	96-20-16DAA	Mason City 11	11/23/29	1,440	1,203	75.0	16.0
	96-20-17DAAA	State Brand Creameries Inc. 2	12/—/56	—	1,250	52.0	24.0
	96-20-17DAAD	State Brand Creameries Inc. 1	09/16/37	47	180	8.5	21.2
	96-20-18BBC	Allied Mills of Iowa, Inc.	07/23/53	450	220	114	1.9
	97-20-33DDAB	Lehigh Portland	—	—	654	75	8.7
Floyd							
	95-15-06BDD	Charles City 4	02/14/39	60	625	10	62.5
	95-15-06DBBD	White Farm Equipment Co.	07/03/70	—	1,500	58	25.9
	95-16-12ADC	Charles City 3	—/—/28	—	300	87	3.4
	95-16-12ADC	Hirsch, C. H.	06/04/55	360	880	113	7.8
	96-17-18CABB	Town of Rudd	09/22/58	120	360	19	18.9
Kossuth							
	95-29-02CBAA	Algona City Well 3	—/—/25	—	200	100	2.0
Mitchell							
	98-17-25BCB	Osage City	06/29/48	222	420	65	6.5

Table 5. Summary of production tests on wells penetrating the Jordan Sandstone of the Cambrian-Ordovician aquifer in north-central Iowa

WATER QUALITY

Water quality is a major factor in the development and operation of any water-supply facility. The specific use establishes the chemical and physical criteria that must be met. Water suitable for irrigation may be unsatisfactory for municipal supply, and that suitable for an industrial cooling supply might not meet the needs of a brewery or a corn processing plant.

The quality of water is determined principally by the composition and solubility of the materials that the water comes in contact with and by pressure and temperature relationships. Water has an opportunity to dissolve minerals in an aquifer as it moves from recharge to discharge areas. Because the mineral composition of aquifers and other materials through which water moves is diverse, the chemical quality of water in the different aquifers varies considerably. Surface water, in addition to dissolving minerals on and near the land surface, usually transports sediment particles and organic materials in suspension. The quality of water also is affected by the agricultural, domestic, and industrial chemicals and wastes that are discharged into water, on and below the land surface, and into the atmosphere. Combinations of the above factors and the relationships between surface and groundwater in any area results in a variety of water quality.

Some chemical constituents in and physical properties of water are listed and explained briefly in table 6. These constituents and properties form the basis for comparisons of water quality from different sources. The maximum recommended and mandatory concentrations listed are for drinking water only. Recommended concentrations for other water uses may vary considerably.

The chemical constituents listed in this report are expressed as ions in concentrations of milligrams per liter (mg/L). One mg/L is one-thousandth of 1 gram of a substance dissolved in a volume of 1,000 cubic centimeters of water (1 liter). An approximate weight-to-weight ratio would be 1 gram of the ion in 1 million grams of water, or 1 part per million.

The quality of water with respect to dissolved constituents can be classified as excellent, good, fair and poor on the basis of the concentration of dissolved solids. Water in Iowa can be classified as follows: excellent quality water contains less than 500 mg/L of dissolved solids, good quality water contains between 500 and 1,000 mg/L, fair quality water contains between 1,000 and 1,500 mg/L, and poor quality water contains more than 1,500 mg/L.

The hardness of water has also been classified according to concentration (Hem, 1970). If the hardness of water, expressed as equivalent to calcium carbonate ($CaCO_3$), is 0-60 mg/L, it is considered soft; 61-120 mg/L, moderately hard; 121-180 mg/L, hard; and more than 180 mg/L, very hard.

Constituent* or property	Significance
Iron	It's objectionable for both domestic and industrial use. It affects the taste and color of beverages, and will stain laundered clothes and plumbing fixtures. The maximum recommended concentration for domestic water supplies is 0.3 mg/L. (U.S. Environmental Protection Agency, 1976)
Manganese	Causes brownish staining of laundry and imparts an objectionable taste to beverages. The maximum recommended concentration for domestic water supplies is 0.05 mg/L. (U.S. Environmental Protection Agency, 1976)
Calcium and Magnesium	Principal constituents of hardness and scale forming properties of water. They decrease the lathering ability of soap.
Sodium and Potassium	Impart a salty or brackish taste when combined with chloride. Sodium salts cause foaming in boilers.
Sulfate	Commonly has a laxative effect when the concentration ranges from 600-1000 mg/L, particularly when combined with magnesium or calcium. This laxative effect is commonly noted to newcomers, who become acclimated to the water 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. The maximum recommended concentration is 250 mg/L. (U.S. Environmental Protection Agency, 1976)
Chloride	Large concentrations combined with sodium impart a salty taste to water. Maximum recommended concentration is 250 mg/L. (U.S. Environmental Protection Agency, 1976)
Fluoride	Fluoride is a beneficial constituent in drinking water. Optimum concentration will substantially decrease tooth decay, but excessive concentrations in drinking water will cause dental fluorosis. The optimum concentration depends on climatic conditions. As the annual average of the maximum daily air temperatures increase, water consumption increases. For an annual average maximum daily temperature of 55° Fahrenheit (north-central Iowa) the optimum recommended fluoride concentration for drinking water is 1.1 mg/L. (U.S. Environmental Protection Agency, 1976)
Nitrate	Waters with large nitrate concentrations should not be used for infant feeding (less than 3 months old) or for very young livestock as it can cause methemoglobinemia or cyanosis. Large concentrations indicate organic pollution from sewage, decayed organic matter, nitrate in the soil, or chemical fertilizer. Large concentrations commonly are found in shallow farm and rural community wells usually because of inadequate protection from barn-yard drainage or from septic tanks. The maximum mandatory concentration for a domestic water supply is 10 mg/L. (U.S. Environmental Protection Agency, 1976)

Table 6. Significance of selected chemical constituents and physical properties of water

Constituent* or property	Significance
Dissolved Solids or residue	This refers to all the material in water that is in solution. Concentrations greater than 2,000 mg/L. will have a laxative effect on most persons. Concentrations as much as 1,000 mg/L are generally considered acceptable for drinking purposes if no other water is available. The maximum recommended concentration is 500 mg/L. (Public Health Service, 1962)
Specific Conductance	Is the ability of water to conduct an electrical current. This is the result of charged ionic species in solution. As the ionic concentration increases, the solution becomes more conductive, thus the conductance measurement is an indicator of ion concentration. In dilute solutions of single salts, the relationship between specific conductance and ion concentration is simple and direct, usually ranging from 0.55 or 0.75 micromhos. Therefore, conductance measurements are useful in extrapolating ground-water analyses in areas where comprehensive analyses are only minimumly available. (Hem, 1970)
Hardness	Hardness, together with other chemical constituents, affects the lathering ability of soap. Hardness is primarily due to dissolved calcium and magnesium and is reported in terms of an equivalent concentration of calcium carbonate. Water becomes objectionable for domestic use when the hardness is greater than 100 mg/L.
Alkalinity	Is the total of all components in water that will increase its pH to more than 4.5. Alkalinity of water effects the quantity of chemicals needed to be added to domestic supplies for coagulation, softening, and corrosion control. The alkalinity of water assists in neutralizing acids added during industrial processes. If the alkalinity is great enough no supplemental materials need be added.
Temperature	Affects the desirability and economy of water use, especially for industrial cooling and air conditioning. Most users want water with a low and constant temperature.
Radionuclides	The effect and significance of small concentrations of radium in public water supplies isn't fully known. However, the Environmental Protection Agency 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 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. (U.S. Environmental Protection Agency, 1976)

[mg/L = milligrams per liter, micromhos = micromhos per centimeter at 25° Celsius, pCi/L = picocuries per liter]

* For an expanded discussion about the significance of water constituents, and recommended concentration for different uses see: U.S. Environmental Protection Agency (1976), and Hem (1970).

SURFACE-WATER QUALITY

SEDIMENT IN STREAMS

Sediment is one of the principal water-quality problems in Iowa streams. Sediment is derived from sheet and gully erosion on the land surface, and from erosion of the bed and banks of stream channels. In addition to the loss of valuable top soil, many detrimental effects are associated with sediment in streams. These include deposition of infertile sand on flood plains; obstruction of drainageways; increased flooding due to decreased channel capacity; loss of storage space in reservoirs; damage to pumps and other facilities at water-treatment plants; deposition on road beds, and blockage of bridge and culvert openings through highway and railroad embankments; hazards to river navigation and increased maintenance cost; destruction of feeding and reproduction areas for fish and other aquatic life; and impairment of recreation values.

North-central Iowa has three distinct regions with differing sediment-yielding characteristics. The regions and relationships between annual sediment yield and drainage-basin area are shown in figure 54. The quantity of sediment an area yields depends on its physical and land-use characteristics. These include topography, climate, soil type, extent and type of tillage, and vegetation cover. All these characteristics were used to delineate the land-resource areas in north-central Iowa. These areas do not have distinct boundaries; there is a transition of characteristics and sediment-yielding potential from one resour area to another. Land-resource area 103 includes the western two-thirds north-central Iowa. This is the area yielding the least sediment, with a approximate average annual sediment yield, for a drainage basin of 100 squa miles, of about 70 tons per square mile. Land-resource area 104 includes mo of the eastern one-third of the area and has a much greater sediment yield th area 103. The approximate average annual sediment yield, for a drainage bas of 100 square miles, is about 450 tons per square mile. Land-resource area 1 is not typical of most of the study region because the sediment-yield values a much greater than the rest of the study area. The approximate average annu sediment yield for area 108, for a drainage basin of 100 square miles, is abo 1,000 tons per square mile.

The sediment-yield values are average annual yields for an area, becau sediment concentrations vary widely, both spatially and temporally. Each bas within a land-resource area yields different quantities of sediment, depending its distinct characteristics. Sediment yields vary with each storm because different quantities of rainfall, intensity and duration, season, and characteristi of the land surface. Generally, maximum sediment concentrations are associat with floods.

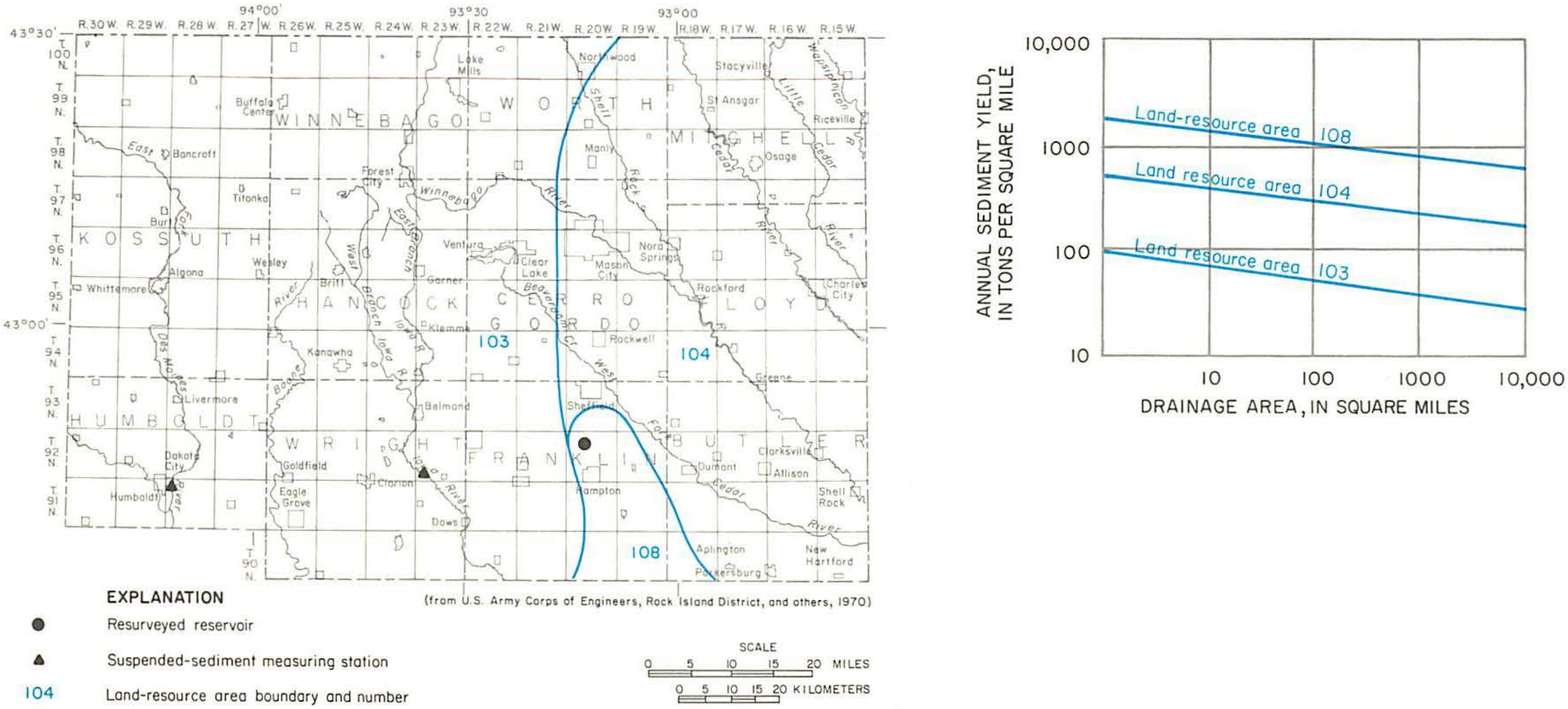


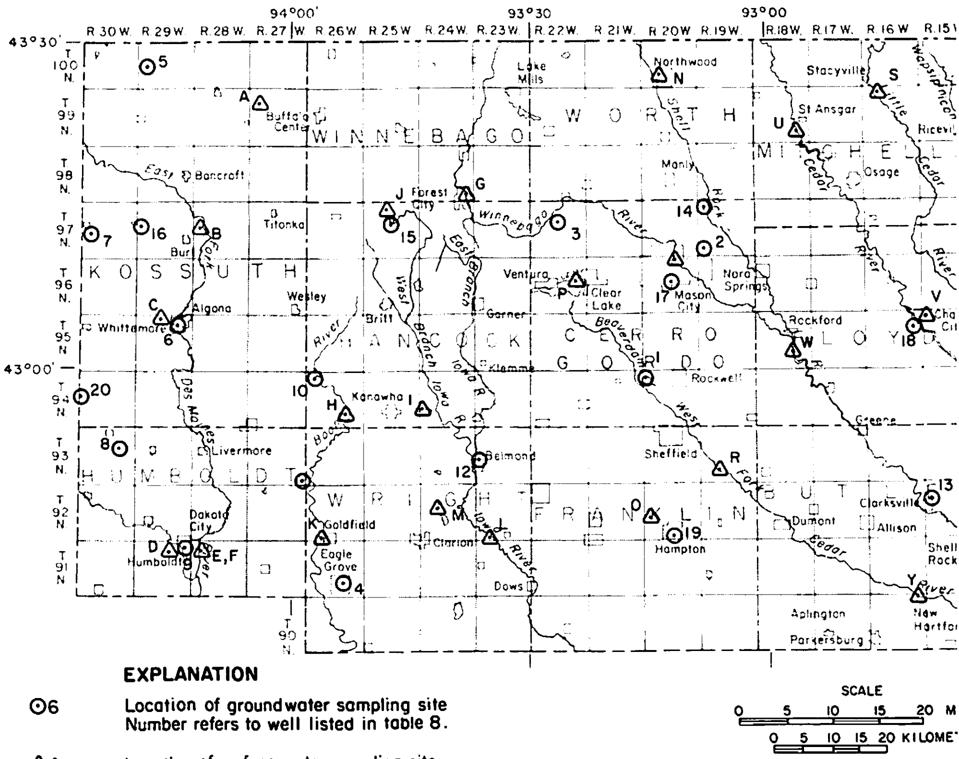
Figure 54. Land-resource areas and annual sediment yields for north-central Iowa

CHEMICAL QUALITY

The chemical quality of streamflow from a drainage basin can be associated with two primary sources: (1) Water that flows either over the land or through the soil mantle at shallow depth; and (2) groundwater discharge, which is the source of the base flow to streams. The dissolved-mineral concentration of stream water usually is least during runoff from snowmelt or recent precipitation. Greater concentrations occur when a greater proportion of the water is groundwater discharge. Although these generalizations are true for dissolved-solids concentrations, the concentrations of some constituents may vary independently of the flow source. For instance, the discharge of municipal or industrial wastes may alter the chemical quality of some streams.

The location of the surface-water quality sampling sites in the report area are shown in figure 55 and the results of sample analyses are listed in table 7. Complete chemical analyses are not available for all sites but some general water characteristics are evident from the available analyses. Values for pH are all more than 7 with most occurring about 8. Hardness values are all more than 100 mg/L and some are more than 180 mg/L. The waters of this region range from hard to very hard.

Specific-conductance values are available for most water analyses. In Iowa, the specific conductance of streams generally ranges between 400 and 800 micromhos. Specific conductance is a measure of the water's ability to conduct an electrical current. Dissolved materials aid in the conducting of electrical currents. Water from groundwater sources generally is more mineralized than surface runoff. This is because the water has had a longer time to contact soluble material. In streams, specific-conductance values may fluctuate considerably throughout the year, and generally are least during high flows, because of the influence of surface runoff, and greatest during low flows, because of the dominance of groundwater discharge. An illustration of this phenomenon is seen by examining the analysis presented for the Shell Rock River (table 7) near Northwood (site N). However, there are exceptions to this pattern. Surface runoff may contain large concentrations of easily dissolved materials that are due to land-use and basin characteristics. Groundwater discharges may be from sources composed of relatively insoluble material. These factors may cause a reversal in the relationship between specific conductance and flow as described above.



EXPLANATION

⊙6 Location of groundwater sampling site. Number refers to well listed in table 8.

△A Location of surface-water sampling site. Letter refers to site listed in table 7.

Figure 55. Location of surface-water-quality sampling sites and selected groundwa sites used to show the chemical characteristics of the water

Station symbol (fig. 55)	Station name	Date of collection	Time	Streamflow (ft³/s)	Temperature °C	pH (units)	Specific conductance (micromhos)	Dissolved solids (mg/L)	Total hardness as $CaCO_3$ (mg/L)	Bicarbonate (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Total sulfate (mg/L)	Dissolved fluoride (mg/L)	Dissolved manganese (mg/L)	Dissolved iron (mg/L)
A	Blue Earth River near Lakota	71/08/23	1510	1	30.0	8.2	730	–	–	–	–	–	–	–	–
		71/10/13	0935	.4	8.0	8.4	770	–	–	–	–	–	–	–	–
B	East Fork Des Moines River near	71/06/24	1045	245	25.0	–	540	–	–	–	–	–	–	–	–
	Burt	73/08/02	1000	28	18.5	7.5	610	–	–	–	–	–	–	–	–
C	East Fork Des Moines River 2 miles north and 1.5 miles east of Algona	74/01/07	–	–	.0	–	900	584	474	–	329	–	–	–	–
D	Des Moines River State Highway	71/10/11	1353	–	14.0	–	72	434	340	285	296	–	0.30	0.10	0.20
	169 bridge at Humboldt	75/08/12	1030	–	26.0	–	720	501	338	218	266	140	–	.05	.06
		76/03/15	1130	–	1.0	–	420	320	192	124	102	72	–	.11	.17
E	East Fork Des Moines River at	73/02/20	1050	185	.5	7.6	840	–	–	–	–	–	–	–	–
	Dakota City	73/06/26	1240	761	25.0	7.9	750	–	–	–	–	–	–	–	–
		73/09/25	0945	53	17.0	8.0	580	–	–	–	–	–	–	–	–
F	East Fork Des Moines River State	77/05/18	0945	–	21.0	–	750	456	–	–	259	15	–	–	–
	Highway 3 bridge in Dakota City	78/03/01	0900	–	.0	–	1,500	1,008	730	417	342	360	–	–	.06
		78/09/19	1710	–	22.0	–	620	570	447	359	294	79	–	–	<.02
G	Winnebago River near Forest City	71/09/01	1120	10	23.0	8.6	790	–	–	–	–	–	–	–	–
		73/09/05	1225	18	22.0	8.0	720	–	–	–	–	–	–	–	–
H	Boone River near Kanawha	71/08/23	1025	1	23.5	8.1	725	–	–	–	–	–	–	–	–
		71/10/13	1240	.4	10.5	8.4	780	–	–	–	–	–	–	–	–
I	East Twin Lake (southeast corner)	76/07/02	–	–	–	–	320	–	170	–	119	22	–	–	–
J	Crystal Lake (southeast corner)	76/07/21	–	–	–	–	345	–	179	–	138	–	–	–	–
K	Boone River near Goldfield	71/08/23	1300	11	25.5	7.8	655	–	–	–	–	–	–	–	–
		71/10/13	1455	4	11.5	8.3	750	–	–	–	–	–	–	–	–
L	Iowa River near Rowan	74/03/18	1050	391	2.0	7.1	460	–	–	–	–	–	–	–	–
		74/06/13	1425	729	17.0	–	700	–	–	–	–	–	–	–	–
		74/08/26	0930	39	21.0	–	540	–	–	–	–	–	–	–	–
M	Lake Cornelia (site 3)	76/07/02	–	–	–	–	310	–	164	–	158	6	–	–	–
N	Shell Rock River near Northwood	72/12/11	1340	79	1.0	7.6	770	–	–	–	–	–	–	–	–
		73/03/16	1220	1,540	5.0	7.5	480	–	–	–	–	–	–	–	–
		73/05/30	1515	368	18.0	8.0	500	–	–	–	–	–	–	–	–
O	Winnebago River at Mason City	72/12/11	1120	159	1.0	7.1	800	–	–	–	–	–	–	–	–
		73/04/19	0955	1,680	9.0	8.0	460	–	–	–	–	–	–	–	–
		73/08/23	0850	100	20.0	7.6	700	–	–	–	–	–	–	–	–
P	Clear Lake	66/03/21	1200	–	20.0	8.1	326	189	188	131	148	10	.25	.05	.02
		67/07/21	1200	–	3.9	8.2	330	187	156	195	148	9	.25	.05	.04
		68/01/08	1200	–	12.8	8.1	380	236	154	217	178	16	–	.05	.04
Q	Beeds Lake	76/07/02	–	–	–	–	460	–	268	–	200	32	–	–	–
R	West Fork Cedar River at County Road S56	78/01/10	1700	–	.0	–	790	500	–	–	292	–	–	–	–
S	Little Cedar River near	71/09/02	1415	4	30.0	8.7	405	–	–	–	–	–	–	–	–
	Staceyville	73/09/05	1950	10	21.0	8.0	440	–	–	–	–	–	–	–	–
T	Wapsipinicon River near Riceville	73/09/14	0835	19	14.0	8.0	370	–	–	–	–	–	–	–	–
		76/08/31	1045	5	20.5	8.3	355	–	–	–	–	–	–	–	–
U	Cedar River near St. Ansgar	73/09/04	1600	–	24.0	–	550	320	–	–	222	–	–	–	–
		76/10/12	1255	–	12.2	–	660	392	–	–	243	–	–	–	–
V	Cedar River at Charles City	77/05/11	1305	–	19.0	–	520	328	247	243	199	43	–	<.01	.04
		77/08/22	1210	–	20.5	–	390	218	172	160	135	34	–	<.04	.10
		77/12/13	1700	–	.0	–	700	412	323	321	263	48	–	<.05	.01
W	Shell Rock River southeast of	77/07/18	–	–	27.0	–	670	380	–	–	206	–	–	–	–
	Rockford	78/01/31	1745	–	.0	–	1,000	643	–	–	338	–	–	–	–
X	Shell Rock River at Shell Rock	73/01/31	1145	1,100	.0	7.7	660	–	–	–	–	–	–	–	–
		73/05/30	1730	3,880	15.0	7.7	560	–	–	–	–	–	–	–	–
		73/08/21	1320	353	20.0	7.6	470	–	–	–	–	–	–	–	–
Y	West Fork Cedar River at bridge, County Road C55	76/06/21	–	–	25.0	–	600	82	326	–	234	–	–	–	–

[Data from U.S. Environmental Protection Agency's STORET computerfile; ft³/s = cubic feet per second; °C = degrees Celsius; micromhos = micromhos per centimeter at 25°C; mg/L = milligrams per liter]

Table 7. Chemical analyses of stream and lake water at selected sampling sites

GROUNDWATER QUALITY

Groundwater quality data from five aquifers in north-central Iowa are shown on figure 55, and tabulated in table 8. The values reported depict the range of constituents and properties from selected analyses for each aquifer. In addition,

Location	Well number (fig 55)	Date	Temperature (°C)	pH (units)	Specific conductance (micromhos)	Dissolved solids (mg/L)	Dissolved calcium (mg/L)	Dissolved magnesium (mg/L)	Hardness as $CaCO_3$ (mg/L)	Hardness, noncarbonate (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Alkalinity (mg/L)	Dissolved chloride (mg/L)	Dissolved nitrate (mg/L)	Dissolved fluoride (mg/L)	Dissolved silica (mg/L)	Dissolved sulfate (mg/L)	Dissolved potassium (mg/L)
SURFICIAL AQUIFER																			
T94-20W-06CC[1]	1	50-01-25	9.0	7.5	490	304	67	22	258	62	239	0	196	5.0	7.2	0.0	–	36	–
T97-19W-30DD[2]	2	50-01-23	–	7.1	1,320	871	165	50	619	347	332	0	272	80	7.0	.0	–	200	–
T97-22W-16AD[2]	3	49-11-30	10.0	7.5	1,120	520	98	40	412	78	407	0	334	9.0	.0	.2	–	49	–
T91-26W-27DB[3]	4	52-08-05	–	7.9	700	463	98	36	393	9	469	0	384	5.0	–	3.0	–	29	4.3
T100-29W-17CCC[3]	5	49-07-19	10.0	7.5	1,475	1,061	144	48	561	167	481	0	394	1.0	.0	.4	–	402	–
CRETACEOUS AQUIFER																			
T95-29W-2CABA	6	72-08-28	12.0	7.1	980	635	100	32	400	32	499	0	368	14	.32	.6	20	150	5.3
T97-30W-18DACD	7	76-11-01	12.0	7.5	1,600	1,270	190	68	759	364	482	0	395	2	–	.4	22	550	6.0
T93-30W-11BDA	8	66-12-07	10.0	7.2	1,000	713	148	43	550	57	601	0	493	.5	.09	.3	22	170	3.4
MISSISSIPPIAN AQUIFER																			
T91-29W-1CBD	9	77-02-09	11.0	7.6	640	404	94	32	366	19	334	0	274	10	3.8	.4	19	49	2.5
T94-26W-6ABAA	10	77-08-03	10.0	7.1	990	657	97	34	387	0	512	0	420	.5	–	.3	23	130	5.9
T93-27W-36ACDB	11	77-01-17	12.0	6.9	840	560	100	37	400	50	429	0	352	<.5	–	.3	20	100	3.3
T93-23W-19CDCC	12	75-09-03	10.0	7.7	600	422	90	33	364	22	417	0	342	5	.16	.3	15	41	1.3
DEVONIAN AQUIFER																			
T92-15W-18BCAA	13	74-10-21	11.0	7.4	700	428	99	22	340	56	344	0	282	16	7.7	.1	18	54	1.8
T97-19W-6DD	14	74-08-19	10.0	7.2	670	382	88	35	350	18	405	0	332	6	–	.2	11	52	3.2
T97-25W-16DAA	15	74-06-05	10.0	7.4	710	443	100	34	368	0	476	0	390	4	–	.2	25	38	5.9
T97-29W-18BCC	16	77-03-01	10.0	7.1	1,600	1,130	130	44	520	157	443	0	404	5	.07	.5	21	460	11
CAMBRIAN-ORDOVICIAN AQUIFER																			
T96-20W-15AAAA	17	76-03-25	13.5	7.2	800	495	110	45	455	124	404	0	331	25	–	.9	10	78	5.2
T95-16W-12BADC	18	77-06-16	10.0	8.1	190	138	23	12	113	48	79	0	65	2.5	.36	.6	12	25	1.7
T92-20W-34BDC	19	76-09-16	12.0	7.2	700	421	83	33	347	56	355	0	291	6	–	.4	17	77	9.9
T94-31W-13AC	20	76-04-12	10.0	7.1	1,500	1,130	200	72	811	–	437	0	0	13	.7	1.1	7	610	17

[1]Alluvial aquifer
[2]Glacial-drift aquifer
[3]Buried-channel aquifer

Table 8. Chemical characteristics of water from the surficial and the bedrock aquifers

figures 56 to 59 show the dissolved-solids concentrations within the bedrock aquifers using all available data.

Dissolved sodium (mg/L)	Dissolved manganese (mg/L)	Dissolved iron (mg/L)	Dissolved silver (mg/L)	Dissolved selenium (mg/L)	Dissolved zinc (mg/L)	Dissolved copper (mg/L)	Dissolved arsenic (mg/L)	Dissolvd barium (mg/L)	Dissolved cadmium (mg/L)	Dissolved chromium (mg/L)	Dissolved lead (mg/L)	Dissolved mercury (mg/L)	Dissolved radium-226 (pCi/L)
						SURFICIAL AQUIFER							
—	0.00	—	—	—	—	—	—	—	—	—	—	—	—
—	.06	—	—	—	—	—	—	—	—	—	—	—	—
—	.04	—	—	—	—	—	—	—	—	—	—	—	—
15	—	3.5	—	—	—	—	—	—	—	—	—	—	—
—	.03	—	—	—	—	—	—	—	—	—	—	—	—
						CRETACEOUS AQUIFER							
82	.09	2.3	—	—	<0.01	<0.01	<0.01	<0.1	<0.01	<0.01	<0.01	—	—
100	.23	2.5	<0.01	<0.01	.21	.01	<.01	<.1	<.01	<.01	<.01	<0.001	—
43	.39	12	—	—	—	—	—	—	—	—	—	—	—
						MISSISSIPPIAN AQUIFER							
4.0	<.01	.01	<.01	<.01	<.01	<.01	<.01	.2	<.01	<.01	<.01	<.001	—
86	.11	2.5	<.01	<.01	.01	.06	.02	<.1	<.01	<.01	.02	<.001	—
38	.4	2.0	<.01	<.01	<.01	<.01	<.01	.1	<.01	<.01	<.01	<.001	2.3
16	.12	1.7	<.01	—	.02	<.01	<.01	.4	<.01	<.01	<.01	<.001	1.0
						DEVONIAN AQUIFER							
3.1	<.01	<.01	<.01	—	.01	.09	<.01	<.01	<.01	<.01	<.01	<.001	—
12	.01	.66	<.01	—	.01	<.01	<.01	<.1	<.01	<.01	<.01	<.001	—
18	.06	1.9	<.01	—	.05	<.01	<.01	.5	<.01	<.01	<.01	<.001	—
180	.19	2.3	<.01	<.01	<.01	<.01	<.01	<.1	<.01	<.01	<.01	<.001	2.1
						CAMBRIAN-ORDOVICIAN AQUIFER							
8.9	.01	.31	<.01	<.01	.08	<.01	<.01	<.1	<.01	<.01	<.01	<.001	2.4
3.4	.11	3.2	<.01	<.01	.02	<.01	<.01	.1	<.01	<.01	<.01	<.001	—
25	.2	2.1	<.01	<.01	<.01	<.03	<.01	<.1	<.01	<.01	<.01	<.001	—
81	.03	1.3	<.01	<.01	<.01	<.01	<.01	<.1	<.01	<.01	<.01	<.001	12.1

[Anaysis by State Hygenic Laboratory of Iowa; °C = degrees Celsius; micromhos = micromhos per centimeter at 25° Celsius; mg/L = milligrams per liter; pCi/L = picocuries per liter]

SURFICIAL AQUIFERS

Generally, wells penetrating shallow aquifers yield less mineralized water than wells that penetrate the deeper bedrock aquifers. This is because the dissolved constituents present in the water are related to the length of time that the water is in contact with the aquifer materials, and the composition of its materials. Water from the deeper bedrock aquifers usually contains more dissolved materials because the water has been in the ground longer.

Water data from five selected wells (table 8) indicate that the concentrations of constituents are quite variable within the surficial-aquifer system. Specific-conductance values ranged from 490 to 1,475 micromhos, and dissolved-solids concentrations ranged from 304 to 1,061 mg/L. Values for pH had a narrow range, between 7.1 and 7.9. All of the analyses indicate very hard water with concentrations greater than 180 mg/L.

Water-quality data from five wells cannot depict the chemical composition of water from such a variable aquifer system. Generally, water from alluvial aquifers has the smallest dissolved-solids concentrations because it has been in the ground the shortest time. Because of the proximity to the land surface and the possibility of surface contamination, the concentration of nitrate may be large. Water from shallow glacial-drift aquifers can have similar characteristics.

Deep glacial-drift and buried-channel aquifers generally contain more mineralized water than alluvial aquifers. This may be because of the length of time that the water has been in the aquifer or because of hydraulic connection with bedrock aquifers, which contain a more mineralized water. The buried channels commonly are incised into water-bearing bedrock. In such instances, the water in the buried-channel aquifer chemically may be similar to water in the adjacent bedrock aquifer.

CRETACEOUS AQUIFER

Dissolved-solids concentrations in the Cretaceous aquifer increase from ea to west (fig. 56), and most exceed the maximum recommended concentratior for drinking water. The three analyses in table 8 show relatively larg specific-conductance values that range from 980 to 1,600 micromhos. I addition, iron and manganese and one analysis for sulfate exceeded recommenc ed drinking-water concentrations. The water is very hard with reported value ranging between 400-759 mg/L. Temperatures of the water ranged between 5C to 54° F (10° to 12° C).

The eastern edge of the Cretaceous aquifer is discontinuous and relatively thi Water from this eastern section is probably a mixture of less mineralized wat from overlying surficial aquifers and the more mineralized water from th Cretaceous aquifer.

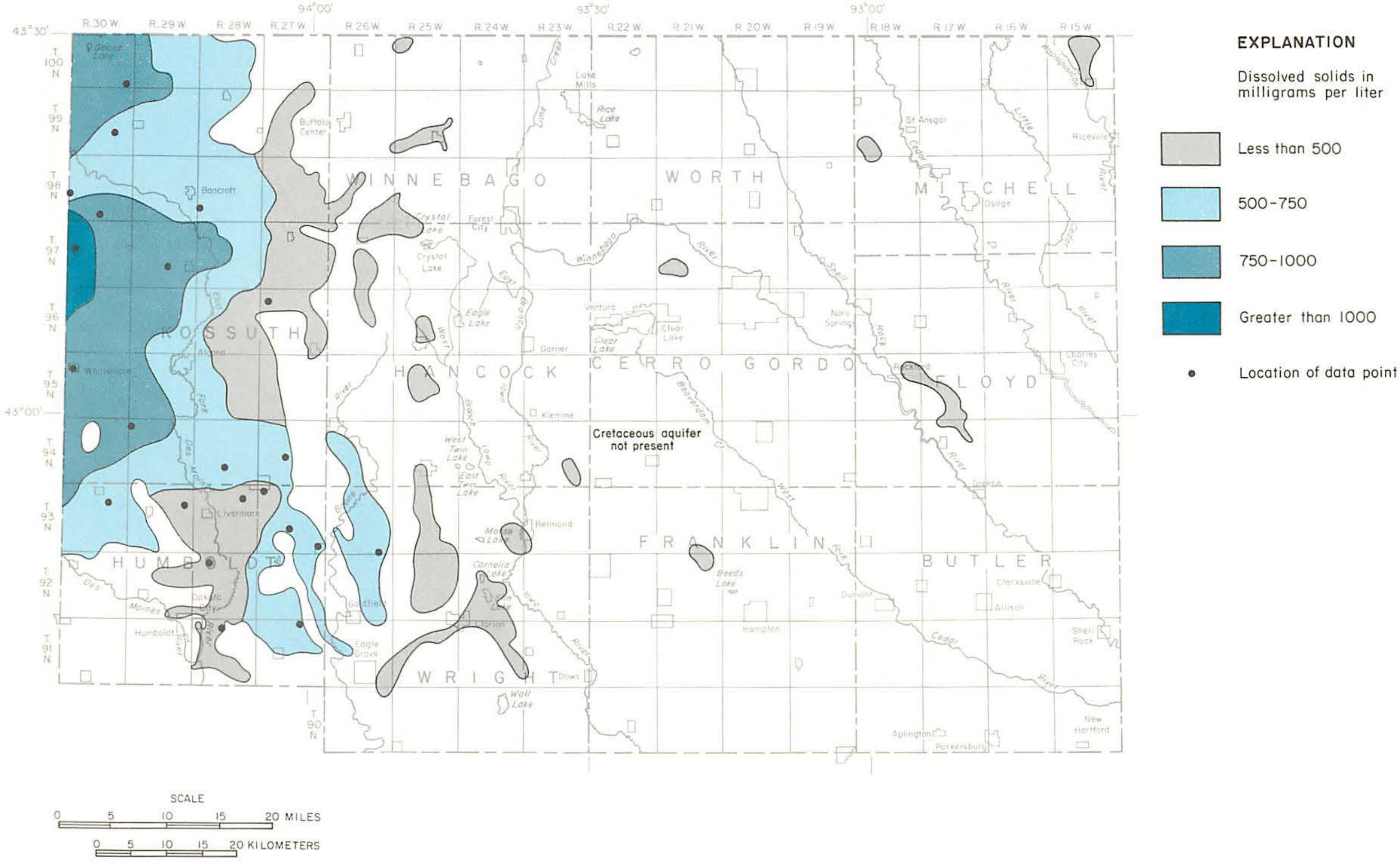


Figure 56. Dissolved-solids concentration in water from the Cretaceous aquifer

MISSISSIPPIAN AQUIFER

Analyses of water from wells in the Mississippian aquifer show that dissolved-solids concentrations increase from east to west and south to north within the study area (fig. 57). The greater dissolved-solids concentration in the northwestern section of the aquifer probably is a result of the Mississippian aquifer being recharged by more mineralized water from the overlying Cretaceous aquifer.

Water from two of the four wells listed in table 8 had dissolved-solids concentrations exceeding recommended limits for domestic supply. Iron and manganese also exceeded recommended concentrations in three of the analyses. Values for pH were about or slightly greater than 7.0 and temperatures ranged between 50° to 54° F (10° to 12° C). The water from this aquifer is very hard; hardness concentrations were greater than 350 mg/L.

Additional information about the water quality of the Mississippian aquifer can be obtained from Horick and Steinhilber (1973).

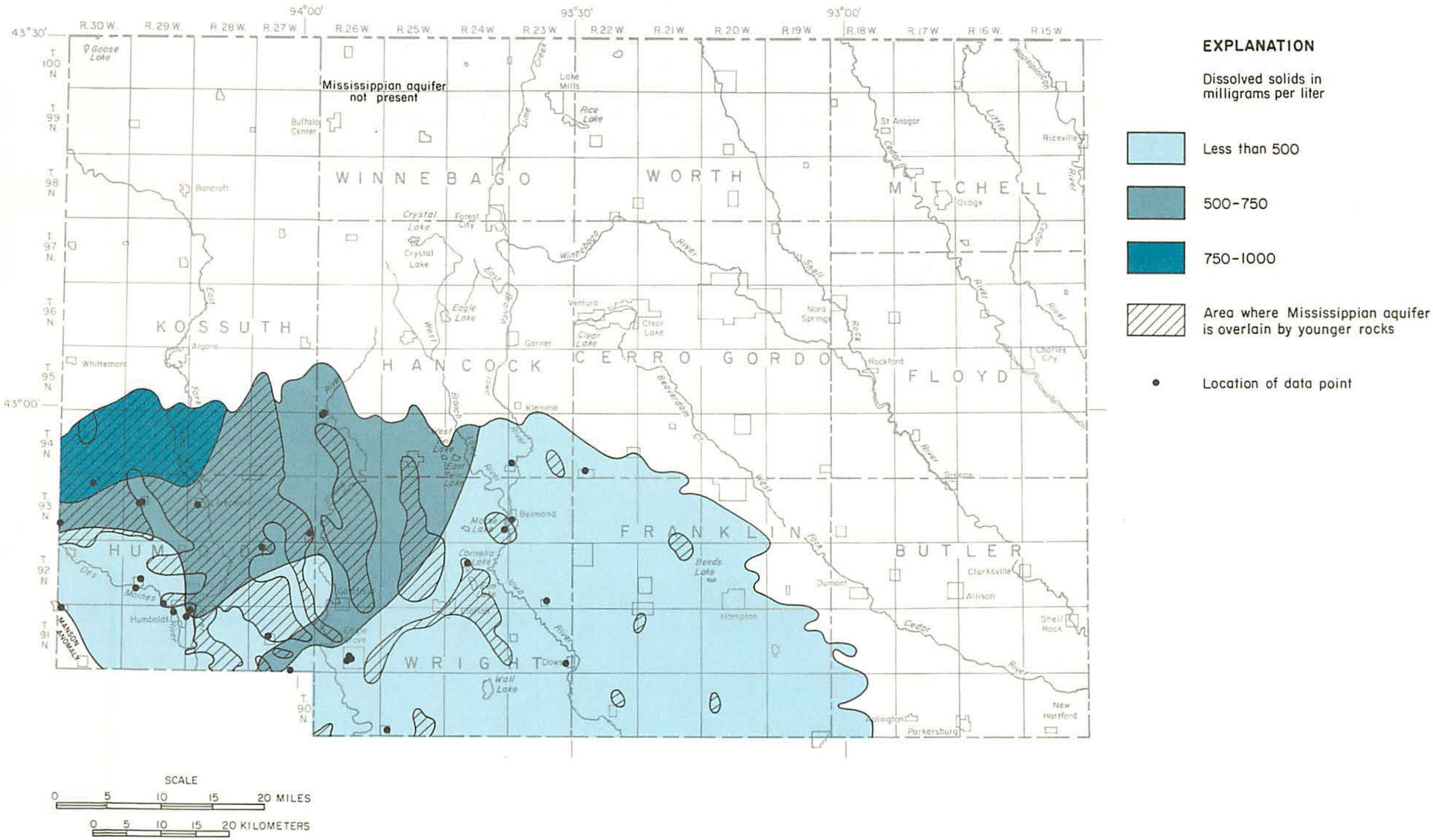


Figure 57. Dissolved-solids concentration in water from the Mississippian aquifer

DEVONIAN AQUIFER

The Devonian aquifer generally yields water with a dissolved-solids concentration of less than 500 mg/L, except in the northwest corner and two isolated areas in the eastern and central parts of the study area (fig. 58). These areas contain water with dissolved-solids greater than 500 mg/L and as much as 1,130 mg/L in western Kossuth County. This suggests that there is a mixing of water due to movement of water from the Cretaceous aquifer into the Devonian aquifer.

Iron and manganese concentrations exceeded recommended limits for drinking water in some wells within the area. Values for pH were about neutral (7.0) and temperatures were consistently about 50° F (10° C). The water is very hard; hardness concentrations ranged between 340 and 520 mg/L.

Additional information concerning the water quality of the Devonian aquifer can be obtained from Horick (1984).

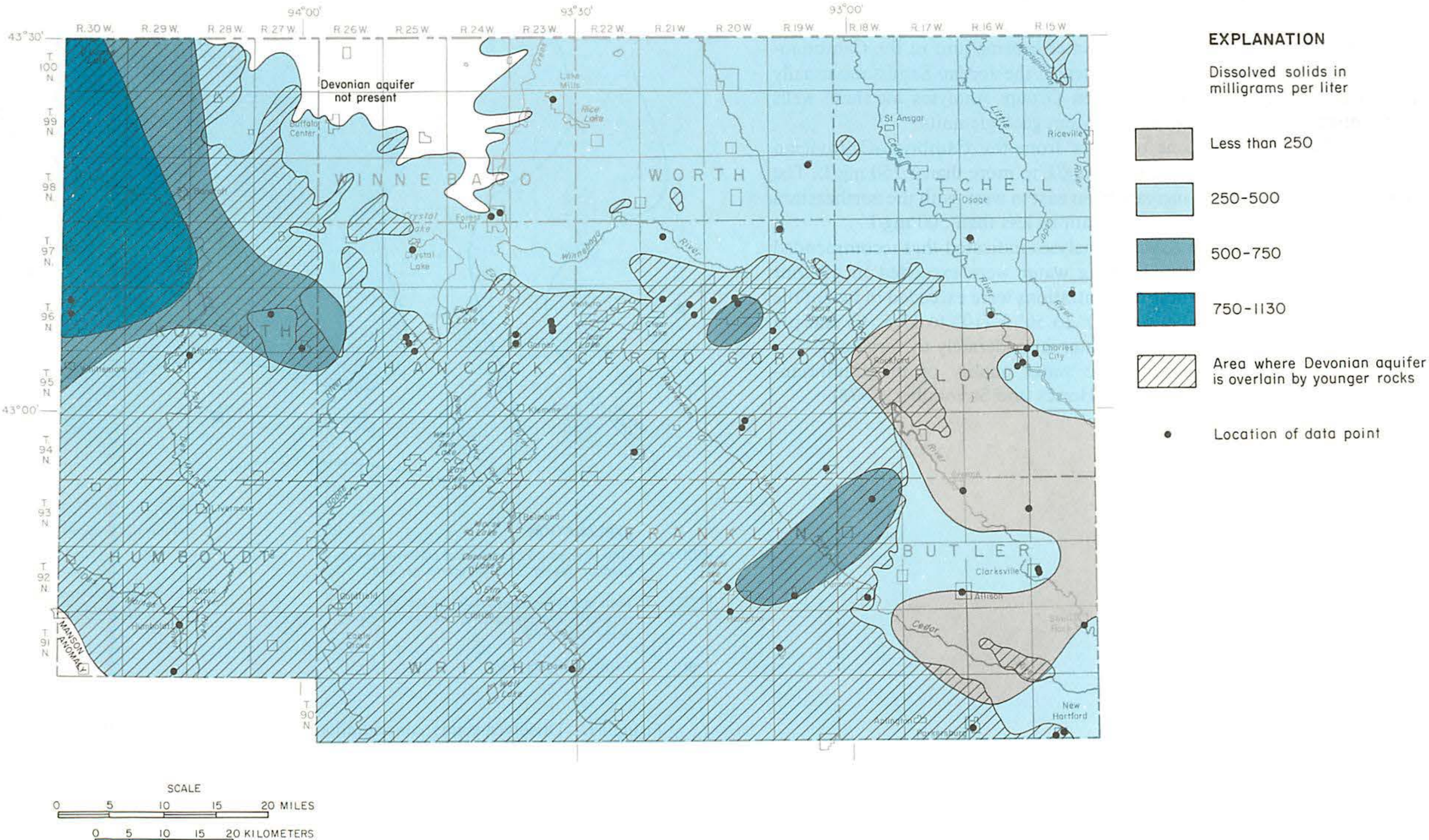


Figure 58. Dissolved-solids concentration in water from the Devonian aquifer

CAMBRIAN-ORDOVICIAN AQUIFER

The Jordan Sandstone is the principal water-bearing unit in the Cambrian-Ordovician aquifer. Wells that are completed in the Jordan Sandstone usually are open to the overlying Prairie du Chien Group. Analyses for these wells represent a mixture of water from two adjacent geologic units.

Dissolved-solids concentrations of water from the Cambrian-Ordovician aquifer (figure 59) vary from less than 500 mg/L to more than 1,250 mg/L. The dissolved-solids concentrations increase from east to west, with the northeastern one-half of the study area having concentrations less than 500 mg/L.

From the wells listed in table 8, water analyses indicated that recommended limits of iron concentrations for drinking water were exceeded in all four analyses, while limits for manganese concentrations were exceeded in two of the analyses. Temperatures ranged between 50° to 56° F (10° to 13.5° C) and pH values ranged between 7.1 and 8.1. The water is moderately to very hard.

Additional information concerning the water quality of the Cambrian-Ordovician aquifer can be obtained from Horick and Steinhilber (1978).

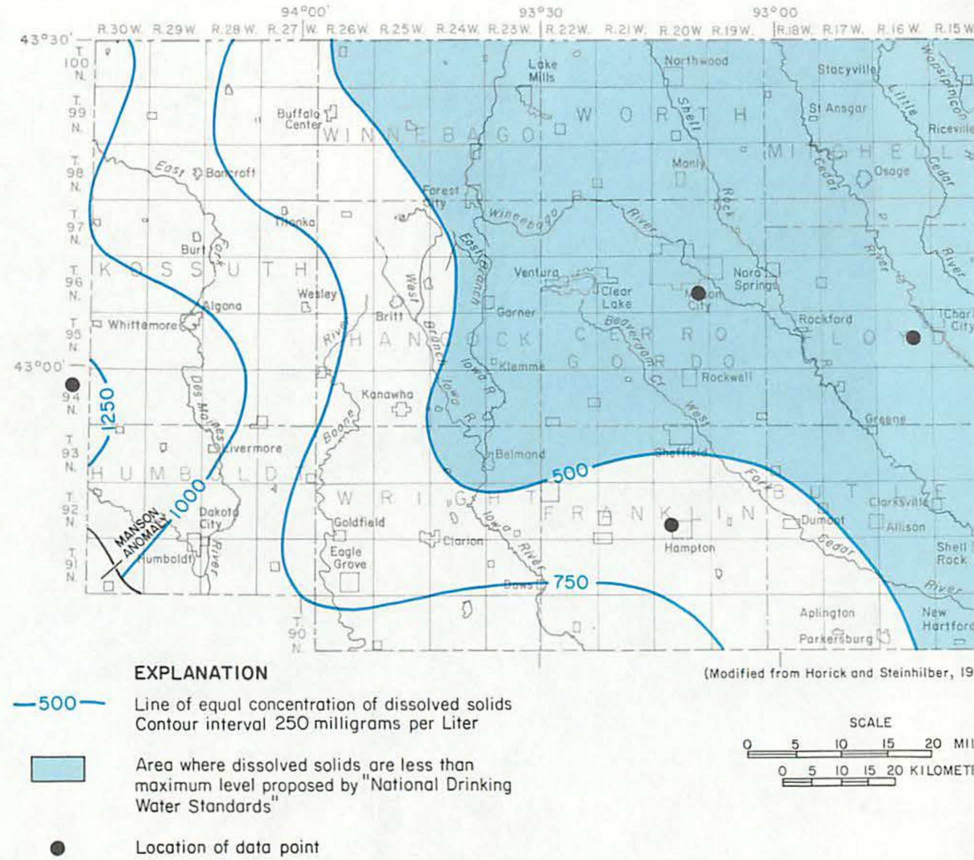


Figure 59. Dissolved-solids concentration in water from the Cambrian-Ordovicia aquifer

WATER USE AND WITHDRAWALS

The major categories of water use in north-central Iowa are municipal, rural omestic and livestock, quarrying, industrial self-supplied, cooling and rigation. Water-use information was collected in the study area during the late art of 1978 and early 1979. In those instances where quantitative data were not vailable, the use was estimated on the basis of population, per-capita onsumption, or related information. In most instances the data were collected or an annual period and converted to average daily use.

Municipal use, in this report, includes all water withdrawn by municipalities or urban-domestic use and for sale to industrial and commercial customers. In ddition, because the use is based on withdrawals rather than metered customer sage, it includes water lost through leakage in the distribution system, water sed for water-main flushing, and other nonmetered uses. Where specific nformation was not available, the municipal water use was estimated from er-capita use in similar communities.

Rural-water use is subdivided into two classes: domestic and livestock. ecause it would be impossible to meter rural water use, estimates for domestic se were made on the basis of per-capita use of 65 gallons per day. Livestock use as based on the animal populations published by the U.S. Bureau of Census 976) and per-head consumption.

Industrial self-supplied use includes the water withdrawn from private ompany or commercial wells and intake systems. The water may be used for ooling processes, for refrigeration and air-conditioning, for washing products nd facilities, for processing food products, or other similar commercial and ndustrial use.

For the purposes of this report, all water use can be classified into two ubcategories: consumptive water use and nonconsumptive water use. Water is onsidered consumed, or lost, when it is no longer available to be managed or sed again. Evaporation is considered to be the primary means by which water lost. Nonconsumptive water use is when the use of the water results in no net oss of water quantity, although there may be a considerable change in water uality. The data in table 9 provide some estimates of the proportion of water onsumed by several of the types of water use identified within the study ea.

During 1978-79 about 48.6 million gallons of water were withdrawn each day n north-central Iowa. These withdrawals are tabulated by county in table 10 and by drainage basin in table 11. The percentage of use by category is shown graphically in figure 60.

Type of use	Percent of water consumed
Public supply	15
Industrial self-supplied	2
Rural domestic and livestock	82
Irrigation	100

[Data from Murray and Reeves, 1977]

Table 9. Estimated water consumption in Iowa

The source of withdrawals for each use are tabulated in table 12. Municipalities account for about 35 percent of the total withdrawals in the area. The relative quantity, location, and the source for these withdrawals are shown in figure 61.

The four largest cities in the area, Mason City, Charles City, Algona, and Clear Lake, account for about 49 percent of the municipal withdrawals. Mason City has the largest withdrawals at 27 percent, Charles City withdraws 11.5 percent, and Algona and Clear Lake 5 percent each. The daily withdrawals for municipal use vary considerably depending on the season and weather conditions. Information from several cities in the area indicates that the average daily withdrawal is about 25 percent greater during the summer than during the winter.

Withdrawals for rural use account for about 32 percent of the region's total withdrawals. Most of this water is withdrawn for livestock use and is well distributed throughout the area. Kossuth County, because of its larger size has the largest withdrawals for this use category.

Industrial self-supplied users account for 14 percent of the withdrawals in the area. Most of this use is concentrated in Floyd and Cerro Gordo Counties where the two largest cities in the study area are located. For this reason the total water withdrawals in each of these two counties are much larger than in any other county in north-central Iowa.

County	Population (1980)	Municipal	Rural domestic	Livestock	Quarrying	Industrial self-supplied	Cooling	Irrigation	Total
Butler	17,668	0.911	0.485	1.412	0.128	—	—	0.235	3.171
Cerro Gordo	48,458	5,727	.410	.960	1.750	1.06	—	.110	10.017
Floyd	19,597	2,346	.446	.920	.077	5.54	—	.230	9.559
Franklin	13,036	1.181	.212	1.350	.910	—	—	.029	3.682
Hancock	13,833	.758	.394	1.080	.025	—	.003	.050	2.310
Humboldt	12,246	.820	.255	.710	.880	—	.062	.065	2.792
Kossuth	21,891	1,587	.654	1.880	—	.26	.295	.025	4.701
Mitchell	12,329	.685	.380	1.030	.290	—	—	.240	2.625
Winnebago	13,010	.989	.260	.560	—	—	—	.087	1.896
Worth	9,075	.389	.310	.690	2.900	—	—	.130	4.419
Wright	16,319	1.360	.322	.790	.055	—	.869	—	3.406
Total	197,462	16.753	4,138	11.382	7.015	6.86	1.229	1.201	48.578

[Water withdrawn, in million gallons per day]

Table 10. Water withdrawals by type of use in counties, 1978-79

Withdrawals for quarrying account for about 15 percent of total water use in north-central Iowa. The water is withdrawn to wash aggregate, to drain quarries and pits, and in some cases to transport sand and gravel out of the pit. Worth and Cerro Gordo Counties have the largest withdrawals for quarrying operations.

Irrigation and power-generation-cooling uses combined, account for about 5 percent of withdrawals in north-central Iowa. Although these two categories represent relatively small withdrawals, they are consumptive types of uses and evaporate a considerable quantity of water. Irrigation withdrawals are largest in Butler, Floyd, and Mitchell Counties although some withdrawals occur in each county in the area. Records indicate power-generation-cooling withdrawals occur only in four counties in north-central Iowa and are significant only in Wright County.

Groundwater sources provide approximately 82 percent of the withdrawals in north-central Iowa. Of the five aquifers used, the Devonian aquifer provides approximately 45 percent of the water withdrawn and the Cambrian-Ordovician aquifer about 16 percent. The Devonian aquifer is important because it is relatively shallow and will provide moderate yields to wells throughout a large part of the area. The Cambrian-Ordovician aquifer is relatively deep but it is a source of large yields to wells and is used by several cities and industries in the area.

Withdrawals from the Mississippian aquifer account for about 10 percent of the total use. Because the Mississippian aquifer occurs only in the southwest part of the area, withdrawals are concentrated in Wright, Humboldt, and Franklin Counties with minor withdrawals in Hancock and Kossuth Counties.

Withdrawals from the Cretaceous aquifer account for about 6 percent of the total, and are concentrated in Kossuth County with minor withdrawals in Humboldt and Wright Counties. The Cretaceous aquifer occurs as outliers in other counties to the east of Kossuth, Humboldt, and Wright Counties. These outliers are relatively thin and generally are not a viable source of water east of the major occurrence.

Surficial aquifers occur throughout north-central Iowa but provide only about 4 percent of total withdrawals. The major withdrawals from the surficial aquifer occur in Wright and Cerro Gordo Counties.

Surface-water sources supply about 18 percent of the withdrawals in north-central Iowa. Cerro Gordo, Franklin, and Worth Counties are the major areas of surface-water withdrawal. The water is withdrawn from several man-made and natural reservoirs in the area as well as from streams. The largest single withdrawal during 1978-79 was from Clear Lake by the City of Clear Lake.

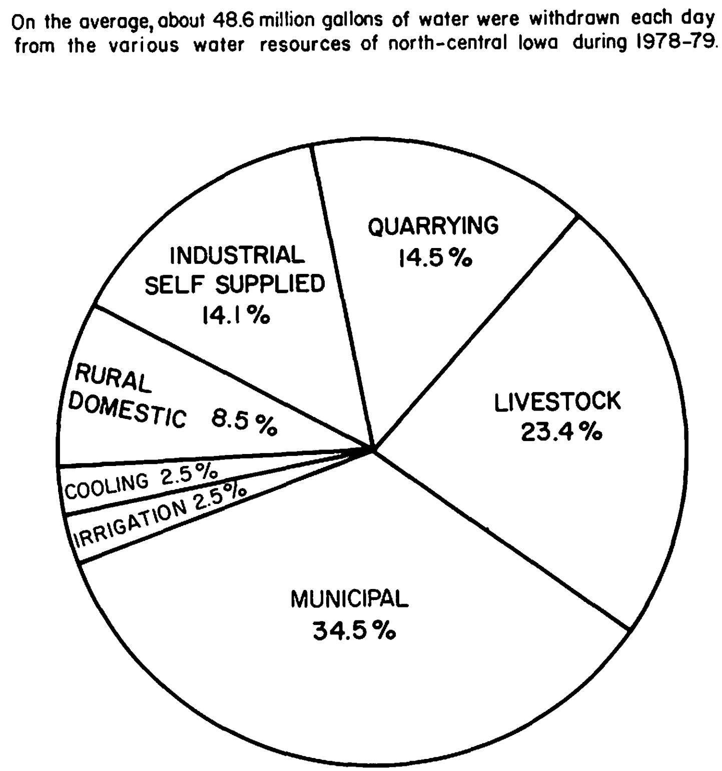


Figure 60. Average daily water withdrawals, in percent, by type of use during 1978-79

River basin	Population (1980)	Municipal	Rural domestic	Livestock	Quarrying	Industrial self-supplied	Cooling	Irrigation	Total
Blue Earth	5,165	0.234	0.202	0.545	—	—	—	0.021	1.002
Cedar	128,236	11.965	2.397	6.566	5.835	6.60	0.003	1.004	34.370
Des Moines	50,045	3.800	1.146	3.152	.921	.26	.357	.124	9.760
Iowa	13,228	.754	.340	1.007	.234	—	.869	.027	3.231
Wapsipinicon	788	—	.053	.112	.025	—	—	.025	.215
Total	197,462	16.753	4.138	11.382	7.015	6.86	1.229	1.201	48.578

[Water withdrawn, in million gallons per day]

Table 11. Water withdrawals by type of use in each basin, 1978-79

Source	Municipal	Rural domestic	Livestock	Quarrying	Industrial self-supplied	Cooling	Irrigation	Total
Reservoirs	0.887	—	0.028	6.540	0.01	—	0.351	7.816
Streams	—	0.218	—	.390	—	0.018	.090	.716
Surficial aquifers	.638	—	.553	.005	—	.869	.080	2.145
Cretaceous aquifer	.951	—	2.028	—	—	—	—	2.979
Mississippian aquifer	2.248	.435	2.208	—	—	—	—	4.891
Devonian aquifer	5.928	3.267	6.285	.080	5.71	.342	.630	22.242
Cambrian-Ordovician aquifer	6.101	.218	.280	—	1.14	—	.050	7.789
Total	16.753	4.138	11.382	7.015	6.86	1.229	1.201	48.578

[Water withdrawn, in million gallons per day]

Table 12. Water withdrawals by source for each type of use, 1978-79

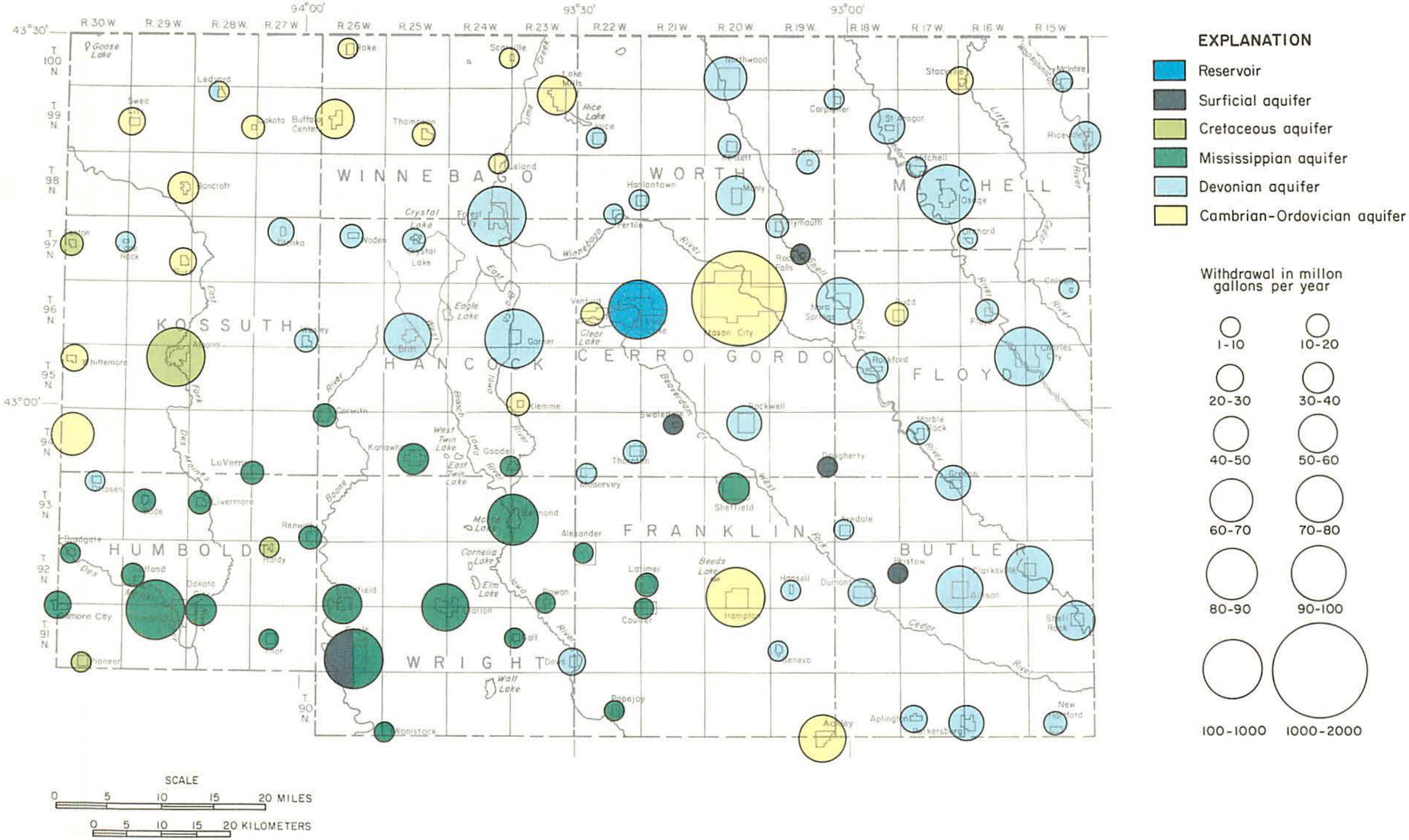


Figure 61. Quantity and sources of water withdrawn from pumping centers, 1978-79

WATER-RESOURCES LAWS AND REGULA

Under Chapter 455B, Code of Iowa, the Water, Air and Waste Management Commission is responsible for defining policy and directing the activities of the Department of Water, Air, and Waste Management (DWAWM). DWAWM administers Iowa water law and regulates water withdrawals and diversions, dams, and floodplain management, as well as waste-water and solid-waste disposal. The U.S. Army Corps of Engineers is given a variety of regulatory responsibilities for waters of the United States under Section 404 of the Federal Water Pollution Act Amendments of 1972 and prior Federal legislation.

STATE JURISDICTION

WATER POLLUTION CONTROL

The Water, Air, and Waste Management Commission is responsible for establishing, modifying, or repealing quality standards for the waters of Iowa and for establishing, modifying, or repealing effluent standards for waste disposal systems.

DWAWM operates programs to prevent, abate, or control water pollution and to regulate public water-supply facilities. DWAWM also has responsibilities related to the operation of private water supplies and private sewage-disposal systems.

Written permits are required from the Executive Director of DWAWM for any of the following activities: (1) the construction, installation, or modification of any disposal system for sewage, industrial waste, and other wastes, including sewer systems, treatment facilities, and disposal systems; (2) the construction or use of any new outlet discharging any sewage or wastes directly into the waters of the State; and (3) the operation of any waste-disposal system other than sewage or industrial waste.

WATER AND FLOODPLAINS

DWAWM has jurisdiction of the public and private waters in Iowa and adjacent lands necessary for regulating water and floodplains. For other than nonregulated uses, the Department investigates all requests for withdrawal or diversion of water with respect to possible effects upon natural flow of the water course, other land owners, and the water allocation priorities of the State. DWAWM also investigates all applications that are made for the maintenance or construction of any structure, dam, obstruction, or excavation on or in the floodplain of any river or stream.

The purpose of floodplain regulation in Iowa is to decrease flood hazards and damage. DWAWM has the authority to establish floodways along rivers and streams. A floodway is both the channel of a river or stream and those parts of the floodplain adjoining the channel that are reasonably required to transport and discharge flood water or flood flow of any river or stream. It is unlawful to erect any structure, dam, obstruction, deposit, or excavation on any floodway that will adversely affect the efficiency or unduly restrict the capacity of the floodway without written application and subsequent approval by DWAWM. DWAWM has the authority to remove or eliminate any existing structure that affects the efficiency or restricts the capacity of a floodway. The procedures for obtaining permission to erect any of these structures are set forth in the Code of Iowa, Chapter 455B. Local governments must submit proposals for changes in encroachment limits, floodplain regulations, or floodplain zoning ordinances to the Water, Air and Waste Management Commission for review and approval.

Many uses of water-supplies are not under the control of DWAWM. Nonregulated uses include use of water for ordinary household purposes, for poultry, livestock, and domestic animals, or the use of surface waters from rivers that border the State or groundwater from islands or former islands in these rivers. Beneficial uses of water within the territorial boundaries of cities prior to May 16, 1957, are considered nonregulated uses as are any other beneficial uses of water that are less than 25,000 gallons per day.

Persons planning to develop a water supply for any purpose under the category of a regulated use must first make application to DWAWM for a permit. The rules under which the water-permit system is administered can be found in the Code of Iowa, Chapter 455B. Regulated use, by law, is any depleting use other than those designated as a nonregulated use. Basically, this refers to all uses which require withdrawal or diversion of water in excess of 25,000 gallons per day.

DWAWM also administers Chapter 469 of the Iowa Code that in Section 469.1 states: "No dam shall be constructed, maintained, or operated in this State n any navigable or meandered stream for any purpose, or in any other stream for manufacturing or power purposes, unless a permit has been granted by the Commission to the person, firm, corporation, or municipality constructing, maintaining, or operating the same." DWAWM conducts an annual inspection of all dams licensed under these provisions.

Approval of the Iowa Conservation Commission is also required for projects that involve construction on the bed or banks of a meandered stream or if they constitute obstructions in navigable waters.

FEDERAL JURISDICTION

Section 404 of the Federal Water Pollution Act Amendments of 1972 assigns responsibility for the regulation of the discharge of dredged or fill material in the waters of the United States to the U.S. Army Corps of Engineers. The following additional types of activities also are regulated under this program: (1) site-developmental fills for recreational, industrial, commercial, residential, and other uses; (2) causeways or road fills; (3) dams and dikes; (4) artificial islands; (5) property protection and/or reclamation devices such as riprap, groins, seawalls, breakwaters and bulkheads, and fills; (6) beach improvements; (7) levees; and (8) sanitary landfills, and backfill required for the placement of structures such as sewage-treatment facilities. For projects in north-central Iowa, approval should be requested from the U.S. Army Corps of Engineers, Rock Island District, Clock Tower Building, Rock Island, Illinois 61201. In addition, projects in or on the banks of navigable streams also require approval by the U.S. Army Corps of Engineers.

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